WORLD HEALTH ORGANIZATION
EUROPE

Quantifying burden of disease from environmental noise: Second technical meeting report

Bern, Switzerland, 15 – 16 December 2005

ABSTRACT

A group of international experts met to review and discuss the preliminary assessment of burden of disease (BoD) from environmental noise in Bern, Switzerland, on 15-16 December 2005. Experts provided background documents and made presentations reviewing the detailed methods and preliminary results of BoD assessment for selected noise-related outcomes: Cardiovascular disease, Sleep disturbance and annoyance, Hearing loss and tinnitus, and Cognitive impairment. For each topic, the state-of-the-art review was made regarding the exposure data, exposure-response relationships, outcome data, on disability weight and DALY calculation. WHO staff provided the topic-specific experts with methodological guides based on previous experience in global burden of disease project. The meeting identified methodological constraints and informational gaps in quantification of DALYs due to environmental noise. Experts agreed to collaborate to improve methods and produce a reliable estimation of noise BoD based on available evidence. WHO agreed to coordinate the Working Group activity in compiling and publishing the results as a series of environmental burden of disease (EBD) reports. For this purpose, an editorial meeting is planned in 18-19 April 2006 to review and edit the first draft of the document estimating BoD of environmental noise.

Keywords

NOISE
ENVIRONMENTAL EXPOSURE - ADVERSE EFFECTS
COST OF ILLNESS
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Introduction

In European region, the environmental noise is becoming one of the major environmental health concerns for the policy-makers as well as the public. The European Directive related to the assessment and management of environmental noise (Directive 2002/49/EC 2002) addresses the action plans to reduce harmful effects of noise exposure. The Regional Priority Goal IV of Children's Environment and Health for Europe adopted by European Ministers of Environment and Health at the 4th Ministerial Conference in Budapest in 2004 also states that children should be protected children from exposure to harmful noise at home and at school.

Reliable information on the burden of disease from various environmental risk factors is an essential tool in prioritizing policies on competing issues for limited resources. However, the burden of disease related to general population's exposure to environmental noise was rarely estimated in non-occupational settings at the international level in Europe. Due to the numerous outcomes and apparently complicated causal pathways involved in environmental noise exposure and its health effects, quantification of disease burden was not easy. Harmonized methods are necessary to assess and calculate the environmental burden of disease (EBD) from environmental noise. WHO proposed to assess disease burden in terms of *Disability-Adjusted Life Year* (DALY) to combine the disease burden due to death and disability in a single index. Use of DALY allows the policy-makers to compare the disease burdens associated with different environmental risk factors in a single unit, and to forecast the possible impact of policies and preventive actions.

Noise burden of disease was reported at the national level in a few countries. However, there has been little international agreement on the selection of noise-related health outcomes and the method of estimation. Therefore the noise and health (NOH) unit of the WHO EURO European Centre for Environmental and Health, Bonn office, initiated a project to estimate noise burden of disease with the support of the German Ministry of Environment, the German Ministry of Social Affairs and the Swiss Agency for the Environment, Forests and Landscape in 2005.

In June 2005, WHO convened a meeting of international experts in Stuttgart, Germany, to develop and agree on the framework of assessing burden of disease from environmental noise in the District Government of Stuttgart. Discussions took place on methodology, country approaches, exposure and health outcomes to consider. The meeting concluded; the methodology previously proposed by WHO will be used, the exposure data will vary by the competency of Member States, and the health outcomes to consider will be hearing impairment, tinnitus, cardiovascular outcomes, sleep disturbance, injuries, and cognitive impairment. As it is not a disease, annoyance will be covered as a separate topic. The meeting also agreed that the experts would produce technical review papers on methods and preliminary results for each health outcome according to the specific terms of reference provided by WHO.
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Meeting

As a follow-up of the first meeting in Stuttgart, the second technical meeting was convened in Bern, Switzerland, on 15-16 December 2005.

The meeting aimed to review the methods and results for each health outcome, and to plan the activities to prepare the document compiling the estimated burden of disease from environmental noise.

According to specific terms of reference as agreed at the first meeting in Stuttgart, the invited experts prepared background papers on the topics of cardiovascular diseases, hearing impairment and tinnitus, sleep disturbance and annoyance, and cognitive development.

After Xavier Bonnefoy (WHO) opened the meeting with welcoming remarks and overall introductions to the objectives of the meting, the following topics were presented and discussed:

- Estimation of the burden of cardio vascular diseases from environmental noise
- Estimation of the burden of sleep disturbance from environmental noise
- Estimation of burden of annoyance from environmental noise
- Estimation of the burden of hearing impairment from environmental noise
- Estimation of the burden of tinnitus from environmental noise
- Estimation of the burden of cognitive impairment from environmental noise
- Lessons from the WHO Environmental burden of disease project

The program of the meeting is attached as Annex. The meeting was supported by the Swiss Agency for the Environment, Forests and Landscape.

This report contains the background papers and presentations at the meeting as Annex, and summarizes the discussions and recommendations of the meeting.

Conclusions and recommendations

Cardiovascular diseases

Risk assessment of cardiovascular diseases from transportation noise in Germany was presented by Woflgang Babisch (Germany). Through a meta-analysis, it was confirmed that there is sufficient evidence for the association between community noise and ischemic heart diseases, and limited/sufficient evidence for the association between community noise and hypertension. Most information comes from road traffic noise studies. The dose-response curve was based on L_{day} of the most exposed fassade. For road traffic noise in urban streets L_{night} is approx. 10 dB lower than L_{day}. Considering this relationship between L_{day} and L_{night}, L_{den} can be used as exposure parameter. The location of the bedroom was not considered in the meta-analysis of noise studies, because such information is not available on a population basis, which means that no attributable fractions could be calculated with respect to bedrooms. We can apply results from road traffic noise studies to aircraft noise until more data on aircraft noise are available. Using L_{day} as exposure parameter, attributable fraction of transportation noise to be 3.22% of the incidence of ischemic heart disease in Germany.

Rokho Kim (WHO) estimated the **burden of ischemic heart disease from road traffic noise in Europe** in terms of DALYs applying the exposure-response relations proposed by Babisch. Based on noise exposure data, Kim estimated attributable fraction to be 4.51% of ischemic heart disease in Switzerland in 1990, and 4.08% for European Union in 1994. A few assumptions were made to estimate DALYs attributable to noise-related ischemic heart disease in European region. First, noise exposure levels and patterns might be similar across the countries. Second, the impact fraction was considered to be 3% of ischemic heart disease on average across Europe (conservative assumption). Third, exposure-response curve will be the same for both men and women. Fourth, exposure-response curve will be the same for myocardial infarction and other ischemic heart disease. Fifth, the impact of noise on the incidence of ischemic heart disease is uniformly reflected on the DALYs for ischemic heart disease. With these assumptions, the total burden of ischemic heart disease related to road traffic noise exposure was estimated to be 880,000 DALYs for Europe in the year 2002.

Questions were raised about **the combined impact of noise and outdoor air pollution on ischemic heart disease.** Outdoor air pollution represents approximately 2% of cardiopulmonary disease mortality, and it is not clear whether the impact of noise on ischemic heart disease is independent, additive or synergistic to the impact of outdoor air pollution. In real life cases, individuals exposed to noise are also likely to be exposed to outdoor air pollution. However, it was also pointed out that the acute effects of short-term changes in air pollution are assessed in time-series studies. If traffic volume is constant from day to day (which is obviously the fact within only small variations), such changes can only occur due to meteorological changes. There can be residual effects of temperature, humidity, atmospheric pressure on acute health effects because human organism responds strongly to meteorological conditions, particularly risk groups such as elderly persons. On the other hand, meteorological conditions do not affect the noise which is often from the street in a typical urban situation. Furthermore, according to the noise hypothesis we do not expect acute cardiovascular effects if the L_{day} varies slightly from day to day. Noise effects, in general, refer to long-term chronic noise stress. In this respect, the confounding between noise and air might be less likely on the basis of short-term effects in time-series studies. The confounding can be an issue on long-term effects observed by cohort studies. In noise studies the exposure was assessed on an individual basis, while most air pollution studies referred to area-related background exposure.[1]

Truls Gjestland (Norway) volunteered to provide a document addressing this issue. Further research is necessary to partition the impact of noise from that of outdoor air pollution.

Babisch's dose-response curve was based on L_{day} of the most exposed fassade. However, data on L_{den} are more easily available in many countries due to the EU Directive on noise. Whenever L_{den} is available, L_{day} must also be available, because it is part of L_{den}. Therefore, it was agreed that **L_{den} can be used as a proxy** because this exposure indicator can be converted into L_{day} and L_{dn} by an appropriate modelling. Truls Gjestland (Norway) agreed to assist in converting exposure data from L_{den} to L_{day}. Because noise map based on L_{den} will be available in most EU countries according to the EC Noise Directive from 2008, adoption of L_{den} for exposure parameter was well accepted. It will enhance the availability of exposure data.

There was also a concern about the **generalization across the EURO regions**. In EURO B and EURO C there is higher incidence of cardiovascular disease due to other competing risk factors such as smoking and drinking. Can the exposure-response relation derived from EURO A be applied to estimate attributable fraction of cardiovascular disease in these regions?

[1] At a meeting, "Epidemiology of long-term air pollution effects," in Bilthoven on 30 January 2006, it was pointed out that several ongoing studies (by Jarupp, Pershagen) include assessment of effects of noise on cardiovascular system. Initial results to be published in about a year indicates possible strong impacts of noise on cardiovascular parameters. The role of exposure assessment misclassification is an important factor attenuating the noise effect estimate, which has to be explicitly stated in our final document. Planned air pollution studies will attempt to include assessment of exposure to noise among the potential confounders or effect modifiers.

The chapter should contain justification of the exposure-response relations, the determination of attributable fraction, discussion of the competing risks of outdoor air pollution and noise, generalizability of exposure-response relations and exposure data across countries and regions, and justification of using L_{den} in place of L_{day} to obtain more exposure data from more Member States.

Gjestland will provide a summary on confounding between noise and air pollution, and propose a conversion model for exposure parameters.

WHO and Babisch agreed to draft a chapter on cardiovascular disease by the end of March

Sleep disturbance and annoyance

Sleep disturbance

Dutch experience of **estimating DALYs for sleep disturbance from noise** was summarized by Anne Knol (Netherlands). The key assumptions were on the exposure-response relations and disability weight. Exposure parameter was L_{night} and levels between 45 and 65 dB(A) were considered to remove uncertainties at low-level exposure and selection bias at high-level exposure. When exposure data are not available for exposure-based estimation, an alternative approach would be to use survey data focusing on severe sleep disturbance related to noise (i.e., survey-based estimation).

Ruedi Müller-Wenk (Switzerland) presented the results from an original study on **disability weight for sleep disturbance related to noise**. It was questioned whether "noise-induced sleep disturbance" is compatible with "primary insomnia". Primary insomnia is included in the global burden of disease estimation, however, it does not include insomnia from environmental factors by definition. Acknowledging this difference in the definition, a disability weight specific to noise-induced sleep disturbance was sought after. Based on consensus of the experts of Switzerland, Knoblauch/MüllerWenk proposed 0.089 (C.I. 0.060; 0.120). This value is slightly smaller than that of primary insomnia (0.089 versus 0.100), and can be used as the best estimate of disability weight for noise-induced sleep disturbance.

Celia Rodrigues (WHO) presented **preliminary results of DALY estimation for noise-related sleep disturbance** applying Miedema's exposure-response relation to exposure data for 15 EC Member States. DALYs were the product of Number of people with severe sleep disturbance from traffic noise x Severity weight x Duration. Three disability weights (0.02, 0.01, and 0.12) were considered. With exposure data on the 15 EC Member States, DALYS for noise-related sleep disturbance was **559,719 for disability weight=0.02, 279,859 for disability weight=0.01, and 2,798,594 for disability weight=0.10.**

The meeting agreed that the DALYs for noise-induced sleep disturbance will be estimated with disability weight as 0.089. The availability of L_{night} will limit the estimation of DALYs in many Member States. If there is a reliable model that can predict L_{night} from L_{den}, widely available L_{den} can be used as exposure parameter. **Truls Gjestland (Norway) will provide an assistance in converting exposure data into L_{night}.**

WHO, RIVM, and Müller-Wenk will be responsible for producing the section on noise-related sleep disturbance.

Annoyance

Dutch experience of **estimating DALYs for annoyance from noise** was presented by Anne Knol (Netherlands). The choice of exposure-response relations and disability weight was key assumptions regarding the parameters. Exposure parameters were L_{dn} and L_{den}. Levels lower than 45 and higher than 75 dB(A) were not considered to avoid uncertainties and selection bias. A disability factor of 0.02 with a relatively large uncertainty interval (0.01-0.12) was proposed. An alternative approach would be to use survey data focusing on severe annoyance to estimate the prevalence, and use the formula for DALY estimation (DALY=Number of people highly annoyed by noise x Severity weight x Duration).

Celia Rodrigues (WHO) presented preliminary **estimation of DALYs from annoyance** using Eurostat survey data (2000). "Proportion of population living households considering that they suffer from noise and pollution" is available under the section "Sustainable development - Public health indicators - Health risks due to environmental conditions" in Eurostat. For conservative estimation, 15% of the above proportion was assumed to be "highly annoyed by noise" as was defined for Miedema-curve in Dutch report. No age groups were considered separately, and children were considered responding the same way as adults, the duration of annoyance was considered 1 year. It was estimated that the DALYs for high annoyance from noise is **278,174 for disability weight 0.02, 139,087 for disability weight 0.01, for 1,669,041 for disability weight 0.12.** When Exposure-based approach was used, DALYs were higher, **529,299 for disability weight 0.02, 264,650 for disability weight 0.01, and 3,175,796 for disability weight 0.12.** Thus, the DALYs based on the Eurostat survey were about the half of those based on noise exposure data Miedema's exposure-response relation estimates. Possible underestimation by survey-based approach was also noticed in Dutch experience. Considering the large uncertainties in the measurement of exposure, outcome and survey methods attached, the results from survey-based and exposure-based estimation are remarkably within a small range.

Colin Mathers (WHO) pointed out that annoyance is not a 'disease' condition classified in WHO's ICD-9 or ICD-10. The meeting confirmed that annoyance will be included in a special section to keep the consistency with the global burden of disease projects in WHO.

WHO and RIVM will be responsible for producing the section on noise-related annoyance.

Hearing impairment and tinnitus

As a background, Hans-Peter Zenner (Germany) summarized scientific evidence for causal association of noise with hearing impairment and tinnitus as Figure 1. There is sufficient evidence that environmental and non-occupational noise impairs hearing and induces tinnitus. There is a well established exposure-response relationship of noise for hearing impairment, but not for tinnitus.

Figure 1. Evidence review for hearing impairment and tinnitus from environmental noise

Noise induces both tinnitus (Ti) and/or hearing impairment (HL)	Clinically generally accepted

↓

Causal pathway for HL in the inner ear(haircells, excitotox.)	Clinically animal experiment molecular
Dose response curve HL Dose response curve Ti	ISO 1990 Missing but possible

↓

Lack of objective measures Ti (like pain)	-
HL + Ti often correlated	Clear temporal association

↓

Primary damage HL + Ti identical Animal / molecular data reflect Ti?	No objective measures

↓

Causal web HL valid for Ti	Plausible for initiation; less for persistence
Dose response curve Ti	Corrected HL encecurve or to be determined

Hearing impairment

Deepak Prasher (UK) presented **impact of environmental noise on hearing impairment**. The levels of environmental noise, particularly transportation noise, is very high in large cities in developing countries. The impact of leisure noise is not as well understood as that of occupational noise. There is an interaction between aging and noise exposure. Middle-aged people are more vulnerable to hearing impairment from noise. A mild hearing impairment is the most common outcome for the type of exposure related to leisure noise. Although severe hearing impairment has been already counted in DALYs calculation in global burden of disease with disability weight 0.333, mild hearing impairments of audiometric ISO value of 26 – 40 dB have not been considered so far. However, a mild hearing impairment in the range of 26 – 40 dB at young age is a public health problem because it leads to a premature hearing impairment at older age.

Colin Mathers (WHO) pointed out that the global burden of disease concept does not account for future damages. If noise-induced hearing impairments lead to premature hearing loss in older ages, these latent effects will be counted in the attributable fraction of older age groups. Three possible approaches were suggested to consider mild hearing impairment:

- Use the global burden of disease definition of hearing impairment (severe impairment of 41dB or greater) and consider the fraction attributable to non-occupational noise.
- Propose a new definition of hearing impairment including mild impairment of 25-40 dB, and assign a corresponding disability weight to this mild form.
- Use a model to predict the outcomes of severe impairment from the population having mild impairment.

In any cases, the mild impairment of hearing needs to be accurately defined and the disability weight needs to be adjusted. If the results from these approaches are biologically plausible and consistent with evidence, this could then be used for estimating the global burden of disease of mild hearing impairment at international level.

Assessing exposure data for leisure noise has to consider the fact that, for intense noise levels a strong convalescence period factor exists and an age factor. All the assumptions made will have to be described.

Prasher is responsible for this chapter in close collaboration with WHO. Zenner will help find some data in Germany regarding fire-crackers and other leisure noise exposure. Deshaies will also further investigate the existence of data for toys and music in Canada.

Tinnitus

Pierre Deshaies (Canada) presented an extensive review of the issues related to the **quantification of the burden of tinnitus caused by community noise** prepared by a working group in collaboration with Hans-Peter Zenner (Germany). The background paper prepared by the working group is attached as Annex.

The burden of disease caused by community noise induced tinnitus had probably been so far largely underestimated. The data demonstrated that it is paramount medically, politically, and economically to implement effective preventive measures for noise pollution, particularly for the protection of minors and young adults. However, evidence was lacking both on the exposure-response relationship and on the exposure to leisure noise, constraining the effort to estimate the burden of disease in Europe.

No direct curative medical treatments are available for tinnitus at this time. Some forms of treatment for chronic tinnitus are instrumental and cognitive-behavioural methods which cannot heal tinnitus but teach individuals how to influence tinnitus cognition or perception. Therefore, a disability weight can be assigned to chronic tinnitus as a form of disability.

The group recommends two disability weights to match with whichever data is available for calculation: one for general tinnitus prevalence data, one for annoying (disabling) tinnitus.

For moderately to severely annoying tinnitus, the analogy is made with chronic pain. Chronic pelvic pain has a disability weight of 0.122 (global burden of disease 1990, WHO) whereas low back pain caused by chronic intervertebral disc has a disability weight of 0.121 (range 0.103-0.125) (global burden of disease 1990, WHO). Primary insomnia have a disability weight of 0.100 while a mild depressive episode has a disability weight of 0.140. As tinnitus may induce in some cases any of these two consequences, an interpolation in those ranges seems reasonable. Thus, a disability weight of 0.120 is suggested. On could argue that this disability weight could be used for any annoying (disabling) tinnitus, including mildly annoying tinnitus.

For global prevalence of tinnitus without reference to its severity, a global disability weight of 0.012 is suggested as a majority of people declaring tinnitus in surveys will either have spontaneous remission or adapt easily. Tinnitus should not be a null disability weight, as it is for mild adult onset hearing impairment. On the other hand, only a small proportion of persons reporting ever having tinnitus will be disabled. A disability weight of 0.012 was proposed based on an estimated 10% who become moderate to severe sufferers.

