Selection of exposure-response relations for road traffic noise

Background paper for the INTARESE project

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Bilthoven, 5 Februari 2009

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1 Introduction

This paper is a background document that can be used for assessing the health impacts attributable to road traffic noise exposure in work package 3.1 of the European 6th framework project 'Integrated Assessment of Health Risks of Environmental Stressors in Europe' (INTARESE). The aim of INTARESE is to provide methods and tools that are essential to enable integrated assessment of environment and health risks, and to develop a methodological framework and a set of tools and indicators for integrated assessment that can be applied across different environmental stressors (including pollutants and physical hazards), exposure pathways (air, water, soil, food) and policy areas. It will review, bring together and enhance the monitoring systems needed to support such analyses, including routine environmental monitoring, bio monitoring and health surveillance. The framework, tools and data will be tested and demonstrated through integrated assessments of exposures and health risks in a number of specific policy areas, including transport, housing, agriculture, water, wastes, household chemicals and climate.[1]

In order to evaluate the health benefits of alternative transport scenarios and measures, case studies were started in five cities (Rome, London, Helsinki, The Hague and Barcelona) in work package 3.1 (Transport) of the INTARESE project. In these cases studies, three transport policy interventions including congestion charging, environmental zoning designed to accelerate replacement of old cars, and measures to promote public transport and cycling/walking were investigated. The results and experiences from these case studies will be used for the refinement and further development of the toolbox for integrated environment and health risk assessment.

To characterise the health impact of transportation one can calculate the number of cases of health damage and the resulting disease burden associated with certain exposure distributions, such as deaths, or hospital admissions, and aspects of the quality of life such as the aggravation of pre-existing disease symptoms, severe annoyance and perceived danger. (De Hollander, 2004). The number of attributable cases and the resulting disease burden can be quantified as part of a health impact assessment (HIA): a "combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population (Gothenburg Consensus Paper, 1999 in: Veerman et al., 2005)", which can provide relevant information for policy makers on the effects of interventions and/or policies on public health. (WHO working group 2000). As Figure 1 illustrates, a HIA contains several steps, during which population exposure distributions, exposure-response relations, disease prevalence, demographics, severity weights, and duration are combined in order to assess the disease burden.

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[1] See also INTARESE-website: http://www.intarese.org/

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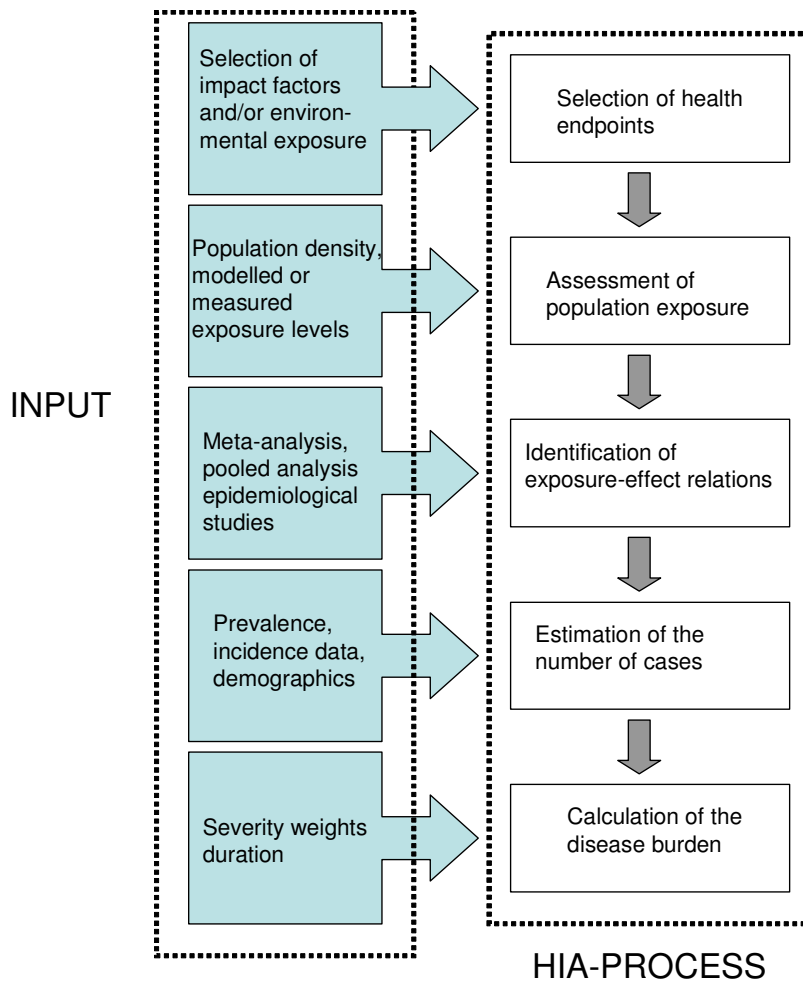
Figure 1. The different steps of a Health Impact Assessment

The aim of this document is to identify relevant exposure-response relations that can be best used when assessing the health impacts attributable to road traffic noise exposure. To this end the weigh of evidence and relevant exposure-effect relations in the field of noise and health are evaluated. Finally, some recommendations are given for the applicability of these exposure-response relations regarding the assessment of health impact of noise exposure.