The meeting recommended that the calculation of DALYs for noise-induced tinnitus will be possible with either survey-based or exposure-based approaches.

Survey-based approach: Identify large-scale (preferably national) surveys estimating proportion of population with noise-induced tinnitus. Estimate the prevalence of noise-induced tinnitus in Europe. Use the formula DALY=Number of people with noise-induced tinnitus x Disability weight (0.012) x Duration (one year). Because reversibility of the condition is already considered in discounting disability weight from 0.12 to 0.012, duration can be assumed to be one year.

Exposure-based approach: Big question is "Can an exposure-response relation between environmental noise and tinnitus be derived from existing literature?" If possible, the exposure-response relationship between 'leisure noise' and tinnitus should be proposed. At this point, there is very scarce literature giving direct answers. So, the well-known occupational noise-NIHL relationship could be used under certain conditions. Estimate the population's exposure to non-occupational noise including traffic and leisure noise by generalizing the exposure data from countries with available exposure data with appropriate assumptions. Survey on leisure noise exposure should be reviewed. Estimate population attributable fraction using the above information to calculate the "environmental noise" proportion of DALYs lost from all tinnitus.

Questions remain how to estimate the total burden of disease from various noise sources and estimate the noise attributable fraction, respectively. To add up DALYs from difference sources, a consistent case definition should be given considering duration and intensity of outcome. The differences between temporary and permanent tinnitus should be accurately described.

The prevalence of tinnitus in the general population should be estimable in surveys and national medical statistics. A paper on noise-related tinnitus has described that 8.5% of the population has permanent tinnitus. However, tinnitus induced by occupational noise should be excluded because this project focuses on environmental noise. Ideally we should have a prevalence/incidence by age. The definition of tinnitus to consider should be the one that causes a significant disability.

Question was raised regarding the voluntary nature of the leisure noise exposure. Tinnitus is caused by voluntary use of toys and entertainments, and people know that loud sounds can be harmful. Although the voluntariness of leisure noise exposure does not change the magnitude of the burden of disease from leisure noise, it will be necessary to mention in the document for policy-makers.

Deshaies will prepare the section on tinnitus in collaboration with Zenner and Prasher.

Cognitive impairment

Staffan Hygge (Sweden) calculated **DALYs for cognitive impairment** in Sweden to be 20,638 based on several assumptions on the outcomes, exposure, incidence and disability weight. Maximizing use of available quantitative data, a preliminary estimation was made. A few methodological issues were discussed regarding the assumptions in the estimation.

Definition of the outcome

There are four components of cognitive impairment related to noise – reading, recall, recognition, and attention showing consistent relationship with noise exposure. There should be an operational definition of cognitive impairment integrating these outcomes for the purpose of EBD estimation.

Response measure in the exposure-response relationship

Reading and recall have steeper slopes than attention and recognition. The studies on recall and reading cluster together and have slopes around 2% per dB. Studies on recognition and attention also group together and generally have slopes in the region of 0.6% per dB. Thus, for recall and reading, it is expected that a reduction of the noise level by 5 dB L_{dn} would result in improved performance by something like 10%. For attentional tasks and for recognition memory, a 5 dB L_{dn} reduction in noise level is expected to result in around 3% improvement of the response. Although a consistent dose-effect relationship is derived from twenty epidemiological and experimental studies, the effect was not measured by incidence or prevalence, but the percentage of cognitive impairment. This makes a problem in estimating the incidence or prevalence of cognitive impairment related to noise exposure. To solve this problem, Hygge assumed an increasing incidence corresponding to varying exposure levels: 50, 100, and 200 per 1000 children age 7-19 for 55-65, 65-75, and >75 dB L_{dn}, respectively. Without empirical data, this approach can be criticized as speculative. Therefore, factual data supporting this incidence model should be presented in order to accept this approach.

Disability Weight

The percentage loss of cognitive impairment cannot be directly converted into disability weight unless the loss is considered as a disability in clinical terms. Therefore, the assignment of disability weight should be based on the clear definition of 'disability.' Because the heterogeneous nature of cognitive impairment considered, a summary value of disability weight will be difficult to choose. To solve this problem, Hygge assumed an increasing disability weight corresponding to varying exposure levels: 0.10, 0.20, and 0.30 for 55-65, 65-75, and >75 L_{dn}, respectively. Application of different disability weight to different exposure levels is not a standard practice in DALY estimation. This approach can be criticized for allowing inconsistent definitions of outcomes depending on the exposure level.

Reversibility of impairment

Most of the noise-induced cognitive impairment is not permanent. However, the cognitive development of children exposed to chronic noise will be delayed, compared to those unexposed. It was argued that cognitive impairment in childhood will hamper the learning ability of the individual in later life and affect the overall quality of life. However, it is not certain whether we can consider a long-term consequence of reversible condition into disability weight. If evidence exists that noise in childhood has a life-long cognitive effect, the burden of cognitive loss should be estimated. Because adults are also learning, and learning capacity can be influenced by noise, noise-related cognitive impairment can be considered for all age group. The question is whether we have consistent evidence of exposure-response relationship in adult population to take account into DALYs.

How to estimate DALY when empirical data are limited

A scenario-based estimation of DALYs was recommended by Mathers..

- The outcome definition should be articulated for reproducibility as possible.
- A single disability weight should be assigned corresponding to the case definition rather than multiple disability weights for variable outcomes. Reversibility and temporariness

should be reflected in the disability weight so that the duration of the outcome can be safely assumed to be one year.

- The total number of case in the population in different exposure groups is estimated. Any assumptions made in this step should be clearly stated.
- DALY can be calculated by multiplying the total number of case by disability weight because duration is considered to be one year.

Overall recommendations

Exposure data

Limited availability of reliable exposure data is a major constraint. To be useful for policy-makers, burden of outcomes should be studied in relation to specific noise source if possible. For example, cardiovascular disease, sleep disturbance, and annoyance were associated with *road traffic noise*, cognitive impairment with *aircraft noise*, and hearing impairment and tinnitus with *leisure noise,* although these associations are not exclusive. For example, sleep disturbance and annoyance are related to all sources of noise. If we use Lden in place of Lday, Lden, and Ldn regardless of health outcomes, the availability of exposure data will remarkably increase in Europe because Lden will be available in most EU countries according to the European Noise Directive in 2007. Prasher agreed to check whether the preliminary data are available from the EU Directive. Gjestland agreed to propose a predictive model to convert Lden to the exposure parameters specified in the exposure-response relationships.

Outcome data

Clear definition of outcomes is needed. A big potential exists for error if we take a GBD weight but then apply it to a prevalence that relates to a much broader (or narrower) case definition. For cardiovascular disease, clear inclusion and exclusion of disease such as myocardial infarction, coronary heart disease, hypertension should be made. For sleep disturbance, annoyance and tinnitus, case definition should correspond to the survey data used in the calculation. For hearing impairment, the definition of mild hearing impairment should be articulated in relation to environmental noise. For cognitive impairment, operational definition can be made to incorporate four domains of outcome.

Disability weight

Disability weight has nothing to do with the value of the person with specific condition. It reflects the preferences for health states of the society. Therefore, burden of disease can be estimated for the conditions without clinical diagnosis such as symptoms or risk factors. Use of self-reported assessments based on survey is acceptable, but it involves more uncertainty. For each proposed disability weight, an attempt should be made to be consistent and compatible with the global burden of disease project.

Adding up the DALYs

Addition of DALYs from different outcomes related to environmental noise to estimate the total burden is acceptable practice. However, care should be taken when double-count the co-morbidities. For example, tinnitus has high rate of co-morbidity with sleep disturbance and depression. Only when we assume that the disabilities caused by tinnitus and sleep disturbance are additive in a society, we can add up the DALYs for tinnitus and sleep disturbance. Such implicit assumptions should be articulated in the document as sources of uncertainty.

Unintentional vs. intentional noise exposures

Babisch suggested that the document has better make a clear division between "unintentional" noise exposures (ex.: traffic noise) and "intentional" noise exposures (ex.: leisure noise). Deshaies recommended that the concept be introduced into the table of contents as it is seems very relevant for public health practitioners and policy makers.

Follow up work

The meeting has identified constraints of knowledge and methodology that should be addressed to quantify noise burden of disease. The next step is to fill those gaps and to reiterate the calculation of DALYs based on the conclusions and recommendation of this meeting. Accidents and injuries will be considered at the next meeting as a special topic. Provisional table of contents of the project product is proposed as Box 1. **The Working Group experts will be responsible for drafting section 3.3 through 3.9.** WHO proposed the terms of reference specifying the topics and tasks to the members of the Working Group as in Annex 1. Box 2 summarizes the status of progress, and main challenges ahead. **The individual chapters will be prepared by assigned authors according to the terms of reference until the 11th of April. The initial draft will be reviewed and edited collectively in a meeting in Berlin on 18-19 April.**

Box 1. Provisional table of contents

Title: Environmental burden of disease series: Environmental noise
- Assessing the burden of disease from environmental noise at national and local levels

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Annex 2: Using noise map and exposure scenarios to inform policy actions (Prasher)
Annex 3: Summary of global burden of disease from environmental noise: Eur-A and Amr-A
References to Annex

Box 2. Progress toward the final calculation of DALYs

	Cardiovascular		**Sleep Disturbance**		**Annoyance**		**Hearing loss**		**Tinnitus**		**Cognitive impairment**	**Injuries**
Choice of method for BoD estimation	Essential (First choice)	Optional (Second choice)	Essential (First choice)	Optional (Second choice)	Essential (First choice)	Optional (Second choice)	Essential (First choice)	Optional (Second choice)	Essential (First choice)	Optional (Second choice)	Essential (First choice)	Essential (First choice)
Exposure definition	Lday	Lden	Lnight 45-65 dBA	Lden	Lden	Lden	Leisure noise (transport noise in developing countries)		Leisure noise (transport noise in developing countries)		Ldn	Lden?
Response definition	Ischemic Heart Disease		Definition by Miedema	Other comparable survey definitions	Definition by Miedema	Eurostat and other comparable survey definitions	Severe NIHL: Hearing loss >41 dB	Mild NIHL: Hearing loss 25-40 dB	Severely annoying tinnitus	Tinnitus without reference to severity	Reading, recall, recognition, attention	Injuries related to noise-induced insomnia
ER Relationship	+++ (Babisch)	?	+++ (Miedema)	NA	+++ (Miedema)	NA	+++ (Occ noise)	++	?	?	++ (Hygge)	?
Disability Weight	DALY for IHD available from GBD project		0.089 Müller-Wenk	0.02	0.02	0.01, 012	0.25	+	0.122	0.012	+	DALY for injuries available
Availability of survey-based DALYs	NA	NA	?	?	?	278,174	?	?	++	+	NA	?
Availability of exposure-based DALYs	880,000	?	2,490,749	559,719	529,299	NA	No exp. data	+	+	+	20,638 in Sweden	?
Provisional DALY proposed in Bern	880,000	?	Need better exp. data	559,719	Need better exp. data	278,174	?	?	?	?	20,638 in Sweden	?
Main challenges	Exposure data?	Conver sion of ex data	Exposure data?	Survey data?	Is it a disability?	Compatibility of definition?	Ex. data on leisure noise?	Survey-based apprch?	ER relation?	Pop. Attrib. Fraction?	Ex. Data ER Relation Case def?	Pop. Attrib. Fraction?
Authors	Kim and Babisch		Kim and Rodrigues		Kim and Rodrigues		Prasher		Deshaies, Zenner, and Prasher		Hygge	Jovanovic

NOTE: +++ Ready; ++ Could be completed within 2 weeks; + Could be completed in 4 weeks; NA not applicable

Annex 1

TERMS OF REFERENCE FOR THE WORKING GROUP

Objectives of the Working Group:
The main objective of the work is to draft the topic-specific sections in the document as the key deliverable of the project on burden of disease from environmental noise. This document will be to submitted to WHO Headquarters for possible publication as one of WHO Environmental Burden of Disease Series.
Topic assignments:

- Cardiovascular disease: Kim and Babisch
- Sleep disturbance and annoyance: Kim, Müller-Wenk, Knol, and Rodrigues
- Hearing impairment and tinnitus: Prasher, Zenner and Deshaies
- Cognitive impairment: Hygge
- Accidents and injuries: Jovanovic
- Exposure data modelling: Gjestland
- Acquisition of preliminary Lden data from EU: Prasher and Gjestland

Organization of the topic-specific section (3.3-3.9 of provisional table of contents):
For each assigned section, the following structure is strongly recommended for the comparability of the methods and the consistency of the format.

- Evidence base for the causal association
  - Literature review based on papers published in peer-reviewed journal
  - Summary of exposure-response relationships
- Definition of outcome and disability weight
  - Outcome definition
  - Disability weight
- Definition of exposure and available data
  - Definition of exposure indicators
  - Determining the distribution of exposure in the population
  - Characteristics of exposed population (age, gender, etc)
- Estimating exposure-response relationships for defined outcome and exposure
  - Pooled or typical odds ratios by noise levels from evidence base
- Estimating the attributable fraction
  - Calculating the attributable faction
  - Calculating the disease burden
- Uncertainty
  - Uncertainty in exposure estimates
  - Uncertainty in relative risk estimates
  - Uncertainty in outcome estimate
- Policy implications
  - Pooled or typical odds ratios by noise levels from evidence base
- References

Writing style:
Because the document is to help local and national policy-makers and related authorities assess disease burden of environmental noise, the writing should be plain and succinct. Avoid unnecessary jargons of acronyms as possible, and use laymen's terms as possible. Target readers are the public health workers and policy-makers in public sector with a basic knowledge of public health terminologies. Burden form occupational noise was already published by WHO, so avoid dealing with issues of occupational noise except when necessary. Any findings or discussions relevant to children should be elaborated and highlighted because WHO is focusing on implementation of Children's Environment and Health Action Plan for Europe, where children's noise exposure is considered as one of Regional Priority Goals. **Try to keep the consistency with the previous WHO guidelines on noise, such as "WHO Guidelines for Community Noise, http://www.who.int/docstore/peh/noise/guidelines2.html" and "EBD series on Occupational Noise (http://www.who.int/quantifying_ehimpacts/publications/en/ebd9.pdf).** "

Feel free to contact WHO secretariat Rokho Kim (rki@ecehbonn.euro.who.int) or Celia Rodrigues (cer@ecehbonn.euro.who.int) for technical or editorial issues. Thank you very much!

Annex 2

BACKGROUND PAPERS AND PRESENTATIONS

Quantifying burden of myocardial infarction related to environmental noise: Based on updated review of the relationship between transportation noise and cardiovascular risk by Dr Wolfgang Babisch

Dr Rokho Kim

Introduction

In 2001, 16.6 million deaths globally were due to cardiovascular diseases (CVD); this figure will increase to 25 million by 2025. The two leading causes of death worldwide are cardiovascular - coronary heart disease (which causes heart attack and heart failure) and cerebrovascular disease (which causes stroke). The direct and indirect costs of CVD are high: enormous health care costs and productivity/income losses.

Ischemic heart disease has a small but verified environmental linkage through air pollution, occupation, and, perhaps also water quality. According to Smith et al., 8-10% of ischemic heart disease can be attributable to environmental risk factors. (How much Global Ill Health Is Attributable to Environmental Factors? Kirk R. Smith,1 Carlos F. Corvalán, and Tord Kjellström. Epidemiology September 1999, Vol. 10 No. 5) So far, exposure to environmental noise was not considered in the estimation of environmental burden of diseases.

WHO European Centre for Environment and Health is preparing a document to estimate ///////

Based on a pooled analysis of four prospective studies of non-occupational noise exposure and cardiovascular diseases.

Objectives

This paper aims at estimating DALYs lost from cardiovascular diseases related to environmental noise in Europe based on available evidence and data. First, DALYs lost from CVD by the traffic noise will be estimated for Germany using the risk assessment of Babisch. Then, DALYs will be estimated for the other countries where noise exposure data are available. Finally, DALYs for EURO regions will be estimated by extrapolating the findings from the countries above.

Methods

Definition of Exposure:
The road traffic noise level during the day (Lday: 6-22 h)

Definition of Outcome:
This study aims at estimating DALYs for cardiovascular disease attributable to environmental noise. This includes hypertensive and ischemic heart diseases. The evidence for the relation between noise exposure and hypertension was considered ‘limited’ to derive a robust ER relation

according to Babisch's updated meta-analysis. Therefore, only ischemic heart diseases (coded as 410-415 in ICD 9) will be considered in this paper.

Exposure-response relation
Babisch derived a exposure-response relation for noise levels and the risk of myocardial infarction. The detailed methods and results of Babisch's risk assessment in the Annex of the WHO meeting report of Stuttgart, June 2005.

Table 1 - Pooled effect estimates (odds ratios and 95% confidence intervals) of prospective studies on the relationship between road traffic noise level (Lday) and the incidence of myocardial infarction

	Road traffic noise level - L_{day} - [dB(A)]					
Analytic studies	**<=60**	**61-65**	**66-70**	**71-75**	**76-80**	**N**
Pooled	1.00	1.05 (0.86-1.29)	1.09 (0.90-1.34)	1.19 (0.90-1.57)	1.47 (0.79-2.76)	

Application of ER relation to ischemic heart diseases
The noise impact on myocardial infarction is more accurately and reliably estimated because the misclassification in the diagnosis is less likely than for angina pectoris and other ischemic heart diseases. Because there is no causal mechanism postulated specifically to myocardial infarction, the impact fraction of traffic noise can be applied to all ischemic heart disease. Therefore, the ER relations observed for the incidence of myocardial infarction will be used for the estimation of DALYs for the ischemic heart disease.

Calcuation of DALYs
Assumptions and methods of DALY calculation will follow those made by WHO EBOD projects as outlined by Annet Prüss-Üstün in June 2005.

To calculate DALYs, we need information on the impact fraction of the risk factor and the health outcome data derived from the population. The impact fraction can be derived from population exposure data and the ER relation parameters such as odds ratios (Impact fraction= [S(Pi * RRi) - 1] / S (Pi * RRi)). Outcome data for major disease conditions can be found in various health statistics in terms of the incidence and prevalence.

Exposure-based approach will be used for the countries and sub-regions where both exposure and outcome data are available. For Germany, the estimation of attributable risk percent and number of cases are given by Babisch. By applying the pooled effect estimates (Table 1) to the noise exposure distribution of German population, Babisch estimated or 3289 cases (3.22 percent of total cases) of myocardial infarction is attributable to traffic noise exposure (Table 2).

Table 2 – Attributable risk percent, population attributable risk percent for myocardial infection due to road traffic noise estimated from the special exposure pattern in Germany.

Road traffic noise 1999	**Risk of myocardial infarction due to road traffic noise**				
Average Sound Pressure Level during the day (6-22 h) [dB(A)]	Percentage exposed [%]	Relative risk OR	Attributable fraction AR%	Population attributable risk percent PAR%	Number of subjects per year
<= 60	69.1	1.00	0.00	0.00	0

>60 – 65	15.3	1.05	4.76	0.76	1,011
>65 – 70	9.0	1.09	8.26	0.80	1,070
>70 – 75	5.1	1.19	15.97	0.96	1,278
>75	1.5	1.47	31.97	0.70	932
Sum				**3.22**	**4,289**

If the impact fraction (also known as population attributable risk) is given, risk factor specific DALYs can be estimated directly from health outcomes data. For the countries and sub-regions where DALYs for cardiovascular disease are available, this direct "outcome-based" approach will be used.

Assumptions
Conservative assumptions will be made when the data are not available or evidence is not sufficient.

Uncertainties
Uncertainties will be discussed and quantified as possible to clarify the limitations in the generalization of the findings.

Results

Germany
Population attributable fraction calculated by Babisch is 3.22 % in Germany.

Road traffic noise 1999	**Risk of myocardial infarction due to road traffic noise**				
Average Sound Pressure Level during the day (6-22 h) [dB(A)]	Percentage exposed [%]	Relative risk OR	Attributable fraction AR%	Population attributable risk percent PAR%	Number of subjects per year
<= 60	69.1	1.00	0.00	0.00	0
>60 - 65	15.3	1.05	4.76	0.76	1,011
>65 - 70	9.0	1.09	8.26	0.80	1,070
>70 - 75	5.1	1.19	15.97	0.96	1,278
>75	1.5	1.47	31.97	0.70	932
Sum				**3.22 3.15 by RK**	**4,289**

Switzerland
Population attributable fraction is 4.5 % in Switzerland using the 1990 estimate of noise exposure distribution and population size (6712200).

Average Sound Pressure Level **during the day (6-22 h) [dB(A)]**	Percentage exposed [%]	Relative risk OR	Pi*RRi
<= 60	30.7	1	0.307
>60 – 65	44	1.05	0.462
>65 – 70	22.9	1.09	0.24961
>70 – 75	2.4	1.19	0.02856
>75	0	1.47	0
Sum	15.3	1.05	1.04717

Impact fraction= [Σ(Pi * RRi) - 1] / Σ (Pi * RRi)=4.5%

EU 1994

Average Sound Pressure Level **during the day (6-22 h) [dB(A)]**	Percentage exposed [%]	Relative risk OR	Pi*Rri (%)
<= 60	55.8	1	55.8
>60 – 65	21.9	1.05	22.995
>65 – 70	14.7	1.09	16.023
>70 – 75	6.2	1.19	7.378
>75	1.4	1.47	2.058
			104.254

Impact fraction= [Σ(Pi * RRi) - 1] / Σ (Pi * RRi)=4.08%

Definition of IHD by ICD-9 and ICD-10
ICD-9 410-414
ICD-10 I20-I25

DALY from GBD World Health Report (0 discount, uniform age)

Male EUR-A
4066 4750660201797355
4916000 201513590
4504894450489420288302O
202883.02

Female EUR-A
2000 2970541211510500

2001 3144000 210375507
2002 2828662212440460

Region	EUR-A	EUR-B	EUR-C
Ischaemic heart disease (2000)	4 066	3 536	7 887

Insomnia and noise-related sleep disturbance

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1 Primary insomnia and its disability weight

Primary insomnia means that a person is having sleep problems that are not directly associated with another health condition or problem like sleep apnea, asthma, depression etc. A disability weight of 0.100 was allocated to primary insomnia, valid for all WHO regions/subregions (Mathers et al 2004, Annex Table 5a).

According to WHO, primary insomnia is defined as follows: 'Cases meeting DSM IV criteria for primary insomnia (307.42) where the insomnia causes problems with usual activities. Cases with co-morbid depressive episode or alcohol and drug use (harmful and/or dependence) are excluded' (Mathers et al 2003, Annex Table 4, position II.E13).

The DSM-IV Diagnostic and Statistical Manual (http://allpsych.com/disorders/sleep/insomnia.html) describes the symptoms of primary insomnia as follows: 'The criteria for a diagnosis of primary insomnia include a difficulty falling asleep, remaining asleep, or receiving restorative sleep for a period no less than one month. This disturbance in sleep must cause significant distress or impairment in social, occupational, or other important functions and does not appear exclusively during the course of another mental or medical disorder or during the use of alcohol, medication, or other substances'.

WHO does not give disability weights for insomnia of organic origin (ICD-9 code 780.5), or for any type of primary insomnia not falling into the abovementioned case description (compare Mathers et al 2003, Annex Table 5a)

In short, WHO provides a disability weight (DW=0.100) for insomnia (characterised by at least one of the following: difficulty falling asleep, waking up frequently during night, too early waking up in the morning, unrefreshing sleep) only under the following conditions:
-- IF NOT due to organic origin OR substance abuse
-- AND IF lasting for a period of not less than one month
-- AND IF having significant day-time consequences in professional OR social life

2 Self-reported sleep disturbance due to nocturnal traffic noise and its disbility weight

Today there is a wide agreement that there is a solid dose-effect relationship between Lnight (outside of the most exposed façade), originating from road and rail noise, and the occurrence of self-reported sleep disturbance (Miedema et al 2003).

The open problem is whether the existing disability weight 0.100 for primary insomnia can be used to express the severity of the cases of self-reported sleep disturbance as resulting from the Miedema dose-effect relationship. This problem can be decomposed into 3 questions:
a) Is self-reported sleep disturbance a case of insomnia?
b) is sleep disturbance originating from night-time traffic noise a case of primary insomnia?
c) If self-reported sleep disturbance originating from night-time traffic noise is not a case of primary insomnia, but at least comparable to primary insomnia, is the mean severity of the former roughly the same than the mean severity of the latter, so that the disability weight of 0.100 can be applied to self-reported sleep disturbance originating from night-time traffic noise?

2.1. Self-reported sleep disturbance, a case of insomnia?
According to the U.S. National Institute of Health (www.nhlbi.nih.gov/health/public/sleep/insomnia.htm) , 'insomnia is the perception or complaint of inadequate or poor-quality sleep because of one or more of the following: difficulty falling asleep; waking up frequently during the night with difficulty returning to sleep; waking up too early in the morning; unrefreshing sleep'.

Self-reporting is included in the above definition by the use of the word 'complaint'. Additionally, this inclusion is confirmed by Colin Mathers of WHO, the main author of 'Global Burden of Disease in 2002- data sources, methods and results' (Mathers et al 2003). In his e-mail dated 10.8.2005, Colin Mathers says that ' this issue (primary insomnia) does not relate to whether data sources are self-report or observed in sleep laboratory'.

The term 'sleep disturbance' as used in Miedema et al (2003), refers to questions in social survey questionnaires that are tabled in Tab 5.2 of Miedema et al (2003). A comparison of these questions with the definition of insomnia from the U.S. National Institute of Health, as given above, shows a clear congruence. This means that 'sleep disturbance' in the sense of Miedema (2003) is synonymous to 'insomnia'.

We therefore use here 'noise-related insomnia' and 'noise-related sleep disturbance' as synonymous terms, bearing in mind that noise in this context is mainly night-time noise from road or rail traffic.

2.2 Sleep disturbance from night-time traffic noise, a case of primary insomnia?
In his e-mail dated 10.8.2005, Colin Mathers gives the following statement referring to this question: ' Primary insomnia is sleeplessness that is not attributable to a medical, psychiatric or environmental cause. So this would appear to exclude insomnia due to environmental noise'. This statement has to be accepted as authoritative. We therefore distinguish here between 'primary insomnia' and 'noise-related insomnia'.

2.3.The disability weight of 0.100 - applicable to noise-related sleep disturbance?
Even if traffic-noise-related sleep disturbance is not included in primary insomnia, the disability weight of 0.100 could possibly be used for the former case.

In his e-mail dated 10.8.2005, Colin Mathers gives the following statement: 'The disability weight of 0.1 relates to the level of disability in terms of limitations of daily activity due to lack of sleep. In terms of the disability weight that should be applied to insomnia caused by environmental noise, the issue is really about the relative severity of the two forms of insomnia. If environmental insomnia on average causes as much limitation in daily activity as primary insomnia, then the disability weight of 0.1 could be applied. If on average there is less disability then the weight would be lower.'

According to Colin Mathers, the person who did the analyses for fixing the disability weight of primary insomnia is José Luis Ayuso-Mateos, Department of Psychiatry, School of Medicine, Universidad Autonoma de Madrid, Spain. In his e-mail dated 29.09.2005, José Luis Ayuso gave the statement 'I agree' to the following question submitted to him: 'Could you agree that this disability weight of 0.100 may be attributed also to insomnia due to night-time traffic noise penetrating into the bedroom, if the insomnia lasts more than one month and if it causes 'significant distress or impairment' in important daytime functions of the affected person?'

This means that the disability weight of 0.100 could be used for noise-related insomnia if chronic and if daytime functions are significantly impaired. In the Miedema dose-effect relationship (Miedema et al 2003, Fig 5.1), the condition of chronicity appears to be fulfilled, because the wording of the questions in the underlying social surveys typically include the term 'often' in conjunction with the occurrence of sleep disturbance (Miedema et al 2003: Tab 5.2).

In contrast, the questions of Miedema's Tab 5.2 refer clearly to complaints during night, and not to the situation on the day after. It is therefore important to clarify with the authors of Miedema et al (2003) if an analysis of the full set of questionnaire answers gives an indication that the complaints refer also to the distress or impairment relating to the functions during the day after the unrefreshing sleep. In his mail dated 05DEC05, Henk Miedema confirms the following: 'My hypothesis would be that if we would analyse the TNO archive of datasets to investigate the relationship between self-reported sleep disturbance and outcome measures that could be considered to operationalize "significant distress or impairment in important daytime functions", we would find such a relation. However, at present such analyses have not been carried out by us.'

In order to fill the important information gap on an alternative track, a survey was executed at the sleep clinic of the regional hospital of St.Gall (Switzerland) where a panel of physicians was asked to rate, on the basis of their current experience, the relative severity of daytime activity limitations originating from primary insomnia, versus originating from night-time traffic noise.

3. The severity of noise-related insomnia in relation to the severity of primary insomnia

The sleep clinic, annexed to the Pulmonary Department of Kantonsspital St.Gallen (Switzerland), has a wide experience with the treatment of persons suffering from OSAS (Obstructive Sleep Apnea Syndrome). The patients are admitted to the hospital by general practitioners of the surrounding region. In contrast, general practitioners would not admit persons suffering from noise-related insomnia to this central hospital because the sleep clinic cannot be expected to offer a therapy to prevent an insomnia originating from environmental noise. Thus it appears that there is no experience at the sleep clinic with persons suffering from a sleep degradation due to night time traffic noise. In contrast, it can be expected that general practitioners have more experience with persons complaining about noise-related insomnia, because these might visit their doctor to make sure that they get adequate sleeping pills accompnied by a control of the long-term risk to their general health.

During the period from January to September 2005, a total of 128 general practitioners admitted OSAS patients to the sleep clinic to St.Gall. A random sample of 14 out of these general practitioners were orally interviewed by a member of the medical staff of the sleep clinic, whereby they were asked to express their opinion on the severity of traffic noise related insomnia, relative to the severity of primary insomnia. Further, the practitioners were asked to give their opinion on the severity of OSAS, relative to the severity of primary insomnia. This was a link for the comparison of the severity judgement between general practitioner and sleep clinic.

The questionnaire applied (Translated from German to English)

Could you please give us your opinion on the relative severity of three different cases of insomnia:
Primary Insomnia, in our region usually called psycho-physiological insomnia
Obstructive Sleep Apnea Syndrome (OSAS)
Traffic noise related sleep disturbance, that may occur with persons who are forced to sleep along through roads with nocturnal motor traffic

Your opinion should be based on the patients you have seen in your office lately, or on other persons of your social environment.
When comparing the severity of the health impairment, the focus should be above all on the person's condition during the day after the sleep-disturbed night.
The absolute value of the severity is less important than the relative severity amongst the 3 cases of insomnia.
The opinion of the severity may be expressed on a linear scale from 0 (no impairment at all) to 10 (impairment almost unsupportable)

Please give me now your judgement on the severity of **primary insomnia**. On the scale from 0 to 10, you may give me your mean value of the severity, or you may give me a span from a low to a high for the severity.
…………….

Please give me then your judgement on the severity of OSAS. Again, you may, on the scale from 0 to 10, give me your mean value of the severity, or a span from a low to a high.
……………..

And finally, please give me your judgement on the severity of noise-related insomnia. Again, you may, on the scale from 0 to 10, give me your mean value of the severity, or a span from a low to a high.
………………

The answers
All of the 14 general practitioners, selected at random from the full list of 128, gave their answers, as listed in the table below. In addition to the answers, table 1 contains the ranking of the 3 severity estimates for each participant, as well as the ratio of noise-severity to PrimaryInsomnia-severity.

Table 1: Severity ratings (10= almost unsupportably disturbing, 0= not in the least disturbing) by 14 general practitioners selected at random

	Primary insomnia				**OSAS**				**Noise Insomnia**				**Noise/ Primary Insomnia**
No	Max	Min	Mean	Rank	Max	Min	Mean	Rank	Max	Min	Mean	Rank	

10	6	4	5	3	8	6	7	1	8	6	7	1	1.40
11	5	3	4	3	9	7	8	1	8	4	6	2	1.50
12			5	3			10	1	7	8	7.5	2	1.50
13	2	3	2.5	2	4	5	4.5	1	1	2	1.5	3	0.60
14			3	2			6	1	1	2	1.5	3	0.50
15			8	2			9	1			6	3	0.75
16			8	1			7	2			4	3	0.50
17			5	1			5	1			3	3	0.60
18	2	3	2.5	2			6	1	1	2	1.5	3	0.60
19			8	1			3	2			2	3	0.25
20			6	2			7	1			4	3	0.67
21			7	2			8	1			0	3	0.00
22			4	3			5	2			6	1	1.50
23													
Mean			**5.231**	**2.077**			**6.58**	**1.231**			**3.85**	**2.538**	**0.80**
Std Deviation													**0.51**
Median													**0.60**

Discussion of results
It is clearly visible that the judgement on the severity of noise-related insomnia varies very much between the participating general practitioners. This is probably influenced by the fact that they do not have a broad experience with persons suffering from any of the three types of insomnia compared in table 1: For instance, general practitioner number 15 might have encountered persons very serious cases of OSAS whilst his experience with noise-related insomnia might refer to persons that were only moderately disturbed by night-time noise in their bedroom. On the other hand, number 22 could have had experience with persons suffering very much from sleep disturbance due to night-time traffic noise, whilst his OSAS or primary insomnia patients were rather borderline cases. We have to accept that even general practitioners do have a limited professional experience with the whole range of cases of each of the three types of insomnia, so that their opinion on the mean severity of noise-related insomnia, compared to the mean severity of OSAS or primary insomnia, cannot be free from bias.

Nevertheless, some conclusions can be taken from table 1:
The majority of general practitioners are ranking noise-related insomnia lower than primary insomnia and OSAS, but two of them put noise-related insomnia in the first rank. Only one of the participants considers noise-related insomnia as a negligible disturbance.
The severity ratio between noise-related insomnia and primary insomnia varies between 0 and 1.5. But 7 of the 14 general practitioners indicate a severity ratio between 0.5 and 0.75, that is to say that half the participants are of the opinion that the severity of noise-related insomnia amounts to 0.5 - 0.75 of the severity of primary insomnia.
The mean of this severity ratio is 0.8, with a large standard deviation of 0.51. The median of the severity ratio is 0.6
Bearing in mind that the WHO disability weight for primary insomnia is 0.100, we provisionally conclude on the basis of the above figures that a best guess for the disability weight for noise-related insomnia can be set at 0.070, with a low estimate of 0.060 and a high estimate of 0.9 .(We consider here 'disability weight' as a case of 'severity weight', so that further disability weights may be derived by multiplication with a severity ratio.)

A comparison to other results

The above proposal for a disability weight for traffic-noise-related insomnia may be compared with comparable studies in the Netherlands, cited in Knol&Staatsen (2005: 46).
A first study was published by Van Kempen in 1998, resulting in a severity weight of 0.100 for severe sleep disturbance basing on the judgement of 13 medical experts working according to a protocol by Stouthard (1997). A second study was published by Den Hollander et al in 1999, with a severity weight of 0.010 for the same condition. In his thesis (Den Hollander 2004:98), den Hollander mentions that a state definition for (noise-related) sleep disturbance was ".. interpolated by a panel of environment oriented physicians, employing the scale of calibration states which was drawn up by Stouthard et al (1997)". There is no information in Den Hollander (2004) that could explain the comparatively low level of his severity weight.

Further, the above proposal for a disability weight for traffic-noise-related insomnia can be compared with the result of a survey with 42 physicians (Müller-Wenk 2002) who developed their judgement by interpolation into a table of disability weights originating from Stouthard (1997). The corresponding disability weight for sleep disturbance was 0.055.

In conclusion, the disability weight of 0.070 for noise-related insomnia proposed here matches fairly well with the result of Van Kempen (1998) and Müller-Wenk (2002) but is hardly consistent with the result of Den Hollander (1999, 2004). The publications of den Hollander do not give enough details for an analysis of this inconsistency.

References:

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http://www3.who.int/whosis/discussion_papers/discussion_papers.cfm?path=evidence,discussion_papers&language=english

Miedema et al (2003), Miedema H M E, Passchier-Vermeer W, Vos H: Elements for a position paper on night-time transportation noise and sleep disturbance, TNO Inro report 2002-59, Delft 2003 www.europa.eu.int/comm/environment/noise/pdf/noisesleepdisturbance.pdf

Müller-Wenk R (2002): Attribution to road traffic of the impact of noise on health, Environmental Series No. 339, SAEFL 2002

EBD ESTIMATION – Sleep disturbance

Based on the methods of:

RIVM – The Dutch National Institute for public health and the environment
SAEFL - Swiss Agency for the Environment, Forests and Landscape
MÜLLER-WENK, R., 2002: Attribution to road traffic of the impact of noise on health. Environmental Series No. 339. Swiss Agency for the Environment, Forests and Landscape, Bern.

Table of contents

9 December 2005 - 1st DRAFT

Introduction – Effects of noise on sleep
Sleep disturbances are frequently considered as the most accurate and predictive consequences of environmental noise on health.

There are different methodologies to assess sleep disturbance
Subjective sleep disturbance reports
Behavioural awakening measures
Indirect sleep disturbance measures (body motility, for instance)
Actual sleep recording and sleep stage scoring
After-effects (short and long term effects)

To some degree, sleep disturbance by noise may be quantified by (Effects on sleep structure):
Delay on sleep onset
EEG arousals
Sleep stage changes
Awakenings
Modifications of temporal structure of sleep
Time spent in the different sleep stages
Premature final awakening

In complement, concomitant modifications in the autonomic functions (heart rate, blood pressure, vasoconstriction and respiratory rate) could be indicative of the reactivity of the sleeper.

The main consequences of sleep disorders include physical effects (daytime sleepiness, fatigue, impair ability to maintain a healthy endocrine and immune system) and psychological effects (deterioration of performance, reduced attention and motivation, diminishment of mental concentration and intellectual capacity). Sleep disorders have an impact on quality of life and on professional and personal behaviour education, absenteeism, risk of motor vehicle, work and domestic accidents.

There is a rather weak overall agreement about exposure - response relationships of noise and sleep disturbance as the scientific literature indicates. Dose-effect curves exist for subjective reporting (next day surveys), motility and behavioural awakenings. The subjective complaint of bad sleep can be reported in the following morning either spontaneously or in response to specific questions. But these are not considered by sleep specialists the best way to assess sleep disturbances, subjective estimates and objective measures of disturbed sleep are often not superimposed. For example the sleep apnoea syndrome (SAS) patients often consider that their sleep is of rather good quality, even if it is restless.

The WHO Community noise guidelines recommend 30 dB LAeq (8 hours) indoor and 45 dB LAeq (8 hours) outdoor as the threshold value for sleep disturbance.