2 Methods

2.1 Identification of effects

Long term noise exposure is associated with a number of effects on health and well-being. These include not only community responses such as annoyance and sleep disturbance, but also physiological effects such as hearing loss. Based on recent reviews regarding the effects of environmental noise, a whole range of effects that are reported in relation to environmental noise exposure, were identified (WHO, 2000; Babisch, 2006; HCN, 1994; 2004; Van Kempen et al., 2002; 2008): direct masking effects; behavioural responses such as coping strategies and complaints; 'social' responses such as annoyance; acute physiological responses; cognitive responses such as task interference and learning; chronic physiological responses; and clinical morbidity such as mental health and cardiovascular disease.

2.2 Selection of effects

For some of the above mentioned effects on health and well-being an association was found with long-term exposure to road traffic noise. For this paper we are only interested in those effects of which organisations such as the World Health Organization (WHO) and the Dutch Health Council conclude that there is evidence[2] for an association. These involved: annoyance, sleep quality, sleep disturbance, insomnia, hypertension and ischemic heart disease and decrease of cognitive functioning. The WHO definition of health which is defined as "a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity", embraces the concept of well-being and thereby renders noise impacts such as annoyance and sleep disturbance as health issues. Hearing loss or hearing impairment was not included as possible health endpoint since it is unlikely that hearing damage occurs at typical levels of road noise exposure, as is made clear in the WHO Community Guidelines for noise stating that hearing impairment is not expected to occur at $L_{Aeq\ 8h}$ levels of 75 dB(A) or below. It is expected that environmental noise with a $L_{Aeq24hr}$ of 70 dB(A) or below will not cause hearing impairment in the large majority of people, even after a lifetime exposure (WHO, 2000).

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[2] In order to assess the degree of certainty concerning the relation between exposure to noise and a particular effect, the available evidence was rated in terms of the categories proposed by the International Agency of the Research on Cancer (IARC) as 'sufficient', 'limited', 'inadequate' or 'lacking'. There is 'sufficient' evidence in case a relation has been observed between noise exposure and a specific health effect, while at the same time chance, bias, and confounding factors can be ruled out with reasonable confidence.

2.3 Selection of exposure-response relations

For each of the selected effects we investigated the availability of valid exposure-effect relations that are known up today, using data published in the epidemiological literature. Exposure-effect relations can be derived either from single studies, a quantitative summary of published data (meta-analysis), a re-analysis of individual data based on primary studies or a prospectively planned pooled analysis of several studies where pooling is already part of the protocol (Blettner et al., 1999). For reasons of power we were only interested in the exposure-response relations that were derived either by means of a quantitative summary of published data or an analysis of individual data based on primary studies (afterwards or prospectively planned).

3 Results

3.1 Annoyance

Annoyance is a collective term for several negative reactions such as irritation, dissatisfaction or anger, which appear when noise disturbs someone's daily activities (WHO, 2000). In observational studies annoyance is usually measured by means of one or more questions as part of a questionnaire or interview. The results of these studies are consistent: most studies find a positive association between noise and annoyance (Van Kempen et al., 2005).

3.1.1 Available exposure-response relations

For adults, the relation for the association between road traffic noise (outdoor level, most exposed façade, L_{den}) and several degrees of annoyance (% a little annoyed, % annoyed, and % highly annoyed) derived by Miedema and Oudshoorn (2001) is at the moment the best available. It is based on a re-analysis of individual data from 26 different studies (19,172 data points) published between 1971-1994 from different European countries and Canada. To be included into the analyses, acceptable L_{den} and percentage annoyed had to be derived. Because there was no practical need for information concerning the annoyance at extreme levels (defined as $L_{den} < 45$ dB(A) or $L_{den} > 75$ dB(A)), Miedema and Oudshoorn (2001) excluded these from the analyses. According to the researchers, at these levels the assessment of noise exposure and/or annoyance is relatively inaccurate (Miedema & Vos, 1998; 2001). In order to derive the exposure-response relations, Miedema & Oudshoorn (2001) made use of multilevel modelling.
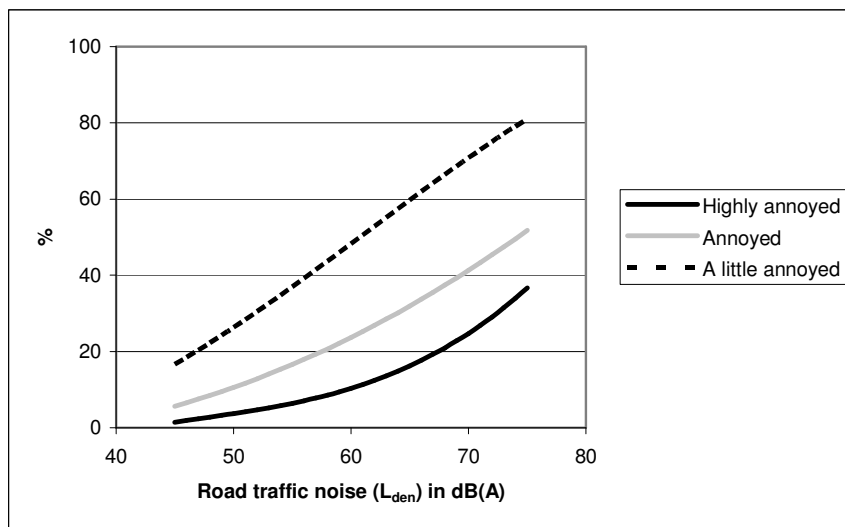

Figure 2. Exposure-response relations for the association between road traffic noise (L_{den}) and several degrees of annoyance derived by Miedema & Oudshoorn (2001). [The formulas are presented in Table 4 or can be found in Miedema & Oudshoorn, 2001].