There are still questions regarding how to design objective measures of sleep disturbance, in terms of arousals and probability of inducing a sleep stage change, even if there is clear evidence of cases where no objective noise effect is accompanied by loud complaints, and cases where people do not complain about the noisy environment and still exhibit clear sleep and/or cardiovascular modifications on the long term. I a recent field study for aircraft noise (Passchier-Vermeer et al., 2002)) an increased probability of instantaneous motility was found for events with a maximum sound level LAmax>32 dB (A), while in a meta-analysis, conscious awakening was found for events with LAmax >42 dB(A) (Passschier-Vermeer et al., 2003). In a recent field study, threshold for EEG awakening was found to be LAmax = 35 dB(A) (Basner et al., 2004).

Above their threshold (indoor level in the sleeping room), these effects were found to increase monotonously as a function of the maximum sound level during a noise event.

1.1 Long term-effects – Insomnia
Insomnia may be considered as a proxy of sleep disturbances experienced by people reporting noise sleep disturbances in for a long period. The long term effects of insomnia are not completely understood by sleep specialists. Nevertheless it seems that chronic insomnia is associated with behavioural impairment (fatigue, poor performance at work, memory difficulties, concentration problems, car accidents), psychiatric (depression, anxiety, alcohol and other substance abuse), medical (cardiovascular, obesity, endocrine impairment, pain, impaired immune system). On a WHO meeting of international experts (2004) the following was concluded: "Due to the absence of experimental studies directly testing the long-term impact of noise on health one way to assess the long-term consequences of noise is to adopt a model. Primary insomnia as defined by DSM-IV and DSM-III (Diagnostic and Statistical Manual of Mental Disorders) has been considered by the expert group as an acceptable model".

Objective and methods
The DALY is a health gap measure that combines both time lost due to premature mortality and non-fatal conditions. This measure was used in "The Global Burden of Disease and Injury (GBD)", a joint study between the World Bank, the World Health Organization (WHO) and Harvard School of Public Health, which began in 1988 with the objective to quantify the burden of disease and injury of human populations and define the world's main health challenges.

The GBD study had three major objectives:
- to facilitate the inclusion of non-fatal health outcomes in the debate on international health policy which were all too often focused on mortality in children under 5 year of age;
- to decouple epidemiological assessment from advocacy so that estimates of mortality and disability from a condition are developed as objectively as possible. Decision-makers at the national and international level are frequently presented evaluations of the burden of disease or injury that have been produced by groups advocating a particular policy change. What they require are independent objective evaluations; and
- to quantify the burden of disease using a measure that could also be used for cost-effectiveness analysis. The power of using a common metric for burden assessment and economic appraisal of intervention options warranted the difficulties of crafting a measure for both purposes.

The DALY was designed to meet these objectives. Using DALYs, the GBD was measured for 1990 and projections were developed to 2020. This measure was also used in The World Development Report: Investing in Health (World Bank 1993) in order to define priorities for investments in health.
The DALY extends the concept of potential years of life lost due to premature death (PYLL) to include equivalent years of 'healthy' life lost by virtue of being in states other than good health. DALYs for a disease or health condition are calculated as the sum of the years of life lost due to premature mortality (YLL) in the population and the equivalent 'healthy' years lost due to disability (YLD) for incident cases of the health condition:

$$DALY = YLL + YLD$$

The loss of healthy life due to non-fatal health conditions requires estimation of the incidence of the health condition (disease or injury) in the specified time period. For each new case, the number of years of healthy life lost is obtained by multiplying the average duration of the condition (to remission or death) by a severity weight that measures the loss of healthy life using an average health state weight. The DALY is described in detail in Murray and Lopez (1996).

In order to use time as a common currency for non-fatal health states and for years of life lost due to mortality, we must define measure and numerically value time lived in non-fatal health states. The 'valuation' of time lived in non-fatal health states formalises and quantifies social preferences for different states of health as health state *weights*. Depending on how these weights are derived, they are variously referred to as disability weights, quality-adjusted life year (QALY) weights, health state valuations, health state preferences or health state utilities. Most such weights are measured as a number on a scale of 0 to 1, where 0 is assigned to a state comparable to death and 1 is assigned to a state of optimal health. Because the DALY measures loss of health, the weights are inverted for DALY calculation with 0 representing a state of optimal health (no loss) and 1 representing a state equivalent to death.

This section presents the method proposed by the RIVM (1) and the method proposed by SAFEL (2). Both methods use the WHO burden of disease assessment method quantifying the impact in DALYs Disability Adjusted Life-Years using the following formula:

DALY = Number of people affected x Severity x prevalence

The RIVM method is based on the exposure-effect relationships derived by Miedema et al (2004) based on survey assessing self reported sleep disturbance results and the SAEFL method explores the use of insomnia as a proxy. This difference reflects on the exposure assessment and on the severity. The first method estimates the number of people exposed using the curves and the second uses surveys results. For insomnia a WHO severity weight already exists, for self reported sleep disturbance by noise a severity weight was derived from expert judgement.

Exposure indicator

The Lnight is a good indicator of assessing the global night noise exposure, while event indices are more accurate to predict sleep disturbance. A large review of the literature shows that it is generally acknowledged that measures of peak sound level are better predictors of disturbances in sleep than measures of average sound level. However for the sake of simplifying the health impact assessment Lnight will be the indicator used. This issue will be addressed on the uncertainty chapter.

The number of sleep disturbed people can also be assessed directly using surveys. But those are normally very costly and not reflect the reality (people tend to "habituate" to noise).

2.1 – The RIVM method

This method is based on the following approach:

Assessment of the exposure distribution of the population using a noise-propagation model or (when not available) a more crude model taking into account traffic and population density. European Commission guidelines for noise calculations and metrics should be applied.

Selection of exposure-response functions based on review of epidemiological studies.

Calculation of the proportion of cases in the study population that can be attributed to noise, based on the basic prevalence in the study population.

There are, however, limitations to this approach. How to deal with uncertainty in causality and exposure-response functions. The transferability of estimates to populations other than the study population, from which the estimate has been derived, is another source of uncertainty.

2 1.1 Exposure data

The required exposure data for self reported sleep disturbance is the number of people exposed to levels of noise higher then 40 dB(A). To use the exposure response curves the number of people exposed to noise classes, according to the following table should be described. If possible this data should be categorized per source.

Taking into consideration the existing situation on European countries regarding data collection and the diversity of methodologies and models, the data needed for computing this indicator can be derived from any of the models existing in countries. In addition if a country has only the exposure for cut-off points (e.g. high noise levels) they should report these data and explain this in a special note. When models are used to provide the data, the model assumptions and calculation method should described in detail.

Exposure category, Lden (dB(A))	**% population exposed to road traffic noise**	**% population exposed rail to traffic noise**	**% population exposed to air traffic noise**
< 45 dB(A)			
46 – 50 dB(A)			
51 – 55 dB(A)			
56 – 60 dB(A)			
61-65 dB(A)			
> 65 dB(A)			
Total	***100%***	***100%***	***100%***

Table 1 – Necessary exposure data

2.1.2 Prevalence

There are at least two ways of measuring the aggregate time lived with a disability. One method is to take point prevalence measures of disability, adjusting for seasonal variation if present, and express them as an annual prevalence. The alternative is to measure the incidence of disabilities and the average duration of each disability. The product of the incidence and the duration will then provide an estimate of the total time lived with disability. This is the approach used for DALY calculation in the Netherlands.

The average duration of a sleep disturbance due to noise was estimated using relevant literature and annual prevalence rates (based on periodic surveys), assuming that people will be sleep disturbed throughout the year. Therefore, the duration is defined as 1 year in the DALY calculations.

2.1.3 Exposure-response relationships

Based on an analysis of original data from 15 datasets (12 field studies, 12000 observations) in the TNO archive, relationships have been proposed (table 1) that give the percentage of highly sleep disturbed (%HSD), sleep disturbed (%SD), and (at least) a little sleep disturbed (%LSD) by road traffic and railway noise as a function of the outdoor Lnight at the most exposed façade

(Miedema et al., 2003). Sleep disturbance questions vary a lot between surveys, in wording and in the number or response categories. In order to obtain comparable disturbance measures the sets in the selected studies were translated into a scale from 0 to 100. Cut-off points to assess the percentage of highly sleep disturbed persons were used analogue to the definitions of percentage (highly) annoyed persons. No relationships for aircraft noise were proposed because of the large variance in results.

Relationships for awakenings and instantaneous and mean motility have also been tentatively proposed (Miedema et al., 2003). Instantaneous motility measured by actimetry correlates well with EEG- and behavioural awakenings. In a recent extensive study around Schiphol Airport mean motility during sleep has been associated with number of sleep and health complaints and self-reported sleep quality (Passchier-Vermeer et al., 2002). Since this study has sufficient power and several short-comings of earlier studies have been accounted for (e.g. control for outcome dependency due to repeated measurements, indoor noise measurements, data on important mediating or confounding factors) Passchier-Vermeer proposes to use the exposure-effect relationships for instantaneous and mean motility derived from this aircraft noise study. An important factor influencing this relationship is the individual long-term aircraft noise exposure during sleep. With higher aircraft noise exposure (Lnight 40 dB(A)) the probability of instantaneous aircraft noise-related increase in motility is much lower. Mean motility during sleep is strongly related to age and is also a function of noise exposure during the sleeping period.

The exposure-effect-relationships are only applicable for the range 45 – 65 dB(A) (Lnight),

The curves described in table 2 have been derived for adults. They describe the level of annoyance due to night-time noise, which is not the same as perceived sleep quality. The curve for aircraft noise is based on only one (but extensive) field study. Further verification of the relationships proposed is needed with attention to construction of the dwellings (insulation, position of the bedroom) and other use of windows.

Effect	**Indicator**	**Source**	**Exposure-response curves**
Sleep disturbance motility (mean)	Lnight	Aircraft	M_{night}=0.000192 x (Lnight – Ldiff1-ldiff2) [b]
Percentage	Lnight	Road	
highly sleep disturbed (HSD)			%HSD=20.8 – 1.05 L_{night} + 0.01486 L_{night}^2
sleep disturbed (SD)			%SD=13.8 – 0.85 L_{night} + 0.01670L_{nigght}^2
A little sleep disturbed (LSD)			%LSD= -8.4 +0.16 L_{night} + 0.01081 L_{night}^2
highly sleep disturbed (HSD)	Lnight	Rail	%HSD=11.3 – 0.55 L_{night} + 0.00759 L_{night}^2
sleep disturbed (SD)			%SD= 12.5 – 0.66 L_{night} + 0.01121 L_{night}^2
A little sleep disturbed (LSD)			%LSD= 4.7 – 0.31 L_{night} + 0.01125 L_{night}^2

Source: RIVM

Table2 Exposure response relationships which can be used to assess health effects of traffic noise in the European Region (sources: Miedema and Oudshoorn, 2001, Miedema et al., 2003; Van Kempen et al.,2002; Passchier-Vermeer et al., 2003))

Since road traffic noise accounts for the bigger proportion of people exposed in most European Countries (data from Netherlands, United Kingdom, Switzerland and France), it is proposed to use the exposure-response relationship for road traffic when the exposure data is not source specific.

2.1.4 Severity weight assignment method

The proposed severity weight for self reported sleep disturbance was determined in the context of a Dutch project where 52 diagnoses of public health significance were given weights by a group of environmental physicians, epidemiologists and public health professionals was asked to evaluate and weigh a number of environment-related health effects on a Visual Analogue Scale ranging from 0 (healthy) to 1 (death), using the scale of calibration states which was drawn up earlier (Van Kempen, 1998). In this project a severity weight of 0.02 was attributed to noise induced self reported sleep disturbance with a relatively large uncertainty interval (0.01-0.10).

2.1.5 Children

Only a few studies investigating the effect of noise on sleep EEG, awakenings and perceived sleep quality in children are available. Most studies in children are limited to (pre-term) children exposed to high noise levels in incubators or hospital wards (Kahn, 2003). The few studies in healthy children involved a very small number of children. Changes in sleep quality and quantity are seen when a child is exposed to noise during sleep. Young children are less prone to awakenings due to aircraft noise than adults (Lukas, 1972). An increase in body movements and awakenings (but no changes in EEG) and time falling asleep was observed in children from a quiet area (n = 8) when exposed to increasing sound levels during several nights (Eberhardt, 1990). After a noise-reduction measure (reducing the noise level in the bedroom by 11 dB(A)) Eberhardt observed a reduction in time falling asleep and a very small increase in REM sleep in children (n = 5) who lived along streets with night traffic. It is assumed that brain restoration occurs mainly during REM sleep. Eberhardt estimates that the same sleep EEG reactions occur in adults and children if the night-time exposure of children is 10 dB(A) higher than the exposure of the adults. During the last third of the night, in which REM sleep is predominant, children under experimental conditions show more noise-induced EEG awakenings than during the beginning of the night (Passchier-Vermeer, 2000). A study by Muzet et al comparing traffic noise-induced sleep disturbance and cardiovascular responses in three age groups showed the highest cardiovascular response in children (6-12) as compared with young adults and elderly people (Muzet et al., 1980).
Although children appear to be less disturbed during their sleep than adults (with respect to awakenings and sleep quality) there is evidence for ‘hidden effects’ occurring during sleep (e.g. cardiovascular and hormonal responses). These effects do not seem to diminish (adaptation) and in the long term might cumulate, adding to the risk for e.g. cardiovascular diseases or hypertension.

The preliminary results from the RANCH study in Sweden show that children seem to have better perceived sleep quality than adults. Children scored better than adults on some sleep indicators (sleep quality, tiredness) but not on others (sleep latency, wake episodes).

For the time being no specific exposure-response relationships exist for sleep disturbance and children, so they will be consider in the same way as adults.

2.1.6 Uncertainties

The exposure response derived by Miedema et al. may not be generally applicable and should be used with great care. The use of surveys, if available, is preferable.

Several exposure-effect-relationships were derived for the effects of several noise sources for a range of effects: awakenings, sleep stage changes, motility and sleep disturbance. From these, the relationships for the association between noise from road, rail and air traffic and sleep disturbance derived by Miedema (2003 and 2004) are best applicable for health impact assessment, for they were derived on a re-analysis of individual data from different studies. The curves describe the level of annoyance due to night-time noise, which is not the same as perceived sleep quality. However, they have to be used with great care. This is especially the case for aircraft noise: in comparison with the curves for road and rail traffic noise, the variance of the responses at a given exposure level was relatively large for aircraft noise. This means that the uncertainty regarding the curve for aircraft noise is large. Several causes are suggested: (i) the time pattern of noise exposures around different airports varies considerably due to specific night-time regulations; (ii) the sleep disturbance questions for aircraft noise show a large variation; and (iii) the most recent studies show the highest self reported sleep disturbance at the same Lnight level, which suggests a time trend (Miedema, 2004). Therefore the curve for aircraft noise must be considered as indicative only. Further verification of the proposed sleep disturbance curves is needed with attention to construction of the dwellings and other use of the windows (Miedema, 2003) (Staatsen et al., 2004).
When estimating the number of sleep disturbed people, smaller numbers were found than was expected on the base of national surveys (see also section 3.2.5). Explanations were already addressed in the annoyance-paragraph. As for annoyance, where risk estimates for sleep disturbance based on national/local surveys are available, this is preferable.

2.1.7 Conclusions

The RIVM method proposes for estimating self reported sleep disturbance the use of following formula:

DALY = Number of people severely sleep disturbed x Severity weight x Duration

It is recommended the use data form surveys or national specific if available. If this is not possible, the generalised relations published by Miedema could be used to estimate the number of people severely sleep disturbed - applied with the necessary care to reflect the situation being analysed.

2.2 – The SAEFL method

The SAEFL method developed by Pr Müller-Wenk has covered in detail the assignment of a severity weight to noise induced sleep disturbance. A 1st approach is based on surveys and expert opinion, based in 1 study performed in Switzerland specific for sleep disturbed by noise and 4 others studies that compared noise sleep disturbance with a sleep disorder (Obstructive sleep apnea syndrome). A second approach uses insomnia as a proxy (already in WHO severity weight catalogues) and expert opinion.

2.2.1 Severity weight assignment method - Insomnia and noise-related sleep disturbance

Noise-related sleep disturbance can be considered as a disease (and not only a nuisance), if its severity is not lower than the severity of health impairments that are commonly accepted to be diseases. Four different attempts to attribute a severity weight to noise induced sleep disturbance were made.

2.2.1.1 – Panel of physicians and patients

A first study (Müller-Wenk 2002) aimed at determining a disability weight for sleep disturbance due to road traffic noise in Switzerland, following the WHO methodology (Murray et al.). For this purpose, a description of road-noise-related sleep disturbance was set up: Essentially, this state of health was assumed to be present if a person indicated that, due to traffic noise, he or she had almost every night problems with falling asleep or with continuing sleep during the night or with early or non-restorative waking up in the morning. In addition, a list was established with already available disability weights for a selection of 28 diseases of various types, covering a range from very light severity to high severity (Müller-Wenk 2002). All 64 members of the medical staff of the Swiss Accident Insurance Institute (SUVA) were then asked in a written questionnaire to determine the hitherto unknown disability weight of sleep disturbance by interpolation, i.e. by inserting sleep disturbance at the appropriate place between the presented 28 diseases that were sorted according to ascending disability weight. These participants were chosen because the physicians of the SUVA, besides of being medical doctors, have a particularly high professional know-how in comparing the severity of different types of disability. 42 questionnaire were completed, whereof 41 were usable.

From these questionnaires, an arithmetical mean of 0.055 of the disability weight for sleep disturbance could be calculated, with a 95% confidence limit of 0.039 at the low end and 0.071 at the high end. This can be compared with the disability weights for diseases that are already available from the catalogues of Murray (1996) or Stouthard (1997). The disability weight of the road-noise-related sleep disturbance was set by the physicians to be roughly similar as of 'chronic hepatitis B infection without active viral replication', the latter having a mean disability weight of 0.06 and a 95% confidence interval from 0.034 to 0.087.

The low end estimate of 0.039 would correspond to the mean disability weight of 'Benign prostatic hypertrophy (symptomatic cases)', whilst the high estimate of 0.071 would correspond to the mean disability weight of 'uncomplicated diabetes mellitus'.

The second attempt to assess the severity of road-noise-related sleep disturbance was made in the study of Riethmüller (2004). In contrast to the abovementioned study, the noise-related sleep disturbance was not compared with completely different diseases, but with OSAS (Obstructive Sleep Apnoea Syndrome), a very similar health impairment. As in a paper by Bruni & Bistrup

(WHO technical meeting) noise and interrupted respiration are two types of signals that may induce quite similar reactions within the sleeping organism, although of unequal severity. OSAS is generally accepted to be a disease, and the social security systems are paying the cost of the corresponding therapies.

The Riethmüller study consisted on a questionnaire applied to patients of the sleep clinic of the district hospital of St.Gallen (Switzerland) who suffered from OSAS and were successfully treated by “Continuous Positive Airway Pressure” (CPAP) therapy. These persons had problems to stay asleep and to wake up in the morning in a sufficiently refreshed state to avoid excessive daytime sleepiness. This unsatisfactory quality of sleep was not caused by noise exposure, but by frequent collapses of the upper airway during sleep, leading to arousal reactions.
A group of 67 patients either living in the city of St.Gallen or coming to the hospital for the periodic routine check-up between january and may 2004 were orally interviewed on the basis of a written questionnaire. The main orientation of the study was directed towards the monetary equivalent in Swiss Francs per night, as attributed by the patients to the intrinsic value of the good sleep quality regained by the CPAP therapy. But in addition, the monetary equivalent was also sought for the relief from noise-related sleep disturbance, in order to verify the corresponding results in Müller-Wenk & Hofstetter (2003). A special interest was therefore given to the information supplied by those 19 patients who reported to have a personal experience not only in OSAS-related sleep disturbance but also in road-noise-related sleep disturbance, because they had passed a part of their lifetime at a location with a night-time noise exposure to a noisy road next to their domicile.