Although not presented in Figure 2, Miedema & Oudshoorn also presented 95% confidence intervals. In their article they clearly explain how these intervals can be derived (Miedema & Oudshoorn, 2001). The exact formulas for the relationships that have been found involve the formula for a normal distribution. Unfortunately, the covariance matrices, which are essential for calculating the intervals, are not presented. However, one has to keep in mind that the 95% confidence interval that are presented by Miedema & Oudshoorn (2001) describe the uncertainty in the line (2001). This is different from the uncertainty in the underlying model.[3]

3.1.2 Assessing the number of highly annoyed

Table 1 illustrates how the exposure-response relation derived by Miedema and Oudshoorn (2001) can be used to assess the number of highly annoyed people.

Table 1. The percentage of people exposed to and highly annoyed by road traffic noise in the Netherlands in 2000 (adults only): an example

Exposure category (dB(A)) L_{den}	Average noise level (dB(A))	% of population exposed	% highly annoyed*	Number per 1,000,000
<40	40	7.5	0	0
41-45	43	11.8	0.5	588
46-50	48	23.1	2.7	6,224
51-55	53	29.4	5.4	15,880
56-60	58	20.2	8.8	17,777
61-65	63	6.7	13.8	9,195
66-70	68	1.2	21.3	2,654
>71	73	0.1	31.8	433
Total		100		52,751

* calculated by means of the formula provided by Miedema & Oudshoorn (2001) (see also table 4). Adapted from: Knol and Staatsen (2005)

To this end it is necessary to obtain information on the population exposure distribution. These data have to be combined with demographic data. Subsequently, the exposure information is combined with the corresponding relationship in the way as is shown in table 1. In this way it was estimated that about 600,000 (500,000 – 850,000) people are severely annoyed by road traffic noise in the Netherlands (table 1).

The relation of Miedema & Oudshoorn (2001) is suitable to assess the fraction of highly annoyed people due to road traffic noise in a strategic assessment. Because the curves have been derived for adults, only persons of 18 years and older were included. People exposed to outdoor levels (at most exposed façade) L_{den} < 45 dB(A) or L_{den} > 75 dB(A) were not included since the relation is only valid in the range between 45-75 dB(A) (L_{den}).

When estimating the disease burden attributable to road traffic noise exposure (expressed in DALYs) only the number highly annoyed respondents are included (Knol & Staatsen, 2005), assuming that 'high annoyance' is a health state where people's daily functioning might be affected. Annoyance and/or a little annoyed are considered not to affect people's daily functioning. A DALY considers the loss of life expectancy due to premature

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[3] In their article, Miedema & Oudshoorn (2001) present a model of the distribution of noise annoyance with the mean varying as a function of noise exposure. The confidence interval is only related to the variation of the mean, which is different from the uncertainty in the underlying modeled annoyance distribution.

mortality, loss of quality of life due to disease, and the number of people affected. Effects such as a small decrease in lung function or increased blood pressure but also (a little) annoyance are therefore not included; normally, they do not affect people's daily functioning.

3.2   Effects on sleep

Several reviews have shown that night-time noise can affect people's sleep (HCN, 1994; 2004; WHO, 2000). These effects may manifest itself in various ways: in the sleeping behaviour (increasing the time awake during the night), in the structure of the sleep (as measured by an electroencephalogram), as physiological response (e.g. increase of blood pressure or heart rate) or as an effect in the period after sleep (e.g. loss of concentration, increased fatigue). Several effects of noise on sleep, varying in severity have been measured:
-    primary effects such as difficulties falling asleep, awakening, sleep stage changes en instantaneous arousal effects during the sleep (e.g. temporary increase in blood pressure, heart rate, increased motility);
-    secondary or 'after' effects measured the next day such as decrease of perceived sleep quality, increased fatigue and decrease in mood and performance; and
-    long-term effects on health and well-being such as increased medication use or chronic annoyance.

For this paper we are only interested in the effects of long-term road traffic noise exposure (expressed in L_{night}) on health and well-being. With regard to this, only three effects with sufficient evidence for an association with road traffic noise were identified: decrease in sleep quality, insomnia, and sleep disturbance.

3.2.1   Sleep quality
A decrease in sleep quality includes difficulty falling asleep, difficulty sleeping through the night, waking up during the night and a shorter sleeping time (Fast, 2004; HCN, 2004). In their systematic review, Franssen & Kwekkeboom (2003) evaluated 20 studies published between 1983 and 2002 investigating the relation between noise exposure and sleep quality. Although, sleep quality was measured by means of a questionnaire, the measurement and definition of sleep quality differed between the studies: some studies used only one question, while others combined the answers of more questions in one score. From the results of the studies it can be concluded that sleep quality improves as road traffic noise levels decrease. It was not possible to derive an exposure-response relation based on the results of these studies.

3.2.2   Insomnia
Insomnia can be defined as the inability to sleep or an abnormal wakefulness. Until now, three studies have investigated the association between night time noise exposure from road traffic and insomnia (Kageyama et al., 1997; Kawada et al., 2003; Passchier-Vermeer et al., 2007). The results of these studies are inconsistent: On the basis of the study of Kageyama et al. (1997) it is possible to derive an exposure-response relation; in the other two studies no

relation was found. However, since the research sample contained only women, the generalisability of the exposure-response relation to other situations remains questionable.

3.2.3 Sleep disturbance

Sleep disturbance is regarded as a particular form of annoyance and is usually measured by means of a direct question as part of an interview or questionnaire. For adults, the relation for the association between noise from night time road traffic (L_{night}) and sleep disturbance derived by Miedema et al. (2003) is at the moment best applicable. It is based on a re-analysis of individual data from 14 different studies (8,459 subjects) from the period 1975-2001. Included were studies where L_{night} was included in the dataset or the probability to estimate this metric on the basis of information regarding the included sites; and studies using questions regarding waking up or being disturbed by noise during the night. Studies using question regarding disturbance of sleep or resting were excluded since resting is different from sleeping and does not need to take place during the night only (Miedema et al., 2003). Furthermore, low exposure levels (L_{night} < 45 dB(A)) were excluded from the analyses because the assessment of these low noise levels is generally relatively inaccurate and in situations with these low levels, other sources may be more important. High exposure levels (L_{night} > 65 dB(A)) were also excluded, because in areas with very high exposure levels there is assumed to be a relatively high risk of self-selection of persons not bothered by noise (Miedema et al., 2003). However, data dealing with this hypothesis are lacking.

In order to derive exposure-response relations for sleep disturbance, the same statistical model was used that was already developed for the analysis for the association between noise exposure and noise annoyance (Miedema & Oudshoorn, 2001). The relation gives the percentage highly sleep disturbed (%HSD), sleep disturbed, and (at least) a little sleep disturbed by road noise as a function of the outdoor L_{night} at the most exposed façade (Miedema et al., 2003).
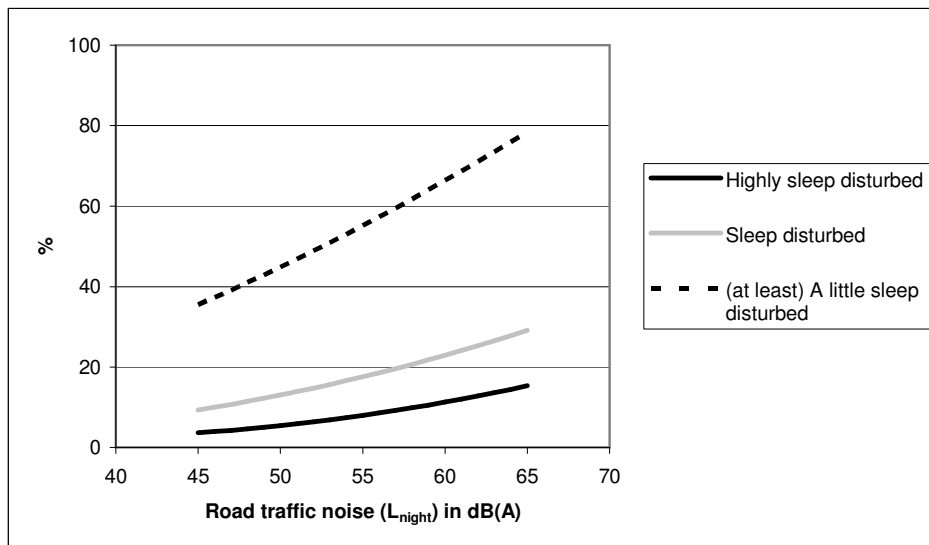

Figure 3.   **Exposure-response relations for the association between road traffic noise during the night (L_{night}) and several degrees of sleep disturbance derived by Miedema et al., (2003).**

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Just like for the exposure-response relationships that are derived for annoyance, for the sleep disturbance curves, the 95% confidence interval describing the uncertainty of the line can be estimated. Because Miedema (2003) works with distributions, no simple formulas are available.

3.2.4 Assessing the number highly sleep disturbed

The calculation of the fraction of sleep disturbed people is similar to the calculation of the fraction annoyed people, applying the exposure-response relation on a given population noise exposure distribution (see also Table 1). Because the relationship is only applicable for the range 45 – 65 dB(A) (L_{night}), persons outside this range are not included in the calculation. Again, only adults are included. Despite methodological issues the relationship is suitable to assess the fraction of (highly) sleep disturbed people due to road traffic noise in a strategic assessment.