These patients were at first asked to express their subjective judgement on the severity of their OSAS-related sleep disturbance (before CPAP therapy) on a linear visual analogue scale (VAS), this scale having a low endpoint 0 (= sleep quality not in the least deficient), and a high endpoint 10 (= sleep quality unsupportably bad). After marking their rating on this scale, the patients were directed to a second VAS scale of the same type, relating now to sleep disturbance caused by road noise. The starting question was to ask the patients if in their experience, the sleep disturbance due to noise was of roughly equal severity than the sleep disturbance due to OSAS, or better or worse. Afterwards the patients were asked to mark on the second VAS scale their subjective judgement on the severity of their noise-related sleep disturbance, in such way that the chosen point for noise on the second VAS scale was appropriate in relation to their choice for OSAS on the first VAS scale.

The people consider sleep disturbance due to OSAS as more serious than sleep disturbance due to night-time road traffic noise, whereby the severity of OSAS is about 1.5 - 3 times as high as the sleep disturbance caused by road noise.

Another study in Canada Toussignant et al (1994) have inquired19 patients with OSAS successfully treated by CPAP therapy. Before therapy and after therapy, the patients had to accomplish a 'Standard Gamble' (SG), where they had to compare their current state of health with an imaginary alternative consisting of full health with probability p and death with probability 1-p. The value of p, where a patient declared himself indifferent in this SG, was the basis for the subsequent calculation of the amount of QALY gained by the CPAP therapy. This amount is equivalent to the disability weight (in the DALY system) of the untreated OSAS-related sleep disturbance. The Toussignant study resulted in a mean disability weight of 0.24 for OSAS-related sleep disturbance. The individual ratings of the 19 patients vary from 0 to 0.92, the extreme values being undoubtedly outliers; the median value of 0.15 might therefore be a better estimate for the disability weight than the mean value.

A similar exercise was done by Chakravorty et al (2002) where a group of 32 patients in the UK with OSAS-related sleep disturbance accomplished a standard gamble SG before and after treatment, in the same way as done by Toussignant with the Canadian patients. The mean QALY increase was again 0.24, with a large standard deviation of 0.23. Chakravorty reduced this standard deviation to 0.09 by an analysis of variance introducing body mass index, AHI and O2-saturation as independent variables. This correction leads to question marks because it is generally acknowledged that correlation between the traditional sleep parameters AHI or O2-saturation and the patient's own health quality rating is low.

In order to validate/re-check the disability weight for noise-related sleep disturbance of 0.055 originating from the SUVA-panel, these 3 studies were compared with the Swiss study. In Table 3, low/mean/high values for the disability weight of OSAS-related sleep disturbance, as derived from Toussignant and Chakravorty, are divided by low/mean/high OSAS/noise ratios from Riethmüller, yielding 9 possible values for a disability weight of noise-related sleep disturbance.

D.W. for OSAS-rel.sleep disturbance based on Toussignant/Chakravorty	low 0.15	low 0.15	low 0.15	mean 0.24	mean 0.24	mean 0.24	high 0.35	high 0.35	high 0.35
OSAS/noise ratio based on Riethmüller	high 3	mean 2.02	low 1.5	high 3	mean 2.02	low 1.5	high 3	mean 2.02	low 1.5
D.W. for noise-rel. sleep disturbance	0.05	0.07	0.10	0.08	0.12	0.16	0.12	0.17	0.23

Table 3: Calculation of disabilty weights D.W. for noise-related sleep disturbance, derived from QALY values Toussignant and Chakravorty

The conclusion from this table is that, in the light of the results of Toussignant, Chakravorty and Riethmüller, the disability weight of noise-related sleep disturbance:
a) is very probably not lower than 0.05
b) is probably not higher than 0.12
This is a fairly good confirmation of the disability weight of noise-related sleep disturbance determined by the 41 physicians of SUVA: best estimate 0.055, with a confidence interval of 0.71*0.055= 0.039, and a high of 1.29*0.055= 7.1

It is concluded from the two studies analysing noise related sleep disturbance (Müller-Wenk 2002; Riethmüller 2004), that:
According to medical experts, persons that declare themselves to be regularly deprived of normal sleep by road traffic noise, have a health state whose disability weight is comparable to 'chronic hepatitis B infection without active viral replication'
People who have an own experience with OSAS-related sleep disturbance as well as with noise-related sleep disturbance gave a severity rating for OSAS-related sleep disturbance which is twice as high as for noise-related sleep disturbance.
The best estimate for a disability weight of noise-related sleep disturbance (persons declaring themselves regularly deprived of normal sleep by road traffic noise) is 0.055, but the true value could be between 0.04 and 0.12.
There is sufficient justification to consider noise-related sleep disturbance as a disease.

2.2.1.2 Primary insomnia and its disability weight
Primary insomnia means that a person is having sleep problems that are not directly associated with another health condition or problem like sleep apnea, asthma, depression etc.

According to WHO, primary insomnia is defined as follows: 'Cases meeting DSM IV criteria for primary insomnia (307.42) where the insomnia causes problems with usual activities. Cases with co-morbid depressive episode or alcohol and drug use (harmful and/or dependence) are excluded' (Mathers et al 2003).

The DSM-IV Diagnostic and Statistical Manual describes the symptoms of primary insomnia as follows: 'The criteria for a diagnosis of primary insomnia include a difficulty falling asleep, remaining asleep, or receiving restorative sleep for a period no less than one month. This disturbance in sleep must cause significant distress or impairment in social, occupational, or other important functions and does not appear exclusively during the course of another mental or medical disorder or during the use of alcohol, medication, or other substances'.

A disability weight of 0.100 was allocated to primary insomnia, valid for all WHO regions/subregions (Mathers et al 2004). However disability weights for insomnia of organic origin (ICD-9 code 780.5), or for any type of primary insomnia not falling into the abovementioned case description (Mathers et al 2003) are not provided.

In short, WHO provides a disability weight (DW=0.100) for insomnia (characterised by at least one of the following: difficulty falling asleep, waking up frequently during night, too early waking up in the morning, unrefreshing sleep) only under the following conditions:
-- IF NOT due to organic origin OR substance abuse;
-- AND IF lasting for a period of not less than one month;
-- AND IF having significant day-time consequences in professional OR social life.

2.2.1.2.1 Self-reported sleep disturbance due to nocturnal traffic noise – can it have the same SW as insomnia?
Today there is a wide agreement that there is a solid dose-effect relationship between Lnight (outside of the most exposed façade), originating from road and rail noise, and the occurrence of self-reported sleep disturbance (Miedema et al 2003 used in the RIVM methodology).

The open problem is whether the existing disability weight 0.100 for primary insomnia can be used to express the severity of the cases of self-reported sleep disturbance as resulting from the Miedema dose-effect relationship. This problem was analysed by Müller-Wenk. According to him there are 3 fundamental questions:
a) Is self-reported sleep disturbance a case of insomnia?
b) Is sleep disturbance originating from night-time traffic noise a case of primary insomnia?
c) If self-reported sleep disturbance originating from night-time traffic noise is a case of primary insomnia (or at least comparable to primary insomnia), is the mean severity of the former roughly the same than the mean severity of the latter, so that the disability weight of 0.100 can be applied to self-reported sleep disturbance originating from night-time traffic noise?

These 3 questions are addressed one per one in the following sections.
2.2.1.2.2. Self-reported sleep disturbance, a case of insomnia?
According to the U.S. National Institute of Health, "insomnia is the perception or complaint of inadequate or poor-quality sleep because of one or more of the following: difficulty falling asleep; waking up frequently during the night with difficulty returning to sleep; waking up too early in the morning; unrefreshing sleep".

Self-reporting is included in the above definition by the use of the word 'complaint'. Additionally, this inclusion is confirmed by Dr Colin Mathers. In an informal consultation (2005), Colin Mathers said that primary insomnia does not relate to whether data sources are self-report or observed in sleep laboratory.

The term “sleep disturbance” as used in Miedema et al (2003), refers to questions in social survey questionnaires. A comparison of these questions with the definition of insomnia from the U.S. National Institute of Health, as given above, shows a clear congruence. This means that “sleep disturbance” in the sense of Miedema (2003) is synonymous to “insomnia” as defined by the US National Institute of health.

2.2.1.2.3 Sleep disturbance from night-time traffic noise, a case of primary insomnia?
Colin Mathers was again consulted and has given the following statement referring to this question: “Primary insomnia is sleeplessness that is not attributable to a medical, psychiatric or environmental cause. So this would appear to exclude insomnia due to environmental noise”.

But a question still arises – is the disability weight of 0.100 - applicable to noise-related sleep disturbance? Even if traffic-noise-related sleep disturbance is not included in primary insomnia, the disability weight of 0.100 could possibly be used for the former case.

Questioned again on this matter, Colin Mathers gives the following statement: “The disability weight of 0.1 relates to the level of disability in terms of limitations of daily activity due to lack of sleep. In terms of the disability weight that should be applied to insomnia caused by environmental noise, the issue is really about the relative severity of the two forms of insomnia. If environmental insomnia on average causes as much limitation in daily activity as primary insomnia, then the disability weight of 0.1 could be applied. If on average there is less disability then the weight would be lower”.

The person in charge fixing the disability weight for primary insomnia is José Luis Ayuso-Mateos. This expert was also consulted and has agreed with the fact that this disability weight of 0.100 may be attributed also to insomnia due to night-time traffic noise penetrating into the bedroom, if the insomnia lasts more than one month and if it causes 'significant distress or impairment' in important daytime functions of the affected person.

This means that the disability weight of 0.100 could be used for noise-related insomnia if chronic and if daytime functions are significantly impaired. In the Miedema dose-effect relationship (Miedema et al 2003), the condition of chronicity appears to be fulfilled, because the wording of the questions in the underlying social surveys typically include the term 'often' in conjunction with the occurrence of sleep disturbance (Miedema et al 2003). Allthougt the questions refer clearly to complaints during night, and not to the situation on the day after.

It is was clarified with Dr Miedema if an analysis of the full set of questionnaire answers gives an indication that the complaints refer also to the distress or impairment relating to the functions during the day after the unrefreshing sleep. He has replied that, hypothetical, if the TNO archive of datasets to investigate the relationship between self-reported sleep disturbance and outcome measures that could be considered to operationalize "significant distress or impairment in important daytime functions", such a relation would be found, but such analyses have were not carried out. Dr Miedema has added: “With respect to the weights for self-reported sleep disturbance in DALY calculations, the fact, noted by Dr Mueller-Wenk, that both insomnia and self-reported sleep disturbance by noise involve self reports that refer to problems with falling asleep, remaining asleep or waking (too) early, appears to be very important. Roughly, even though the causes are different (no specified cause versus environmental factor noise as cause), the effects on sleep are similar and consequently, also the secondary effects during the day can be expected to be similar. This is even more likely because it appears that the effects of both insomnia and noise-induced sleep disturbance are mediated by increased arousal during (part of) the sleep"

It seems very plausible that the value of the WHO GBD catalogue (Matthers) can be applied for sleep disturbance provoked by environmental noise during the night. A new study in Switzerland is under way at the sleep clinic of the regional hospital of St.Gall (Switzerland) to help clarify these unanswered questions. A panel of physicians has been asked to rate, on the basis of their experience with patients, the relative severity of daytime activity limitations originating from primary insomnia, versus originating from night-time traffic noise. The results, expected towards the end of 2005, could be used to support a disability weight for traffic-noise-related sleep disturbance being a fraction of the disability weight 0.100 for primary insomnia.

2.2.1.3 Conclusions
The first attempts to attribute a severity weight to sleep disturbance have concluded that 0.055, was the most likely value for a disability weight of noise-related sleep disturbance but evidence shown that the correct value would be between 0.04 and 0.12.

In the other hand expert opinion has shown that it appears that the value of the WHO GBD catalogue (0,10) can be applied for sleep disturbance provoked by environmental noise during the night.

For the purpose of estimating the disease burden of noise both values will be used calculating the disease burden for several scenarios. These results can be found in annex XXX.

2.2.3 A dose-effect relationships for noise-related sleep disturbance

In an attempt to attribute noise-related health effects in Switzerland to 1000 vehicle-kilometres as the source of noise, dose-effect relationships were worked out in (Müller-Wenk 2002), considering sleep disturbance as a night-time health effect of road traffic noise, and communication disturbance as a daytime health effect. The data supporting the dose-effect relationships were derived from a social survey with 2052 participants executed in Switzerland in year 1991 (Oliva 1998). The answers given by the participants to a questionnaire presented in an oral interview were still available on a data file in year 2000 so that a complementary processing of the data could be made.

Depending on the equivalent sound pressure level LAeq at the outside façade most exposed to night-time road noise, the respondents were classified in 4 groups <46 dB, 46-50 dB, 51-55 dB, >55 dB. For each of these 4 groups, the percentage of the respondents was calculated when they:
- gave a positive answer to the question if road traffic noise prevents them every day or every few days from sleeping through the night or getting to sleep
- AND indicated the intensity of their disturbance by scale level 8 to 10 ("highly annoyed") on a visual analogue scale (VAS) with low end 0 (= not in the least disturbed), and high end 10 (= insupportably disturbed).

With these percentages, a dose-effect relationship for sleep disturbance due to night-time road noise could be developed as shown in Figure 1.

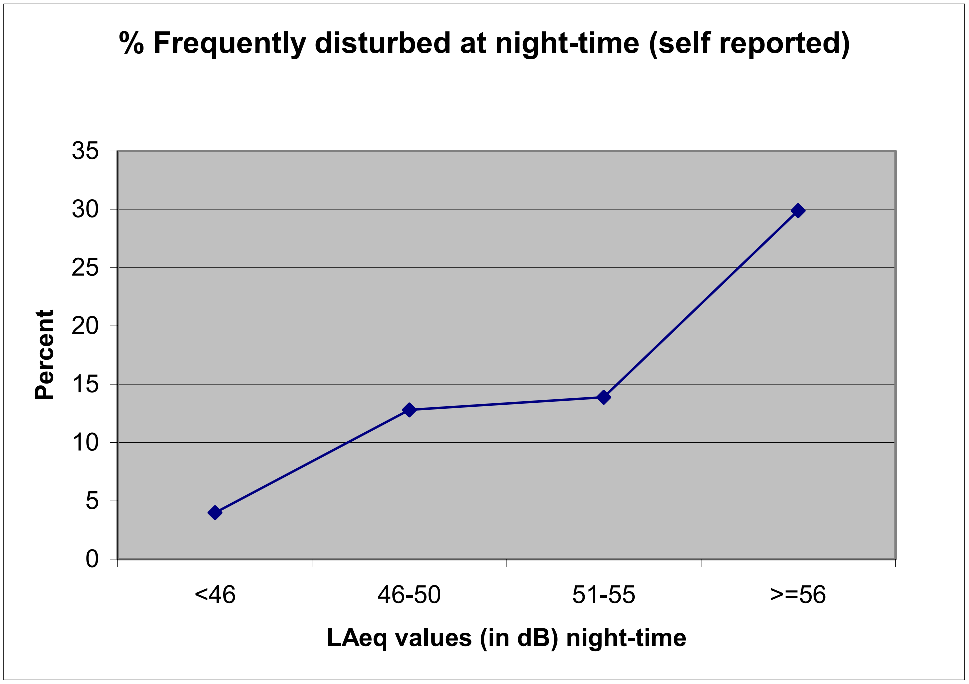

Figure 1: Dose effect relationship for sleep disturbance due to night-time road noise, developed on the basis of oral interviews with 2052 persons in Switzerland in year 1991

A weak point for this relationship is the fact that it only contains the two open classes <46 and >=56 dB, but it is very plausible to assume that almost all of the cases in class <46 dB are between 41.0 and 45.9 dB, and almost all of the cases in class >=55 dB are between 55.0 and 59.9 dB, so that the class width in Figure 1 is essentially constant. Nevertheless, this dose-effect relationship for sleep disturbance has weaknesses that could be improved
by bringing the questions asked to the participants into a better congruence to the medical description of chronic insomnia
by introducing questions controlling for non-noise cause of chronic insomnia
by ensuring that the participant's answer to the 'intensity of disturbance' question (grade of annoyance) relates precisely to sleep disturbance
by replacing the noise level outside of the façade by the noise level at the sleeper's ear
by introducing information on noise peaks Lmax in addition to LAeq
by reducing the class width to 3 dB

However, this dose-effect relationship appears to be useful as a coarse estimate. The adequacy of this relationship can, to a certain extent, be checked by a comparison with results from the noise study of the Spandau Health Survey (Maschke 2003) and the DLH study on noise effect from Köln airport (Samel et al 2004).

2.2.3.1 Discussion on DF relationships

According to Maschke (2003), the analysed population showed a significant increase of the Odds-Ratio for hypertension treatments if the equivalent continuous sound pressure level LAeq (outside of the dormitory window) of the nocturnal street traffic noise exceeded 50-55 dB. The relative risk was approximately 1.7 for 50-55 dB and 1.9 for 55+ dB, in comparison with apartments where the LAeq was below 50 dB. If we assume that noise-related hypertension goes in parallel with perceived sleep disturbance, these figures can be compared with Fig 2. Then, it could be concluded that Fig 1 gives rather high estimates when beginning the probability increase already at 46 dB and showing a triplication from 50 dB to 56+ dB.

The DLR study (Samel 2004) supplies data on the probability of an aircraft-noise-related arousal as a consequence of a single noise event with a noise peak Lmax at the sleeper's ear, based on laboratory tests (Samel 2004) and field tests (Samel 2004). Whilst the field tests show an almost negligible influence of the Lmax on the number of arousals, the probability of an arousal increases clearly with higher Lmax in the case of laboratory tests. On the basis of DLR laboratory results, it is possible to calculate the expected noise-related arousals per hour of sleep as a function of LAeq outdoors, if the windows are assumed to be tilted, if the background noise is assumed to be 30 dB, and if the number of noise peaks per hour is varied as a parameter. The results are then as shown in Tab 4.

LAeq outside of building (dB)	**55**	**50**	**55**	**50**	**55**
Number of noise events per each of the 8 hours of sleep	4	4	8	8	16
LAeq at sleeper's ear (dB)	37	32	37	32	37
Lmax at sleepers ear (dB)	56	50	55	<50	50
Number of noise-related arousals per each of the 8 hours of sleep (probability x number of noise events)	0.6	0.4	1.2	0.8	1.6

Table 4: Noise levels and arousals according to the DLR study. Source Samel 2004, Basner 2001

If one additional arousal per hour, caused by noise, is taken as a threshold point for sleep disturbances, the DLR results can be interpreted in such way that the threshold for sleep disturbances is around LAeq 50 dB (outside of building), if the number of noise peaks is around 10 per hour. Above this threshold, the Lmax (at the sleepers ear) goes roughly in parallel with the LAeq (outside the building), if the hourly number of noise events is kept at 8 and the windows are tilted (Basner 2001). The dose-effect relationship (Samel 2004) could then be interpreted, in combination with Basner (2001) as follows: At Lmax (at the sleepers ear) of 65 dB, corresponding to a LAeq (outside of building) of 48.8+18 dB in the case of 8 hourly noise events, the hourly number of arousals would be three times as much than with Lmax (at the sleepers ear) of 50 dB.