When estimating the disease burden attributable to road traffic noise exposure (expressed in DALYs) only the number highly sleep disturbed respondents are included (Knol & Staatsen, 2005), assuming that 'high sleep disturbance' is a health state where people's daily functioning might be affected. Sleep disturbance and/or a little sleep disturbed are considered not to affect people's daily functioning. A DALY considers the loss of life expectancy due to premature mortality, loss of quality of life due to disease, and the number of people affected. Effects such as a small decrease in lung function or increased blood pressure but also (a little) sleep disturbed are therefore not included; normally, they do not affect people's daily functioning.

3.3 Effects on the cardiovascular system

The biologic mechanism of noise exposure leading to cardiovascular effects seems plausible although it is quite complex: noise-induced cardiovascular effects can be regarded as the consequence of stress, which can arise in several ways in relation to noise (Van Kempen et al., 2002).

When looking at studies investigating the effects of noise exposure on the cardiovascular system a broad range of effects have been reported: (i) differences in blood pressure; (ii) changes in the occurrence (prevalence and incidence) of hypertension, angina pectoris and myocardial infarction; and (iii) changes in the number of hospital admissions, medication use, visiting a GP or specialist and/or mortality due to cardiovascular disease. Usually the effects that were found were small (Van Kempen et al., 2005; Babisch, 2006); transient stress-related hemodynamic responses that are harmless on an individual level may result in slight shifts in blood pressure on population level. In a smaller, susceptible proportion of the population this may lead to increases in hypertension and, eventually, prevalence of ischemic heart disease, including angina pectoris and myocardial infarction.

3.3.1 Available exposure-response relations

Since 2000, several attempts have been done to derive exposure-response relations describing the association between road traffic noise exposure and effects on the cardiovascular system (Van Kempen et al., 2002; Babisch 2006; Van Kempen, 2008; Van Kempen and Houthuijs, 2008).

To gain more insight into the potential health impact of noise exposure, in 2000 a meta-analysis of 43 epidemiological studies published between 1970-1999 and investigating the relation between noise exposure (both occupational and community), blood pressure and/or ischemic heart disease (ICD-9: 410-414) was conducted. A wide range of effects, varying from blood pressure changes to a myocardial infarction, was studied. Quantitative summaries were obtained by means of a random effects model. Only estimates from studies adjusting for at least age and gender were included into the analysis. Because it was not possible to indicate the shape of the curve and a threshold value on the base on the available data, it was decided to use two models for the meta-analysis: an exponential and an additive model. The latter assumes that the increase in prevalence per unit of noise is constant, while the first assumes a constant relative risk (RR) per unit of noise (in other words the relation between the exposure and the prevalence of the effect concerned is exponential). Eventually, both models seemed to fit the data (Van Kempen et al. 2002). Nine studies investigating the effect of road traffic noise exposure have been identified. With respect to the association between noise exposure and blood pressure, small blood pressure differences were noticed. Road traffic noise exposure ($L_{Aeq, 16hr}$) was not associated with hypertension [$RR_{5dB(A)}$ 0.95 (95%CI: 0.84 – 1.08)] nor with angina pectoris [$RR_{5dB(A)}$ 0.99 (95% CI: 0.84 – 1.16)]. A positive, but non-significant association was found between road traffic noise exposure and the prevalence of myocardial infarction [$RR_{5dB(A)}$ 1.03 (95%CI: 0.99 – 1.09)].

Since the publication of Van Kempen et al (2002), several new studies were published. As a consequence Van Kempen updated her meta-analysis with observational studies investigating the association between road traffic noise exposure and ischemic heart disease that were published after 2000. The aim was to investigate whether the conclusions that were drawn in 2002 had changed. After including the results of new studies, a positive but statistically non-significant association was found between road traffic noise exposure ($L_{Aeq\ 16\ hrs}$) and the prevalence of hypertension: an $RR5_{dB(A)}$ 1.12 (95%CI: 0.97 – 1.30) was estimated. Road traffic noise exposure is positively, but non-significantly associated with the prevalence of angina pectoris. After including the results of studies that have been published after 2000, an $RR_{5dB(A)}$ of 1.05 (95%CI: 0.95 – 1.17) was estimated. For the association between road traffic noise exposure and the prevalence of myocardial infarction, data aggregation of the cross-sectional studies produced a positive, but non-significant estimate [$RR_{5dB(A)}$ 1.02 (95%CI: 0.99 – 1.06)]; a similar effect was found after pooling the results of case-control studies and one follow-up study [$RR_{5dB(A)}$ 1.06 (95%CI: 1.01 – 1.11)] (only the estimates for men were included).

In his meta-analysis, investigating the effects of road traffic noise exposure, Babisch (2006) pooled the results of three case-control studies and one follow-up study (the same studies as Van Kempen (2008) included), estimating risks (Odds ratio's) per noise exposure group (see also Table 2). Persons exposed to noise levels equal or less than 60 dB(A) were considered as reference group. Thereby, Babisch implicitly assumed that no effects of noise will occur below these levels. In the meta-analysis only men were included.

3.3.2 Estimation of the number of myocardial infarctions attributable to road traffic noise exposure

Until recently, it was more common to estimate the disease burden attributable to road traffic noise exposure using the relation between noise exposure and hypertension ($RR_{5dB(A)} = 1.26$ (95% CI: 1.14 – 1.39) which was based on data for air traffic and the relation between hypertension and mortality (RR = 1.4 (1.2 – 1.6) (Knol & Staatsen, 2005) (De Hollander, 2004). However, the relation between noise exposure and hypertension was based on pooling the results of cross-sectional studies. In the meantime, the results of cases-control and follow-up studies came available. The designs of these studies (which can be used to derive incidence estimates) are considered as stronger than a cross-sectional study design (producing prevalence estimates). For this reason we consider the relation between road traffic noise exposure and myocardial infarction as most valid.

As section 3.3.1. already made clear, two exposure-response relations describing the association between road traffic noise exposure and myocardial infarction are available at the moment. It is difficult to indicate which exposure-response relation can be best used to estimate the number of myocardial infarctions attributable to road traffic noise, since a direct comparison between the results of both Van Kempen & Houthuijs (2008) and Babisch (2006) is difficult. In case de results of Van Kempen & Houthuijs (2008) are applied from noise levels of 60 dB(A) (expressed as $L_{Aeq,\ 16\ hrs}$) and higher, it appears that the RR differ from the pooled ORs that were estimated by Babisch (2006). In perspective of the range of the 95% confidence intervals, these differences are however limited. As a consequence, the difference between the methods caused differences in the estimated myocardial infarctions per year,

where lower estimates are produced when using Van Kempen & Houthuijs (2008) (see also Table 3). However, a sensitivity analysis demonstrated that differences in the estimated magnitude of number of myocardial infarctions between the two relations depends on the road traffic noise levels at which people are supposed to be at risk (e.g. starting at 60 dB(A) or below 60 dB(A) and where to start then) and/or the population (are only men included or also women?) on which the relations were applied (Van Kempen & Houthuijs, 2008).

Table 2:   Estimation of the number of attributable cases of myocardial infarction due to road traffic noise exposure in Germany (source: Babisch, 2006)

Road traffic noise ($_{LAeq\ 6-22hr}$) in dB(A)	% of population exposed	Odds ratio (OR)	Attributable fraction (AR%)[a]	Population Attributable Risk (PAR %)[b]	Number of subjects[c]
≤ 60	69.1	1.00	0.00	0.00	0
60-65	15.3	1.05	4.76	0.76	1011
65-70	9.0	1.09	8.26	0.80	1070
70-75	5.1	1.19	15.97	0.96	1278
> 75	1.5	1.47	31.97	0.70	932
Total				**3.22**	**4289**

a) AR % = (OR – 1)/OR * 100; b) PAR% = P_e/100 * (OR-1)/(P_e/100*(OR-1)+1)*100; c) N_d * PAR% where N_d = disease occurrence

Table 3. The number of attributable cases of myocardial infarction due to road traffic noise exposure in The Netherlands in 2004: comparison between Babisch (2006) and Van Kempen & Houthuijs (2008) (Source: Van Kempen & Houthuijs, 2008).

Meta-analysis	Exposure-response relation applied from	Number of subjects[†]	95% confidence interval
Babisch (2006)[*]	60 dB(A)	130	0 – 550
Van Kempen & Houthuijs (2008)[*]	60 dB(A)	84	21 – 150

* In 2003 the incidence of Acute Myocardial Infarctions in The Netherlands among men and women was 28200 (Feskens et al., 2006)

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3.4   Cognitive functioning

In past decades, there has been a great deal of research on the effects of noise on children. The possible effects of noise on cognitive functioning were studied the most. In studies investigating the effects of chronic noise- exposure to air-, rail-, and road traffic, effects were found on reading, attention, problem solving and memory. In summary, the following results have been found in children exposed to high levels of environmental noise, compared to children in quieter schools: (a) deficits in sustained attention and visual attention; (b) difficulties in concentration; (c) poorer auditory discrimination and speech perception; (d) memory impairment for tasks that require high processing demands; and (e) poorer reading ability and school performance on national standardised tests (Stansfeld et al, 2000) (Stansfeld & Haines, 2002). The general finding is that mainly performance on the complex tasks is affected.

However, most of the studies investigating children's cognitive functioning focused on the effects or air traffic noise; only a few studies have investigated the effects of road traffic noise. The conclusions that can be drawn from these road traffic noise studies are limited and inconsistent and no exposure-effect relations are available.

4 Discussion

For the assessment of health impacts related to traffic noise exposure, exposure-response relationships are available describing the association between noise exposure and annoyance, sleep disturbance and the cardiovascular system. For these outcomes the evidence is sufficient and they are likely to occur at typical levels of community noise. The relationships evaluated in this report, were derived either by means of a quantitative summary of published data or a re-analysis of individual data based on primary studies.

4.1 Annoyance and sleep disturbance

The relationships for the association between noise and annoyance and sleep disturbance derived by Miedema & Oudshoorn (2001) and Miedema et al (2003) are at the moment the best currently available. They are based on a re-analysis 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). Their applicability was demonstrated in section 3.1.2.