The following figure shows the dose-effect relationship of Samel it is important to mention that the DLR study included healthy persons of age 18-65 years only, and we cannot exclude that the participants had a positive attitude bias towards air transportation in general and Köln airport in special.

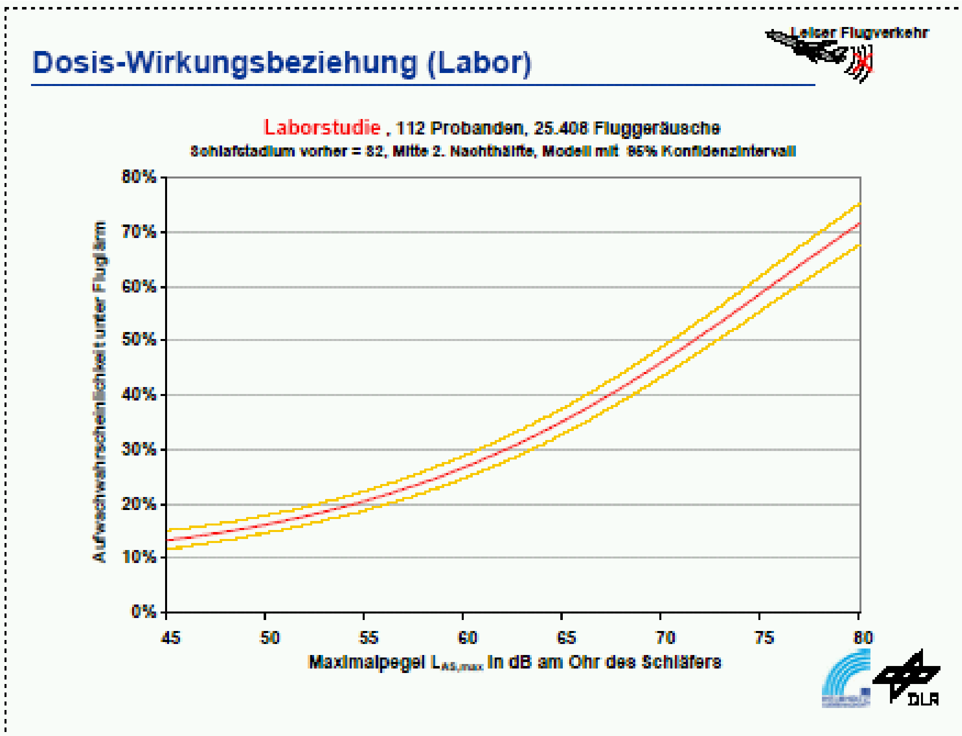

Figure 2: Probability of arousal and Lmax at the sleeper's ear. Source: DLR

As a conclusion, from the comparison with the Spandau and the DLR studies, it might be stated that the probability of sleep disturbance depending on LAeq, derived from the Switzerland survey is high plausible.

2.2. 4 Exposure to night-time traffic noise

Similarly to the RIVM method only the population's exposure to night-time noise from road traffic was assessed, because road traffic is the dominant source of community noise.

On the basis of a national traffic noise model (LUK, developed by Kanton Zürich – a computer model on the basis of recorded traffic densities. and road/terrain properties) the exposition of the Swiss population to night-time road traffic noise was calculated. It was aggregated into 5-dB-classes as the following table illustrates.

LAeq night (22.00-06.00)	Number of persons exposed	% of the population
(outside of the buildings)		
46-50 dB		
51-55 dB		
56-60 dB		
61-65+ dB		

Table 5: Exposure data for night-time road traffic noise, grouped into 5 dB classes

2.2.5 Uncertainty

The fraction of persons complaining about noise-related sleep disturbance increases with higher noise levels, on the basis of the results of the Swiss noise study 90 (Oliva 1998). In analogy to the DLR results, we linearise now this dose-effect relationship but fix here the no-effect level at LAeq (outside of building) 50 dB, as derived from the DLR data. The slope of the straight line is maintained to have an increase per additional dB of 1.7 cases of perceived sleep disturbance per 100 exposed persons. This slope may be compared to the DLR annoyance characteristics according to Samel (2004) which indicate a slope of 5% additional cases of medium/high night-time annoyance with laboratory probands, and 1% additional cases of medium/high night-time annoyance with field probands. Although the graph of Samel (2004) does not indicate cases of sleep disturbance but the cases of medium/high annoyance at night-time, it is not unreasonable to assume that annoyance and sleep disturbance are correlated. Figure 3 shows that the slope of the red line, used here for a 'low' estimate, is cautious in the light of the DLR results.

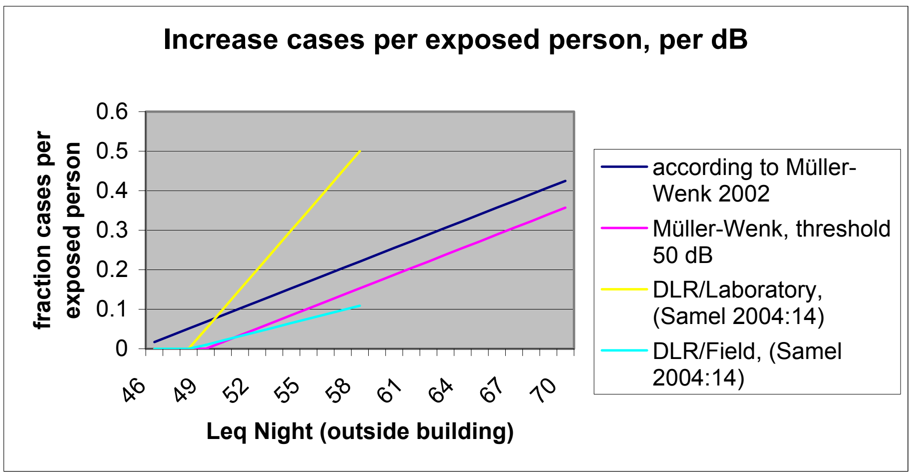

Figure 3: slopes of dose-effect characteristics

Assuming an equal distribution of population within the 5 dB classes, the number of sleep disturbance can be calculated, by multiplying the number of exposed persons with the fraction of cases per exposed person (red line in Fig 4), and summing up the results over the relevant decibel interval.

The dependence of sleep disturbance on noise is ideally described by the magnitude and the hourly number of noise peaks Lmax at the sleeper's ear. In a typical traffic noise situation, it can be assumed that a threshold level of approximately 50 dB (LAeq outside façade of bedroom) is applicable.

2.2.6 Conclusions

This method proposes the following for estimating the disease burden of noise induced sleep disturbance:

Only road traffic exposure data should be used because it is the major source and the most reliable data;

The needed exposure data is people reporting sleep disturbance when exposed to <45 dB(A) Lnight, 46-50 dB dB(A) Lnight, 51-55 dB dB(A) Lnight, 56-60 dB dB(A) Lnight, 61-65+ dB dB(A) Lnight and > 66 dB(A) Lnight road traffic

The severity weight of 0,10 is very plausible to be applied – however a new study is being performed to validate this point.

Conclusions and recommendations

From the analyse of the two methods it is proposed:

To use road traffic exposure data
Surveys should be used to assess the number of people reporting sleep disturbance
If not the available exposure-response curves (Miedema et al.) for assessing the severe sleep disturbance should be used
It will be considered that people will be sleep disturbed throughout the year

A series of calculations are made at the meeting using different scenarios.

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Studies used for deriving the existing exposure-effect relationships for the effects of noise on sleep (Miedema 2003)

Characteristics of Studies used

Author(s)	Year	# studies / design	Method applied to derive an exposure-effect	Noise source	Noise parameters
Lukas	1975	7/ lab	Re-analysis of individual data	Stimuli from road traffic, air traffic, sonic booms	EPNL
Griefahn	1976	10 /lab	Re-analysis of individual data	Stimuli from airplane noise, sonic booms, pink and traffic noise	LAmax and number of stimuli
Pearsons et al.	1989	21 / lab & cross	Re-analysis of individual data		LAmax of a noise event and SEL indoor
Finegolg	1994	21 / lab & cross	Re-analysis of individual data		ASEL indoor
Hoffman	1994	NA/Lab&field	Meta-analysis	Stimuli from aircraft noise	
Fidell	1998	8 / field	Meta-analysis	Comm. & military aircraft, ambient noise sonic booms, heavy truck, railway	SEL
Fineglod and Elias	2002	8 / field	Meta-analysis	Comm. & military aircraft, ambient noise railway	ASEL
Passhier	2003	1 / field	Data of a single study	Aircraft noise	Lmax indoor, Lnight outdoor
Miedema et al	2003	14 / field	Meta-analysis	Road traffic noise	Lnight outdoor at most exposed façade
Miedema et al.	2003	7 / field	Meta – analysis	Rail traffic noise	Lnight outdoor at most exposed façade
Miedema et al.	2004	8 / field	Meta-analysis	Aircraft noise	Lnight outdoor at most exposed façade
Breugelmans	2005	1 / field	Data of a single study	Aircraft noise	Lnight

Source: RIVM

EBD ESTIMATION - Annoyance

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1. Introduction / Definition of outcome

Annoyance is the most reported effect of environmental noise, also because people are asked about it when questioned on what they experienced when exposed to noise. It is estimated that 22% European population is annoyed or highly annoyed by noise (EC noise green paper).

Noise annoyance is a very widespread phenomenon all over the world. A definition of annoyance is “a feeling of displeasure associated with any agent or condition known or believed by an individual or a group to be adversely affecting them” (Lindvall and Radford, 1973; Koelega, 1987). However, apart from “annoyance” people may feel a variety of negative emotions when exposed to community noise, and may report anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, or exhaustion (Job, 1993; Fields et al., 1997; Fields et al., 1998).

Considering the broad WHO definition of health, noise related annoyance can be considered as a health problem. The WHO Community noise guidelines recommend 55 dB LAeq (16 hours) outdoor as the threshold value for serious annoyance.

The degree of annoyance caused by noise exposure depends on several characteristics, such as sound level and spectral characteristics, and varies with time of the day or season. During the night and late evening noise is more annoying because quietness is expected.

Based on the results of surveys it has been observed that noise exposure explains about 25-30% of the observed variance in annoyance. Non-acoustical factors also play a major role (Job, 1999; Stallen, 1999; Guski, 1999). Examples of non-acoustical factors are individual noise sensitivity, fear with respect to the source, attitude towards (those in charge of) the source, perceived control over the situation, and perceived economic or societal advantages of noise generating activity. Several reviews show that anxiety (fear of the noise source) and noise sensitivity are the most important non-acoustical factors of influence on exposure-response relationships (Fields, 1993; Guski, 1999; Job, 1999; Stallen, 1999; Miedema and Vos, 1999). According to Guski factors with a social character (appraisal of a noise source, trust - in those responsible for noise and noise abatement - and history of noise exposure) are especially important, because they apply for whole groups of the population and can therefore be used as an entry point to reduce noise annoyance.

Noise annoyance is assessed at the level of populations measured by means of postal or oral administered questionnaires. Recently, efforts have been made by the International Commission on Biological Effects of Noise (ICBEN) and the International Organization of Standardization (ISO) towards the use of standardized questions asking for the degree of annoyance in a 0-10 or 100 scale. To determine the percentage of people annoyed and highly annoyed, a cut-off value of 50 and 72 is being used (EU noise directive, Miedema 1992).

In this section a method for estimating the burden of disease due to noise annoyance is proposed. This method was developed by the Dutch National Institute for public health and the environment, and it will be used for international calculations as agreed on a WHO international consultation of experts. It is part of the WHO EBD series as a separate chapter, but it can be added to the total disease burden (see section xxx).

International recommendations for assessing annoyance

In the EC position paper on dose response relationships between transportation noise and annoyance (2002) the following is recommended:
- It is recommended to use Lden as a predictor for annoyance;

- In order to describe the degree of annoyance, it is recommended to use the percentage annoyance and the percentage high annoyance. “These descriptors” of annoyance are derived from transforming various annoyance scales to a 0 to 100 basis and using a cut-off at the scale value 50 (for %A) or 72 (for %HA), respectively.’
- In order to assess the fraction (highly) annoyed at population level it is recommended to use the exposure-response relations derived by Miedema and Oudshoorn (2001) With regard to the application of these relations, the following is stated: “The dose-response functions and their curves recommended here are only to be used for aircraft, road traffic and railway noise and for the assessment of long term situations. They are to be utilised for strategic assessment. They can be used in target setting, in translating noise maps into overviews of numbers of persons annoyed, in cost-benefit analysis and Environmental Health Impact Assessment. They are not applicable to local, complaint-type situations, or to the assessment of the short-term effects of a change of noise climate”.

Several elements from this position paper were included into the EU Directive 2002/49/EC:
- As a predictor for annoyance Lden should be used;
- For estimating the fraction annoyed at population level the following is stated: 'Dose-effect relations should be used to assess the effect of noise on populations. The dose-effect relations introduced will concern in particular: the relation between annoyance and Lden for road, rail and air traffic noise and for industrial noise, the relation between sleep disturbance and Lnight for road, rail and air traffic noise and for industrial noise,
If necessary, specific dose-effect relations could be presented for:
- dwellings with special insulation against noise
- dwellings with a quiet facade,
- different climates/different cultures,
- vulnerable groups of the population,
- tonal industrial noise,
- impulsive industrial noise and other special cases.

The ISO norm gives specification about how to best measure annoyance, so that the comparability between different studies will be increased. In their technical specification they present two options:
- question with verbal rating scale (The question using a 5 point liker scale)
- question with numerical rating scale, with introduction (the 11 point scale).

Specifications about how to define severe or high annoyance are not given; only the following is mentioned: “in this document no specification is given for defining the percentage of respondents who should be regarded to have at least a certain degree of annoyance, such as e.g. 'highly annoyed'. This should depend on the cut-off scores used in individual countries or preferred by individual researchers. On the basis of the specified frequency distributions any cut-off score can be chosen”.

2 – Methods for assessing the burden of disease from noise induced annoyance: DALYs

Disability Adjusted Life Years (DALYs) measures health gaps as opposed to health expectancies. It measures the difference between a current situation and an ideal situation where everyone lives up to the age of the standard life expectancy, and in perfect health. Based on life tables, the standard life expectancy at birth is set at 80 years for men and 82.5 for women. The DALY concept combines in one measure the time lived with disability and the time lost due to premature mortality (Pruess et al.).

DALY calculations can consider age weights and time preferences. Age weights indicate the relative mainly economic importance of healthy life at different ages. For example, importance (and thereby value) increases from birth until age 25 and declines thereafter. Time preference weights compare the economic and societal value of health gains today to the value attached to health gains in the future. In economic theory, the latter is assumed to be lower than the former. For assessing noise annoyance, the authors of the method (Hollander, Staatsen, Kempen) have not used age weights or time preference weights, thereby not distinguishing between older and younger people, or between current of future health gains.

For noise annoyance, the DALYs were calculated using data on population exposure, exposure-response relationships and a combination of incidence and prevalence rates according to the following formula:

DALY = Number of people affected x Severity x Duration

2.2.1 Exposure data

The most appropriate noise measurement for assessing noise annoyance is the Lden[2] (day-evening-night level) considering the day, evening and night periods expressed in A -weighted decibels, dB(A), as recommended by the Environmental noise Directive. This measure is usually used on annoyance surveys and in calculation methods. The noise sources to be included will be road traffic (municipal, provincial and national roads), rail traffic and air traffic (around the major airports).

In order to use the method developed by RIVM, the required exposure data for annoyance comprises the number of people exposed to levels of noise higher then 40 dB(A). To use the exposure response curves, the number of people exposed to various noise classes should be described, according to the following table. If possible these data should be presented per source.

[2] European Environmental noise Directive (2002/49/EC) - Lday is the A-weighted long-term average sound level as defined in ISO 1996-2, determined over all day periods of a year, Levening is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the evening periods of a year, and Lnight is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods of a year

Exposure category, Lden (dB(A))	% population exposed road traffic noise	% population exposed rail traffic noise	% population exposed air traffic noise
< 40 dB(A)			
41 - 45 dB(A)			
46 – 50 dB(A)			
51 – 55 dB(A)			
56 – 60 dB(A)			
61-65 dB(A)			
66 – 70 dB(A)			
> 71 dB(A)			
Total	***100%***	***100%***	***100%***

Table 1 – Necessary exposure data

Example for the Netherlands

For calculating the noise exposure of the Dutch population, a Geographic Information System computer model - the EMPARA (Dassen, 2001) was used. This model considers the different noise sources, estimates the noise emissions, and generates noise maps.

These data were translated to human exposure, using noise propagation paths and demographic data. An estimation of the number of dwellings exposed to certain levels of transport noise (per 1 dB) was made and by multiplying the percentages of exposed dwellings with the average living population per dwelling, estimating the number of people exposed to the various noise levels.

2.1.2 Prevalence

In contrast to other health outcomes, by definition there is no base prevalence for noise annoyance. The prevalence of noise annoyance is estimated using exposure-response models. This is an indirect way of estimating the prevalence. These relationships are based on combined results from various studies (see annex 1). Because questions and response categories in these studies differ, all results have been translated to a 0-100 scale (Miedema et al, 2001), in which a 72 cut-off is applied for the percentage of people that is highly annoyed (cut off at 50 is the percentage of people being “annoyed”).

This poses some problems due to cultural differences, therefore, if available, it is preferable to make use of region specific curves or surveys which should moreover be updated since there are indications that generalised curves easily “age”.

2.1.3 Exposure-response relationships

Exposure-response relationships indicating the percentage of people (lowly, annoyed or highly) annoyed at certain noise exposure levels have been derived by Miedema et al. They have been derived for road, rail and air traffic noise. Miedema has also developed a method to calculate the cumulative noise levels by taking into account the differences in annoyance-response levels to various noise sources, expressed as Environmental Exposure Level (EEL; Miedema, 1998) but this method is still under debate. Hence, since road traffic noise accounts for the bigger proportion of people exposed in most European Countries (data from Netherlands, United Kingdom, Switzerland and France), it is proposed to use the exposure-response relationship for road traffic when the exposure data is not source specific.

The next figure shows the exposure-response curves by Miedema et al for air, road and rail traffic.

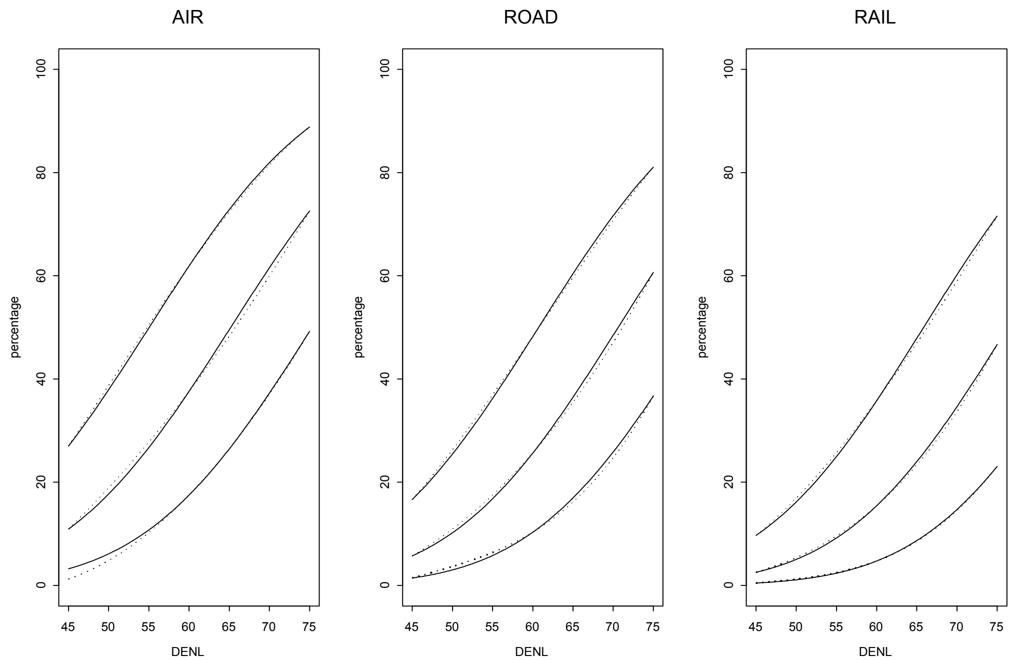

Figure 1: Exposure – response relationships for aircraft, road traffic and railways LA- A – annoyance; HA – Highly annoyance
%LA - low annoyance (upper row), *%A – Annoyance* (middle row) and *%HA Highly annoyance* (lower row) as a function of *DENL* together with the 95% confidence intervals. The curves were found by fitting the model of the annoyance percentages to the data from field surveys. Source: Miedema et

Aircraft: $\%HA=-9.199 \cdot 10^{-5}(DENL-42)^3 + 3.932 \cdot 10^{-2}(DENL-42)^2 + 0.2939(DENL-42)$;
Road traffic: $\%HA = 9.868 \cdot 10^{-4}(DENL-42)^3 - 1.436 \cdot 10^{-2}(DENL-42)^2 + 0.5118(DENL-42)$;
Railways $\%HA = 7.239 \cdot 10^{-4}(DENL-42)^3 - 7.851 \cdot 10^{-3}(DENL-42)^2 + 0.1695(DENL-42)$.

For avoiding an over estimation of effects only highly (severed) annoyed people will be considered on the DALY calculation.

For severe annoyance, data below 45dB and above 75dB (Lden) are excluded because these were judged less essential (<45 dB) and too uncertain (>75 dB) (Miedema, 2001).

The number of people severely annoyed by road traffic noise can be estimated by combining the noise exposure distribution with the exposure-response function (ERF) derived by Miedema (2001). Third order polynomials which Miedema proposed as workable versions of the more complicated original curves are propose by RIVM to derive the percentage severely annoyed (see table 2). Furthermore, for the polynomial, a zero severe annoyance level has been set to 41 dB.

Exposure category, Lden (dB(A))	**% people severely annoyed (derived from Miedema curves) per category**
< 42 dB(A)	0 %
42 - 45 dB(A)	0.97 %
46 – 50 dB(A)	2.77%
51 – 55 dB(A)	5.4 %
56 – 60 dB(A)	8.8 %
61-65 dB(A)	18.8 %

66 – 70 dB(A)	21.3 %
> 70 dB(A)	31.8 %

Table 2 – Percentage of people severely annoyed by road traffic noise per noise category derived from exposure-response curves derived by Miedema (2001). Source: RIVM

2.1.4 Prevalence – duration of exposure
For noise annoyance annual prevalence rates (based on periodic surveys – using the exposure-response curves) were used, assuming that people will be annoyed throughout the year. Therefore, 1 year is proposed as duration for DALY calculations. If local surveys are used the prevalence will be different (see section 2.2).

2.1.5 Severity
Since some people do not recognize annoyance as a disease, it is not included in most weighting exercises, such as the GBD disability weight project (Matthers CD et al). Furthermore, compared to other 'harder' health effects, it is hard to weigh 'annoyance', and it is difficult to relate it to existing weighted outcomes. A severity factor of 0.02, with a relatively large uncertainty interval (0.01-0.12) was proposed by RIVM. The minimum value (0.01) is based on De Hollander et al. (1999), who used a panel of environment-oriented physicians to attribute severity weights to various health states based on a protocol by Stouthard (1997). The maximum values (0.10 and 0.12) are based on Van Kempen (1998) who did a panel study with 13 medical experts, also based on a protocol by Stouthard. In that study, sleep disturbance and annoyance were weighted relatively high. Since the weight factors are so small, these variations can have a relatively big impact on the DALY outcomes.

2.2 Using surveys
Alternatively, local surveys can be used to assess exposure and prevalence. The differences will be on the considered number (percentage) of people exposed and duration of exposure (it will be resulting of the survey). In the example of the Netherlands the results vary greatly from the results based on the generalised exposure-response relationships.

The number of people reporting annoyance in surveys is generally higher than the numbers that might be expected based on models using the established exposure-response relationships even though these models are principally based on survey data. This discrepancy can be caused by various reasons, which will be addressed in the uncertainty section. The authors of the method suggest using surveys, if available.

2.3 Age differences
The way annoyance is experienced varies with age. Studies have proven that annoyance increases from 18 years and up having the highest rate at the age of 50, starting then to decrease (Miedema, 2003).

Only a few field studies are known in which residential noise annoyance of children is measured in a systematic and quantitative manner. Most studies focus on aircraft noise.

In the Munich studies an increase in annoyance in children living near the new airport was observed during the measurement period (three waves) while the mean annoyance in the children living near to the old airport dropped from a high to a low score. A child-adapted questionnaire with 21 Likert-scaled items was used, covering different degrees of noise perception, air quality and residential qualities (green space, playgrounds etc) (Bullinger, 1998/99).

In an experimental study within the Tyrol studies children were asked to assess the annoyance of road and railway noise sounds presented via headphones by using a Visual Analogous Scale. Children from the quiet area (n = 63, LEq8hr < 40 dB(A)) had consistently higher annoyance scores for both highway and railway noise than children from the noise exposed group (LEq,8-night > 50 dB(A)). For both groups an increase in annoyance ratings with (laboratory) noise levels was observed. Rail noise was rated more annoying at 60 dB(A) and 70 dB(A), but equally annoying as motorway noise at 50 and 80 dB(A) (Sukowski, 2000). A survey among 530 13-15 year old children in Germany (using the same questionnaire as in the Munich study) also showed that children report lower mean annoyance levels than their mothers. The highest mean annoyance ratings were observed in the aircraft exposed rural areas while road traffic noise annoyance ratings equalled those of air pollution or odour annoyance (Bullinger et al., 1997).

Focus group discussions in a small international (n=36) sample indicate that the interviewed children were most affected by neighbours noise and road traffic noise (Millenium Conference Study, Haines 2003). This is comparable with the results of community surveys in adults. The children rated water pollution as the most damaging source of pollution, followed by air and lastly noise: “It depends where you are though. Long term it’s water pollution and air pollution, but walking down the street it’s noise pollution that affects you more”.

Analysis of a small sample (n=18) of the West London School Study showed that the impact of noise exposure on everyday activities (eg schoolwork, homework, playing) was larger for the children exposed to high levels of aircraft noise (Leq 16 hr > 63 dB(A)) compared with the low noise exposed children (<57 dB(A)) and focus group samples. The sample of children exposed to aircraft noise expressed high annoyance levels, with responses consistent with those in adults (irritation, fear, anger). In both studies when asked, children selected their bedrooms and green areas in their neighbourhoods as places to find some respite from noise pollution (Haines, 2003). The sample sizes of both studies are too small though to derive a more definite conclusion on coping strategies in children.
A non-linear association with mean annoyance was found for children and aircraft noise in a recent study (RANCH, 2005[3]). In the Dutch case within RANCH an exposure-response relationship was derived on the pooled data for the association between aircraft noise at school (LAeq, 7-23) and high annoyance by aircraft noise at school in children.

All the four analysed field studies showed that children are annoyed by long-term noise exposure and their emotional response to noise exposure seems to be consistent with adult reactions. At this stage, there are no available relationships for annoyance and children, therefore for the time being, the children will be considered in the same way as adults. The RANCH team is producing specific annoyance curves for children, when new results are available this section should be emended.

3. Uncertainties

Quantifying annoyance is a difficult task due to the large uncertainties in assessing the number of people exposed, on considering that everybody will react according to the exposure response relationships, because of the influence of non-acoustic factors, of the subjective estimates of severity factors etc. This difficulty is illustrated by the fact that different approaches to measure noise annoyance can yield diverse results.

3.1 Uncertainty in exposure assessment

The estimation of number of people exposed should be interpreted with caution. Varying degrees of isolation of houses can influence personal exposure and affect the exposure distribution. The form of the exposure curves is probably realistic, however, uncertainty lies mainly in the locations of the peaks of the curves. For compensating this weakness, an uncertainty range of +/- 1 dB(A) is suggested for categorising exposure.

The European recommendations should be used for exposure assessment.

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[3] RANCH - Road Traffic and Aircraft Noise Exposure and Children’s Cognition and Health, Stansfeld et al, The Lancet - Vol 365 June 4, 2005

3.2 Uncertainty in ER relationship

The relationships for the association between noise and annoyance derived by Miedema and Oudshoorn (2001) are at the moment the best currently available. They are based on a reanalysis of individual data from 45 different studies, which makes them rather unique. Recently they were recommended for use in the EU Directive on Noise (EU 2002).

The studies that were included in the Miedema relationships were carried out in the period 1965-1992, leaving a gap of about 15 years. In a recent publication, Guski (2004) showed on the basis of the Miedema data that there has been a trend in the last decades: the number of people that is highly annoyed increases at lower day-night levels). If the results of Guski are correct, then possible explanations for this trend might be found in the fact that the composition of aircraft noise has changed over the years: the single noise events become less loud, but the number of events increased considerably. Furthermore, sounds get their meaning in relation with other sounds. It is possible that the changing composition of sound pressure levels evokes differences in perception (Wirth, 2004).

In addition these exposure-response curves can only be applied to long-term stable situations (no changes in number of flight, flight routes, etc) and cannot be used to analyze short-term or local noise problems. Whether this precondition is realistic is questionable, since a stable situation is hardly ever reached at airports, where development and change is practically ongoing (Van Kempen et al., 2005).

Differences are expected to be observed when comparing the number of annoyed people estimated by means of national surveys with the number of annoyed people estimated by means of combining exposure-distributions with the Miedema relations.

If surveys and local risk estimations are available, their use is preferred to the use of the exposure-response curves.

4. Conclusions and recommendations

For estimating annoyance the following formula, is proposed:

DALY = Number of people highly annoyed x Severity weight x Duration

Responses regarding annoyance of people in different countries might be different due to differences in cultural expectations about the acceptability of transportation noise exposure, differences in climate and the adequacy of housing sound insulation techniques. As a result it is recommended the use of national reference data if available. If this is not possible, the generalised relations published by Miedema could be used to estimate annoyance levels - applied with care to reflect the situation being analysed.
The following table should be completed.

Exposure category, Lden (dB(A))	**Number of people highly annoyed in these category A**	**Severity weight B**	**Duration C**	**DALYs**
< 40 dB(A)		0.02	1 year	AxBxC
41 - 45 dB(A)		0.02	1 year	
46 – 50 dB(A)		0.02	1 year	
51 – 55 dB(A)		0.02	1 year	
56 – 60 dB(A)		0.02	1 year	
61-65 dB(A)		0.02	1 year	
66 – 70 dB(A)		0.02	1 year	
> 71 dB(A)		0.02	1 year	
Total				

Table 3 – Summary table for calculation the number of people annoyed

If a survey assessing the number highly annoyed does not exist the following calculation should be done filled to assess the number of people highly annoyed based on the exposure- response relationships.

Exposure category, Lden (dB(A))	**Population exposed A**	**% of people highly annoyed in this noise category B**	**Number of people highly annoyed**
< 40 dB(A)		0 %	AxB
41 - 45 dB(A)		0.5 %	
46 – 50 dB(A)		2.7 %	
51 – 55 dB(A)		5.4 %	
56 – 60 dB(A)		8.8 %	
61-65 dB(A)		18.8 %	
66 – 70 dB(A)		21.3 %	
> 71 dB(A)		31.8 %	
Total			

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Annex 1 - Datasets used to establish the relationships between noise exposure and annoyance

Aircraft

Fields' code	Name of study
AUL-210	Australian Five Airport Survey (1980)
CAN-168	Canadian National Community Noise Survey (1979)
FRA-016	French Four-Airport Noise Study (1965)
FRA-239	French Combined Aircraft/Road Traffic Survey (1984)
NET-240	Schiphol Combined Aircraft/Road Traffic Survey (1984)
NOR-311	Oslo Airport Survey (1989)
NOR-328	Bodo Military Aircraft Exercise Study(1991-1992)
NOR-366	Vaernes Military Aircraft Exercise Study(1990-1991)
SWE-035	Scandinavian Nine-Airport Noise Study (1969, 1970, 71,72, 74,76)
SWI-053	Swiss Three-City Noise Survey (1971)
UKD-024	Heathrow Aircraft Noise Survey (1967)
UKD-242	Heathrow Combined Aircraft/Road Traffic Survey (1982)
UKD-238	Glasgow Combined Aircraft/Road Traffic Survey (1984)
USA-022	U.S.A. Four-Airport Survey (phase I of Tracor Survey) (1967)
USA-032	U.S.A. Three-Airport Survey (phase II of Tracor Survey) (1969)
USA-044	U.S.A. Small City Airports (small City Tracor Survey) (1970)
USA-082	LAX Airport Noise Study (1973)
USA-203	Burbank Aircraft Noise Change Study (1979)
USA-204	John Wayne Airport Operation Study (1981)
USA-338	U.S.A. 7-Air Force Base Study (1981)

Road Traffic

Fields= code	Name of the survey
BEL-122	Antwerp Traffic Noise Survey (1975)
BEL-137	Brussels Traffic Noise Survey (1976)
CAN-120	Western Ontario University Traffic Noise Survey (1975)
CAN-121	Southern Ontario Community Survey (1975/1976)
CAN-168	Canadian National Community Noise Survey (1979)
FRA-092	French Ten-City Traffic Noise Survey (1973/1975)
FRA-239	French Combined Aircraft/Road Traffic Survey (1984)
FRA-364	French 18-site Time of Day Study (1993/1994)
GER-192	German Road/Railway Noise Comparison Study (1978/1981)
GER-372	Ratingen-Dusseldorf Road Traffic/Aircraft Survey (1985/1986)
GER-373	Ratingen Road Traffic/Aircraft Study (1987)
NET-106	Dordrecht Home Sound Insulation Study (1974)
NET-240	Schiphol Combined Aircraft/Road Traffic Survey (1984)
NET-258	Amsterdam Home Sound Insulation Study (1975)
NET-276	Netherlands Tram and Road Traffic Noise Survey (1993)
NET-361	Netherlands Environmental Pollution Annoyance Survey (1983)
NET-362	Arnhem Road Traffic Study (1984)
SWE-142	Stockholm, Visby, Gothenburg Traffic Noise Study (1976)
SWE-165	Gothenburg Tramway Noise Survey (1976)
SWI-053	Swiss Three-City Noise Survey (1971)
SWI-173	Zurich Time-of Day Survey (1978)
UKD-071	B.R.S. London Traffic Noise Survey (1972)
UKD-072	English Road Traffic Survey (1972)
UKD-157	London Area Panel Survey (1977/1978)
UKD-242	Heathrow Combined Aircraft/Road Traffic Survey (1982)
UKD-238	Glasgow Combined Aircraft/Road Traffic Survey (1984)

Railway

Fields= code	Name of the survey
FRA-063	Paris Area Railway Noise Survey (1972)
GER-192	German Road/Railway Noise Comparison Study (1978/1981)
NET-153	Netherlands Railway Noise Survey (1977)

NET-276	Netherlands Tram and Road Traffic Noise Survey (1983)
SWE-165	Gothenburg Tramway Noise Survey (1976)
SWE-228	Swedish Railway Study (1978-1980)
SWE-365	Swedish 15-site Railway Study (1992-1993)
UKD-116	British National Railway Noise Survey (1975/1976)

Working paper for WHO second technical meeting on quantifying disease from environmental noise
Bern, Switzerland, 15-16 December 2005
Noise exposure and cognitive impairment in children – An attempt to quantify burden of disease
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Dose-effect curves for noise induced cognitive impairment

In a report to the WHO in June 2005 I made an attempt derive simplified dose-effect relationships between noise exposure doses and impairment of cognitive functions such as memory, reading, and attention (Hygge, 2005). The basic simplification consisted in picking out pairwise contrasting noise conditions out of the studies reported, one with noise exposure and one more in quiet (but both with known dBA-levels), and calculating the average percentage cognitive impairment/improvement with an increase or a decrease in dB-level. In this way four cognitive performances measures, reading, memory-recall, memory recognition, and attention were plotted. Graphical representations of the slopes are shown in Figure 1. Although the studies included were a mixture of experiments with acute noise exposure and field studies with chronic noise exposure, different sound sources and different versions of the cognitive tests, fairly consistent patterns both within and between the four groups of cognitive measures emerged.

As can be seen from Figure 1:

1. Reading and recall have steeper slopes than attention and recognition
2. There is not much of a difference in slopes between children and adults where they both have been studied with similar tests. (Note that reading was only studied for children.)
3. There is not much of a difference between experimental studies with acute noise exposure and field studies with chronic noise exposure.

This can be summarized in quantitative terms: The studies on recall and reading cluster together and have slopes around 2% per dB. Studies on recognition and attention also group together and generally have slopes in the region of 0.6% per dB. Thus, for recall and reading in it is expected that a reduction of the noise level by 5 L_{dn} would result in improved performance by something like 10%. For attentional tasks and for recognition memory, a 5 dB L_{dn} reduction in noise level is expected to result in around 3% improvement of the response. This is summarized in Figure 2.

From dose-effect curves to disability

Which disability weights (between 0 and 1) should be assigned to impairment of reading and recall memory? How disabling then is a 20% reduction of reading and memory skills? Is a disability weight of .20 a fair estimate of a 20% reduction?

A dose noise-dose effect curve does not by itself say much about how disabling the noise effect is in terms of Disability Adjusted Life Years (DALY), which is the sum of YLL (Years of Life Loss) and YLD (Years Lived with Disability). A 20% impairment of reading and memory capacity does not by itself have a disability weight (DW), which in DALY calculations varies between 0.0 meaning no disability and 1.0, meaning death. Finding a DW is not by itself a fact-finding process, it is basically a societal-ethical issue where a weight is agreed upon and assigned to a an impairment in terms of how disabling the impairment in question is in relation to other impairments or disabilities, e.g., cognitive impairment from lead exposure, iron-deficiency anemia, from Parkinson's and Alzheimer's diseases, or deafness. The DWs reported or suggested for the named conditions are listed in Table 1, and were taken from Prüss-Üstün et al. (2003), Mathers (2005), and Essink-Bot et al. (2003). Additionally, suggested DWs for severe noise annoyance and noise disturbed sleep (Staatsen et al., 2005), and for indoor and outdoor annoyance from noise (Westerberg & Glaumann, 2002) are entered although annoyance by itself is a transient impairment.