Since these exposure-response relations are not developed for local, complaint-type situations, or for the assessment of the short-term effects of a change of noise climate, they have to be applied with great care on local situations such as is the case in the studies of work package 3.1: From the literature it is known that new or fast changing noise situations (e.g. changes in traffic flow rates, road bypass construction) can cause a change in the reaction to the people that live in the surroundings of the noise source: respondents whose noise exposure has increased as a consequence of a change in their noise situation report more annoyance than can be expected on the base of the generalized exposure-response relation; or respondents whose noise exposure has decreased as a consequence of a change in their noise situation report less annoyance than can be expected on the base of the generalized exposure-response relation. In their review Brown and Van Kamp (2005; 2008) have demonstrated that such a 'change-effect' is unequivocally present in the results of road traffic noise studies where the intensity of the road traffic source changes through changes in traffic volume on the source roadways. This effect is present even for quite small changes in noise exposure. Until now, several studies have tried to estimate the magnitude of the change effect. The results of these studies, which are rather consistent, are more or less summarized by Brown & Van Kamp (2008) (see also Figure 4). Since the studies were heterogeneous in terms of metrics, designs and since the approximations necessary to estimate the change-effect from the data reported in these studies differed, it was not possible to derive some kind of relation between the change in noise exposure and the change effect. It is possible that the issues that are addressed in relation to annoyance are also true for sleep disturbance, since sleep disturbance is regarded as a particular source of annoyance.
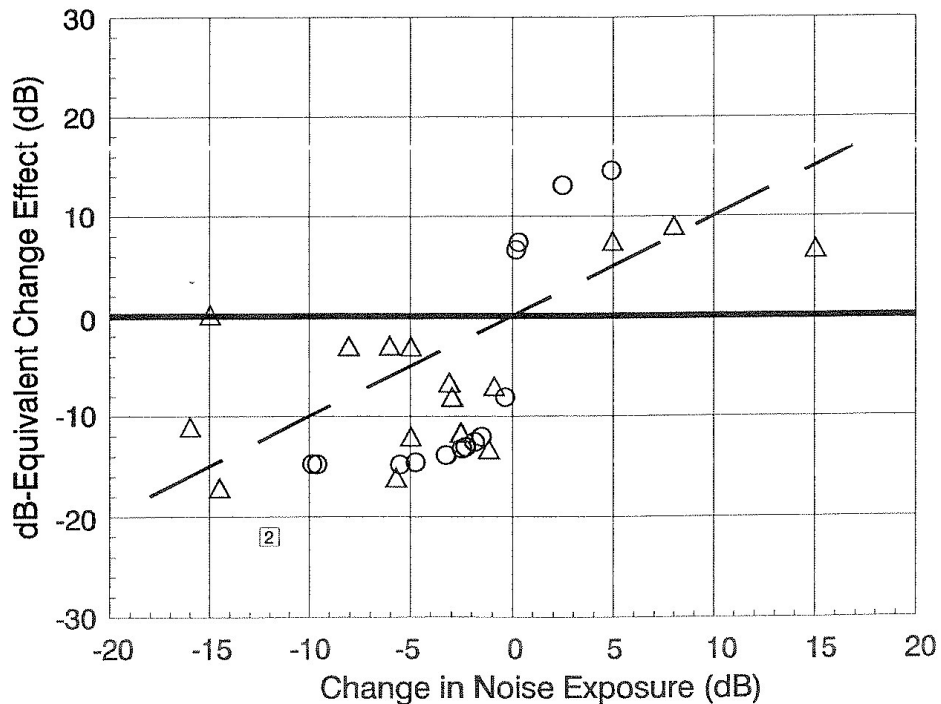
Figure 4. Decibel-equivalent excess response change-effect for studies investigating situations where the change in noise exposure has resulted from changes in the roadway source itself, the construction of new roadways, either as new sources or providing traffic relief on existing roadways, or some other change in traffic flow. The broken line indicates a change-effect of the same magnitude (dB-equivalent) as the change in noise exposure Source: Brown & Van Kamp, 2008).

4.2 Cardiovascular system

In relation the effects of noise on the cardiovascular system the results of the meta-analyses of Van Kempen & Houthuijs (2008) and Babisch (2006) can be best used for estimating the number of myocardial infarctions attributable to road traffic noise exposure. Because there is much uncertainty about the shape of the relationship and the threshold or observation value, it is difficult to indicate which relation can be best used.

It cannot be ruled out that the observed effects on the cardiovascular system are not only attributable to road traffic noise exposure; the observed associations between noise exposure and cardiovascular disease could also be explained by exposure to traffic-related air pollution (Rosenlund, et al., 2006) On the other hand it is also possible that the effects of traffic-related air pollution on the cardiovascular system might also be caused by exposure to noise.

4.3 Limitations of underlying studies

The number of usable relationships is limited in contrast with the amount of research that is carried out until now. This has several reasons that can be found in the underlying studies.

Most single studies used in the studies deriving an exposure-effect relations were cross-sectional. A problem that arises in relation to the interpretation of cross-sectional studies in general is that this confounds both the determination of the direction of the causation and the accurate estimation of the exposure (Stansfeld et al., 2000).

Another problem that emerges often in environmental epidemiological studies involves the estimate of the exposure and the inability to apply individual exposure estimates (if available) to larger study populations. The way noise exposure was assessed was fairly crude in most studies: noise exposure for each respondent was assessed by linking home addresses to modelled equivalent road traffic noise levels, predicting the average outdoor noise exposure during a specified time interval. Because it is a ground-based source with a complex propagation path from source to receptor and because of the uncertainties in traffic flow throughout the day, road traffic noise levels are difficult to predict.

Another problem is that to date, most assessments of the impact of noise exposure have involved between-group comparisons (high vs low): noise levels are measured or estimated for a residential area, a neighbourhood or a city. Subsequently, this noise level is assigned to everybody who is a member of that group: the respondents living in that particular neighbourhood, residential area. Such comparisons between groups are subject to exposure misclassification.

Finally, it appears that health outcomes of people living in proximity tend on average to be more alike than those form other areas. This may also be the case in noise studies investigating the effects on health and well-being (Pattenden, 2001).

4.4 Transferability/generalizability

Health impact assessments usually apply exposure-effect estimates derived from a study in one population to estimate impacts in another. Such assessments assume that the exposure-effect estimates are transferable. The validity of this assumption implicitly requires that the two populations be similar with regard to factors that influence the magnitude of the exposure-effect estimate, such as structure of the morbidity, basic health status, or noise type (Krzyzanowski et al., 2002).

For annoyance and sleep disturbance, the generalizability of the derived exposure-effect curves to different countries and different areas has not been well established. What makes it complicated is that not only personal but also situational problems play a role: it is not unlikely that there are substantial differences in terms of susceptibility to noise. There are reasons to believe that the annoyance responses of people in different countries might be different from the established curves because of differences in cultural expectations about the acceptability of transportation noise exposure, differences in climate and the adequacy of housing sound insulation techniques (Staatsen et al., 2004). Until now, it was not possible to quantify this. The same is valid for sleep disturbance: individuals differ from one another both in terms of their biological responses to night-time noise and in terms of the effects on their health and well-being. Much depends on the extent to which a variety of inherent and acquired personal factors interact with environmental factors (HCN, 2004). Other factors that may produce bias in terms of transferability to other populations are differences in daily pattern of activity, climatic conditions, housing, and different importance of confounding factors that might not have been properly controlled for in the epidemiological studies. But also differences in flight patterns and the composition of the aircraft- and road traffic fleet between the countries can be of importance (Van Kempen et al., 2003).

5 Conclusions and recommendations

This evaluation reveals that the following exposure-response relations are suitable for health impact assessment purposes at this stage. These are:
- the relation for the association between road traffic noise exposure and high annoyance derived by Miedema and Oudshoorn (2001);
- the relation for the association between road traffic noise exposure and high sleep disturbance derived by Miedema et al. (2003); and
- the relation for the association between road traffic noise exposure and the incidence of myocardial infarction (ICD-9: 410) derived by Babisch (2006) or Van Kempen and Houthuijs (2008).

Table 4: Recommended exposure-effect relations for the effect of road traffic noise exposure.

End point	Applicable range	Formula	Reference
High annoyance	L_{den}[*] 45 – 75 dB(A)[§]	%HA = 9.868×10^{-4} $(L_{den} - 42)^3$ – 1.436×10^{-2} $(L_{den} - 42)^2$ + 0.5118 $(L_{den} - 42)$	Miedema et al. 2001
High sleep disturbance	L_{night}[† ‡§] 45 – 65 dB(A)	%HSD = - $1.05 \times L_{night}$ + $0.01486 \times L_{night}^2$	Miedema et al., 2003
Myocardial infarction	$L_{Aeq\ 16hr} \geq 60$ dB(A)[§]	See table 3 of paragraph 3.3	Babisch, 2006
	$L_{Aeq\ 16hr}$[§]	$RR_{5dB(A)}$ = 1.06 (1.01 – 1.11)	Van Kempen & Houthuijs, 2008

[*]L_{den}: The Day-evening-night level is the equivalent sound level over 24 hours, increasing the sound levels in the evening (19-23 hours) with 5 dB(A) and those during the night (23-07 hours) with 10 dB(A).

[†]L_{night}: the equivalent sound level over night-time (11 pm to 7 am).

‡ these are outdoor noise exposure levels of the most exposed façade.

§ these are outdoor noise exposure levels.

Because the responses regarding annoyance and sleep disturbance of people in different countries might be different due to differences in cultural expectations about the acceptability of transportation noise exposure, differences in the adequacy of housing sound insulation techniques, the use of the annoyance and sleep disturbance curves for local situations should be applied with great care.

At the moment two risk estimates for the association between road traffic noise and myocardial infarction (ICD-9: 410) are available and could be indicatively used for health impact assessment estimations (Van Kempen & Houthuijs, 2008; Babisch 2006). It is not possible to indicate which is the best, since the threshold of no-effect to be used and the shape of the relation are still under debate. In order to get a feeling how these uncertainties might affect the estimates, we recommend that they are applied both.

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