Table 1. Disability weights (DW) for different impairments of relevance to noise exposure or cognition

Effect	DW
Alzheimer	.640
Mild mental retardation attributable to lead exposure	.361
Parkinson	.320 -. 390
Deafness	.180 - .220
Common cold	.030 - .040
Iron-deficiency anemia	.024
Severe noise annoyance	.020
Severe noise disturbed sleep	.020
Indoor comfort problems from noise	.010
Outdoor comfort problems from noise	.010

Thus, suggested DWs for cognitive impairment may have .010 - .020 at its lower end.

From dose-effect curves to incidence rates

How strongly is the cognitive impairment related to the noise exposure levels? How many children out of 1 000 are as negatively affected by the noise levels as the DWs state?

In contrast to DWs, incidence rates are on principle results of a fact finding process, but the empirical facts about how many children are exposed to noise at different noise levels are not there. And even if they were, there would still be a matter of further fact finding to establish the incidence rates in relation to the magnitude of the assigned DW within that noise level segment. However, what is available is estimate of the percentage of people exposed to noise at different levels in the EC. For instance, Rovers et al 2000 (as quoted in Staatsen et al., 2004) stated that around 67% are exposed to L_{dn} –levels < 55, 20% to 55-65, 10% to 65-75 and 3% to > 75, see Table 2, although statistics for the specific countries within the EC may vary (cf. PINCHE, 2005, p. 94 ff.).

Table 2. Noise levels (L_{dn}) and population exposed (%)

< 55 L_{dn}	55-65 L_{dn}	65-75 L_{dn}	> 75 L_{dn}
67%	20%	10%	3%

But then again, the distribution of noise exposure is not the same as the fraction of the population actually affected by noise, and also not how much they are affected within the exposure segment. That has to be sorted about by means of incidence rates, meaning how many percent of those exposed will develop the cognitive impairment meeting the criterion of the disability weight chosen. As there as yet is no answer to those questions, the best choice is to make some educated guesses and see what happens to the YLDs per 1 000.

The noise exposure distribution shown in Table 2 is estimated for adults, but there is no reason to believe that children are less exposed than adults. If there is a difference it is probably in the direction that children are more noise exposed than adults.

To make the assumptions explicit on which the (hypothetical) calculations are based Sweden is taken as an example. The number and proportion of the Swedish children in the age range of the mandatory school system in 2004 is shown in Table 3. It can be noted that the proportion of people up to 19 years (23.95%) fits closely with the 24.2% for the European Union in 1998 as reported by PINCHE (2005, p. 94). Table 3 is then combined with Table 2 to estimate the number of children exposed to different noise levels.

Table 3. Population in Sweden end December 2004

Age group	**Frequency**	**Percent**
0-6	668 841	7.42
7-19	1 489 437	16.53
20-	6 853 114	76.04
Total	9 011 392	99.99

However, if 1 000 children are exposed to a noise level of 65 L_{dn}, how many of them can be assumed to be impaired in their reading and memory to such an extent that their average DW is the weight chosen (e.g. .020) for that exposure level? Thus, this does not solve any incidence rate problems, and again there is no empirically based answer to the incidence rate question, but one guess could be up to 30% at the highest noise exposure level and maybe as low as 5% at the lower levels.

Years lived with disability (YLD)

One way to approach an answer to the size of the BoD from cognitive impairment caused by noise is to calculate DALY by systematically varying disability weights and incidence rates in small steps around "reasonable" values and see how much the BoD is changed. The DALY will be computed only from YLD as deaths caused by noise are not an alternative.

In Table 4 different sets of assumptions of incidence rates (per 1 000) children and DWs are combined to get a general idea about what ranges of YLDs per 1 000 children we can come up with. Note that the YLDs in Table 4 is computed only for children. This was done on purpose, just to make a clean case for the estimates of noise induced cognitive impairment for children. The calculations in Table 4 was adapted from the YLD-calculation template in Box 3.2, Prüss-Üstün et al. (2003, p. 35), but did not divide the material into males and females and employed an average life expectancy of 80 years. Table 5 shows how one of the YLDs (2.3 – line 5 from top in Table 4.) is calculated.

At the noise levels < 55 L_{dn} the DW is set to 0, as is the incidence rate. That is, no impairment effects are expected at these levels. In the next noise exposure segment (55-65 L_{dn}) the top half of Table 4 is restricted to DWs up to .010, which is the lowest vales from table 1. From the segment (55-65 L_{dn}) up to the next two segments, the DWs increase in steps that are roughly equal from one step to the next. Thus, the assumed function is roughly is rather more linear than exponential or a power function. The two latter function forms, which could also have been argued for a theoretical point of view, would have resulted in higher YLDs than in our examples. In this respect then our examples probably are on the conservative side, i.e. underestimating rather than overestimating the real effect.

Table 4. YLDs per 1 000 children under different assumptions about noise levels L_{dn}, DWs and incidence rates per 1 000

< 55 L_{dn}		55-65 L_{dn}		65-75 L_{dn}		> 75 L_{dn}		
DW	*Incid*	DW	Incid	DW	Incid	DW	Incid	YLD per 1 000
.0	0	.005	50	.010	100	.020	200	1.3
.0	0	.005	100	.010	200	.020	300	2.3
.0	0	.005	50	.010	100	.024	200	1.4
.0	0	.005	100	.010	200	.024	300	2.5
.0	0	.010	50	.020	100	.030	200	2.3
.0	0	.010	100	.020	200	.030	300	4.2
.0	0	.010	50	.024	100	.040	200	2.8
.0	0	.010	100	.024	200	.040	300	5.0

.0	0	.020	50	.030	100	.040	200	3.5
.0	0	.020	100	.030	200	.040	300	6.5
.0	0	.030	50	.040	100	.060	200	5.1
.0	0	.030	100	.040	200	.060	300	9.3
.0	0	.050	50	.080	100	.120	200	9.6
.0	0	.050	100	.080	200	.120	300	17.6

Some conclusions about the stability of the YLD per 1 000 children can be drawn from Table 4. With the incidence rates as assumed here, DWs up to .010 for the exposure range 65-75 L_{dn} results in YLDs per 1 000 < 3. Increasing that DW to .030 yields YLD per 1 000 up to 6.5, and only DWs around .080 result in a value around or higher than 10 YLD per 1 000. So, what then is a "fair" DW estimate of children's cognitive impairment form noise exposure? Taking the values quoted in Table 1 for annoyance and comfort (.010 – .020) and stating that cognitive impairment in the region > 75 L_{dn} is twice as disabling as for what is assumed for annoyance, a YLD per 1 000 estimate would approach 6 or slightly more. Only when claiming that the exposure range 65-75 L_{dn} carries a disability weight that is four times higher than that of annoyance results in YLDs in the region 10 or higher per 1 000. A conservative conclusion then would then be that a YLD per 1 000 for cognitive impairment in children from noise exposure is 5 or lower.

Table 5. Estimated YLDs for children in Sweden December 2004

Age groups and noise exposure level	**Population**	**Incidence**	**Incidence per 1 000**	**Age at onset**	**Duration (years)**	**Disability weight**	YLDs	**YLD per 1 000**
Age 7-19, < 55 Ldn	997 923	0	0	13.0	67.0	0.000	-	0.0
Age 7-19, 55-65 Ldn	297 887	14 894	50	13.0	67.0	0.010	4 300	14.4
Age 7-19, 65-75 Ldn	148 944	14 894	100	13.0	67.0	0.020	8 599	57.7
Age 7-19, > 75 Ldn	44 683	8 937	200	13.0	67.0	0.030	7 739	173.2
All other age groups	7 521 955	0	0	52.5	0.0	0.000	-	0.0
Total	9 011 392	38 725	4.3	13.0	67.0	0.02	20 638	2.3

Table 6. The Burden of Disease in YLD for a sample of diseases and injuries in Sweden

Disease or injury	Total YLD
Down's syndrome	5 212
Gastritis	5 772
Traffic accidents (not deaths)	7 338
Diabetes	14 160
Injuries by falling (not deaths)	15 154
Vision impairment	15 822
Asthma	23 570
Hearing impairment	38 172

Note: Deaths and YLL were excluded. Incidence of asthma may have increased since 1998.
The burden of disease in YLD in Table 5 from cognitive impairment of noise exposure in children 7-19 years old, according to my examples in Tables 4 and 5, can be compared to the estimated total burden of disease in the whole Swedish population in a sample of diseases and injuries, as reported by Folkhälsoinstitutet (1998) and shown in Table 6. Assuming the values

given in Table 5, the cognitive impairment of noise exposure in children 7-19 years amounts to more than that of impaired vision. Doubling the YLD per 1 000 to 4.6 will result in a burden that is in around that of hearing impairment. The relative comparisons of the magnitude of noise induced cognitive impairment with that of hearing and vision impairment, makes some sense and can be argued for.

Discussion – Clarifications and limitations

There are several crucial assumptions made in my estimates of YLD that should be explicitly spoken out. Some of them have a conservative effect of the YLD, yielding YLD values that are lower than any "real" value, others may tend to inflate the YLDs.

Some of the calculations and dose effect curves are based on experimental studies with acute noise exposure, other on chronic noise exposure in real settings. Although the slope of the dose-effect curves for reading and recall-memory are roughly equal, they may impair cognition in different ways. I acute and in chronic noise exposure. The acute noise effect may be just restricted to cognitive impairment while trying to learn (encode) something new at the same time as being exposed to noise, while the chronic noise effect on learning can be conceived as operating also when there is no acute noise exposure. That is, the chronic noise effect may affect cognition also when there is no acute noise exposure, maybe as a result of impaired general skills for taking in or encoding new information.

There is some evidence from the Munich study (Hygge, Evans & Bullinger, 2002) that after the offset of the aircraft noise the children (age 9-11 years) recover within 18 months to the cognitive performance levels of their year-mates not having been exposed to much of aircraft noise. Thus, it is possible that at least for young children, chronic noise effects are reversible and that the DWs will diminish with increasing age.

My calculations assume life-long disability, which in one way implies living a whole life in a neighborhood as noisy as the one you lived in as child. This does not take into account moving in and out of noisy areas, which, however may balance out each other if there is no consistent trend of people moving to more quiet living areas.

No adjustment has been made for certain periods of the life span being more valuable than others That is, one childhood year free form disability could be said to be more valuable than a year after the age of 80.

Changing onset from 13 years to 7, and duration from 67 to 72 years in Table 5, only changes the YLD per 1 000 by 2.5%.

Calculating the YLD per 1 000 not on the whole Swedish population, but only on the population aged 0-19 years, yields about six times higher YLDs per 1 000 children.

The dose-effect curves I have set up do not cover all relevant noise studies in children. I have mainly included studies that show a significant noise effect, so the picture I have presented may overestimate "real" effects.

The studies reporting significant effects of noise exposure also have an overrepresentation of aircraft noise studies. Road traffic noise, and in particular rail and train noise, sometimes are reported to have a less steep dose-effect curves (cf. Hygge, 2003; Stansfeld et al., 2005).

For some of the studies reported in Figure 1 (studies 13-15, 18-19) irrelevant speech was the noise source. It has been pointed out that negative cognitive effects of irrelevant speech (at least on short-term serial memory) are less dose-sensitive than for other noise sources (Tremblay et al., 2000). That is, irrelevant speech has its full negative effect at *lower* noise levels than other sources and does not increase from that level.

In a similar vein studies of aftereffects of noise and perceived control of the noise source (Glass and Singer, 1972) also have shown examples of noise effects that are not much graded by noise dos0. Deteriorated performance on post-noise tasks was fully balanced out by giving participants perceived control over the noise source, or by arranging the noise bursts in predictable time sequences.

As the noise effects become stronger with more difficult and demanding task than on easy tasks, it could be argued that the disabling weight or the incidence rate also should take into account how often such tasks have to be performed. When the occurs often, as while trying to learn in school, the weight should be higher but if that maximum capacity is seldom used, the weights and rates could be set lower.

In line with this reasoning it may also be suggested that an alternative to evaluate cognitive impairment from noise is not to cast it in terms if disability units, but in wasted learning units, which have their price in wasted teaching hours in schools, wasted both for the teachers, the pupils and society.

Some of the L_{dn}-levels that are reported in Figures 1 and 2 refer to indoor levels others are outdoor levels. However, this does not matter since the present analysis relies on the slopes of the dose-effect curve, and not from where the upper end of the curve has its starting point.

For the present paper, calculations were restricted to an example from Sweden. Before an attempt to widen the scope of the calculations to include other geographical areas with other distributions of age groups and noise exposure levels, the DWs and incidence rates suggested here first should be put to scrutiny and evaluated in a wider setting of critical and experienced experts.

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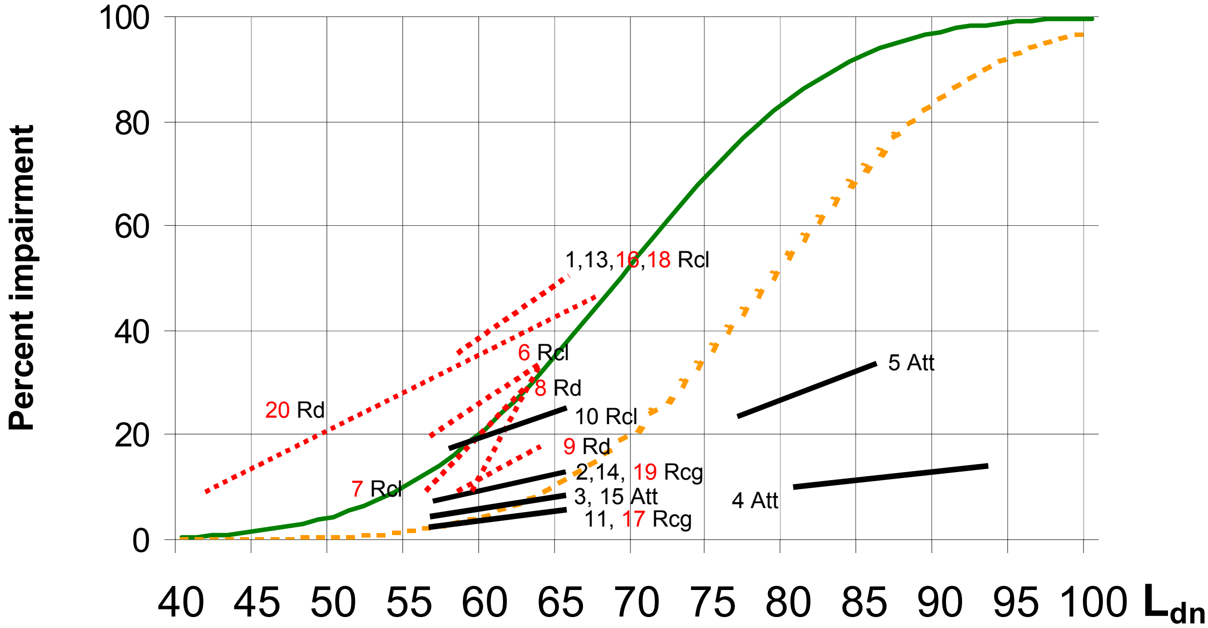

Rd = reading, Rcl = recall, Rcg = recognition, Att = attention

Figure 1. Hypothetical dose-effect curves and approximated results from different studies .

1 Recall, adults, Enmarker (2004)
2 Recognition, adults, Enmarker (2004)
3 Attention, adults, Enmarker (2004)
4 Attention selectivity, adults, Hockey (1973)
5 Attention and vigilance, adults, Jones, Smith & Broadbent (1979 exp 4)
6 Recall, children, old airport, Hygge, Evans & Bullinger (2002)
7 Recall, children, new airport, Hygge, Evans & Bullinger (2002)
8 Reading, children, old airport, Hygge, Evans & Bullinger (2002)
9 Reading, children, new airport, Hygge, Evans & Bullinger (2002)
10 Recall, young adults, Hygge, Boman & Enmarker (2003)
11 Recognition, young adults, Hygge, Boman & Enmarker (2003)
12 Attention, young adults, Hygge, Boman & Enmarker (2003)
13 Recall, adults, irrelevant speech, Enmarker (2004)
14 Recognition, adults, irrelevant speech, Enmarker (2004)
15 Attention, adults, irrelevant speech, Enmarker (2004)
16 Recall, children, Boman (2004)
17 Recognition, children, Boman (2004)
18 Recall, children, irrelevant speech, Boman (2004)
19 Recognition, children, irrelevant speech, Boman (2004)
20 Reading, children, Stansfeld et al. (2005).

In 1-12, and 20 the noise sources were aircraft noise or road traffic noise, in studies 13-15 and 18-19 irrelevant speech of the same average level (66 LAeq) as for the road traffic noise in the studies indexed by 1-3, 10-12, and 16-17. In 6-9, 15, and 20 the noise exposure was chronic, and for the others acute. Lines referring to studies on recall and reading are shown as dashed lines. Studies on children are referred to with red numerals.

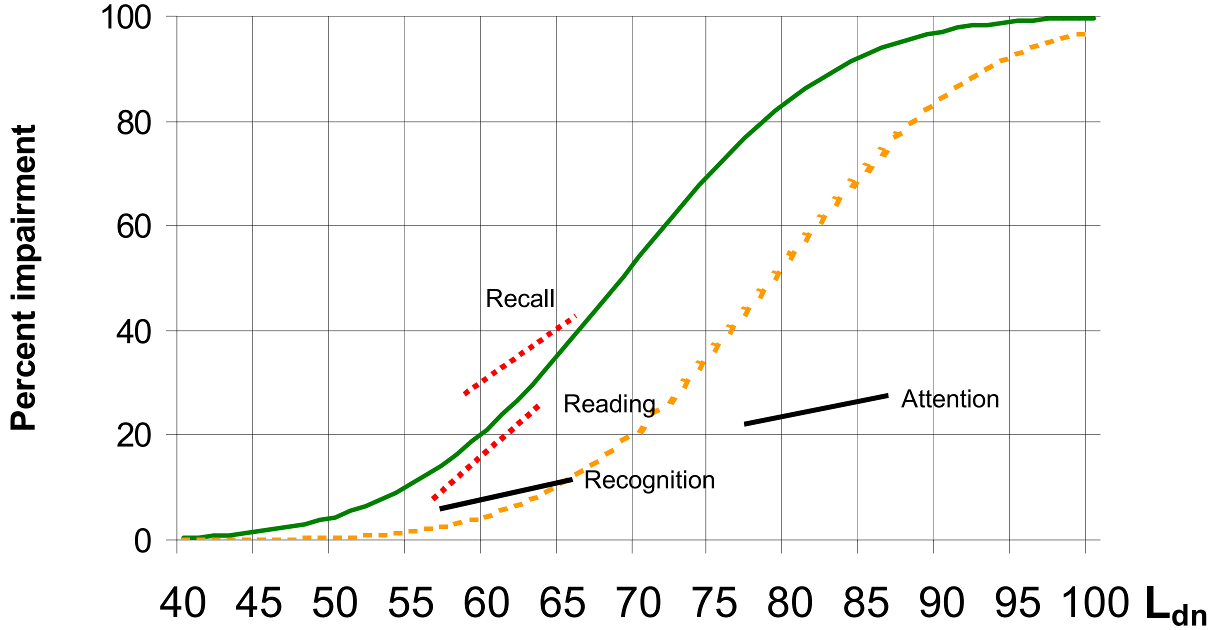

Figure 2. Hypothetical dose-effect curves and summary of approximated results from different studies sorted by cognitive functions.