Estimating Dose-Response Relationships between Noise Exposure and Human Health Impacts in the UK

TECHNICAL REPORT

Bernard F Berry
Director Berry Environmental Ltd - BEL

Ian H Flindell
Ian Flindell Associates

DISCLAIMER
This report presents conclusions based on the best available information at the time. Neither Berry Environmental Ltd, nor any of its associates can accept liability for any actions taken as a result of the information given in this report.
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1. INTRODUCTION - AIMS

1.1 Background

There is growing evidence of a number of adverse health outcomes which are caused by noise pollution. At present, there is no agreed methodology for assessing or valuing these impacts to inform policy decisions in the UK. To address this gap, the Interdepartmental Group on Costs and Benefits Noise subject group (IGCB (N)) is looking to develop and agree such a methodology. The work described in this Report will form the first part of this process by looking to estimate a quantifiable link between noise exposure and a number of adverse health impacts.

Currently, health effects from various pollutants are controlled primarily through the use of limit values and with regard to noise, this principle can be found in the Control of Noise at Work Regulations. Other advice can be found in World Health Organisation guideline values, but for noise, some of these tend to focus on the level of exposure below which there is no adverse effect expected. Consequently, the health effects of noise are not fully taken into account in the appraisal of policy. One way to improve the situation would be to explore whether it is possible to define robust dose-response functions to translate noise exposure into health end points.

This research aims to address this gap in the methodology and ultimately enable IGCB (N) to develop a framework which could be used for valuing the health impacts of noise in the UK. As such, there are four key aims of the research:

- Identify the potential adverse health impacts and review the current state of evidence for each of the impacts.
- Where a robust evidence base exists, to develop robust dose-response functions for the impacts of noise and health which could be applied to policy appraisal in the UK;
- Identify emerging adverse health impacts that should be kept under review; and
- Identify any structural challenges to developing a robust dose-response function

Berry Environmental Ltd, in association with Dr Ian Flindell of Ian Flindell Associates, were commissioned by Defra, on behalf of the IGCB (N), to undertake the project. Dr Rokho Kim of the World Health Organisation ECEH acted as a Special Adviser to the project. Nicole Porter provided the section on Dose-Response Relationships for Noise induced Sleep Disturbance, and made other contributions concerning the criteria. John Bates provided statistical advice and Graham Loomes provided the Economist input.

To achieve these aims this research undertook a two stage literature review of the existing evidence on the links between noise and health.

**Phase one** - undertook a review of the links between exposure to noise and a comprehensive list of health outcomes. This stage included links to annoyance, mental health, cardiovascular and physiological impacts (including ischemic heart disease and hypertension), night time effects (including on sleep patterns, awakenings, sleep quality, and performance the next day) performance by school children and hearing impairment. The results of this review were then used to focus a more detailed review of specific links to key health outcomes.

**Phase two** – then undertook a detailed focused analysis on the key health outcomes identified for further research, namely cardiovascular impacts, hypertension and sleep disturbances. For each of these areas a comprehensive review of the existing literature was undertaken to identify if and which existing links between noise and health might be used to inform policy decisions. This work was supplemented with visits to a number of international experts on the links between noise and health.
It was decided at the Project Inception Meeting that an Interim Report was needed on Phase 1 of the project which would set out “the initial findings for each health effect” and also assist the process of defining further stages of the project, in particular to help decide which effect[s], and associated dose-response relationships, would be the subject of more detailed study, in Phase 2 of the project.

The Interim Report was produced in time for a meeting with Defra officials and the project Steering Group on October 28 2008. On the basis of that meeting, Phase 2 of the project then proceeded.

This Technical Report should be read in conjunction with the associated Project Report which provides a summary of the main features and outcomes of the project.

- Section 1 provides a summary of the key concepts and ideas which underpin the work in this research.
- Section 2 of this Technical Report summarises the key outcomes of Phase 1 of the project. Thus Section 2.1 briefly reviews current evidence on the various health effects, based mainly on previous published and unpublished reviews. It also looks at existing dose-response functions [Section 2.1.3].
  - Section 2.1 thus identifies the “general criteria” to evaluate the existing evidence on, such as;
    - “quality and depth of evidence”
    - the status of existing dose-response relationships
    - “What noise sources does evidence exist for? “
  - Section 2.2 looks at current evidence and dose-response etc in the light of “additional criteria” which are relevant to the kinds of application which Defra have in mind. An overall “Matrix” is proposed to summarise the information.
  - Section 2.3 provides Interim conclusions and recommendations for Phase 2 of the project.
- Section 3 of the report documents the work done in Phase 2 of the project.
  - Thus Section 3.1 provides a summary of the crucial review by Babisch from 2006.
  - Section 3.2 summarises more recent studies on cardiovascular effects, including input from a Statistical Adviser
  - Section 3.3 documents discussions with other experts at RIVM and UBA Berlin
  - Section 3.4 gives a review of dose-response functions for sleep disturbance
  - Section 3.5 briefly reviews other Health effects, and dose-response functions, where available.
  - Section 3.6 provides a survey/review of Valuation Methodologies in other countries
  - Section 3.7 gives the views of a senior economist on the dose-response approach.
- Section 4 provides a general discussion of criteria and implications for a valuation methodology
- Section 5 gives an outline of the steps which would be followed in using the Babisch dose-response relationship for cardiovascular effects in an overall methodology for valuation.
- Section 6 gives Overall Conclusions and Recommendations, including requirements for research and further work which have been noted during the course of the work.
1.2 Noise and Health – Basic concepts

1.2.1 General
There are some basic underlying concepts and ideas which underpin research on Noise and Health, which need to be outlined and borne in mind for the present project. The purpose of this section is to introduce and outline these underlying concepts, as a basis for understanding later sections of this Technical Report and to assist later discussions on future directions etc.

1.2.2 Noise and Health – “models”.
Noise has the potential to affect health in a variety of ways; some of the effects can be defined as “auditory” and occur as a direct impact of the noise on the auditory hearing mechanism.

There are also a wide range of non-auditory health effects that may be associated with exposure to environmental noise, although the pathways, strength of association, and possible causal mechanisms pathways for these are not fully understood.

Examples of non-auditory health effects, sometimes referred to as “endpoints” or “outcomes”, which have been linked to environmental noise, include:

- Annoyance;
- Mental Health effects;
- Cardiovascular and physiological effects;
- Night time effects, sleep disturbance;
- Cognitive effects of noise on children;

Various researchers and authors of the many previous reviews of the subject have made use of a number of conceptual “models”, in order to;

- try to simplify and describe the complexities of the subject, and
- guide the process of formulating hypotheses for designing future research,

Some of these models deal with a single health effect, others with the “overall picture”.

Annoyance
One such model or “representation” is shown below and illustrates the various underlying relationships between noise and reported annoyance showing both direct and indirect routes from stimulus [noise] to effect. It also indicates some of the “moderating factors” which can be “personal, attitudinal etc”, as well as what we might call the “consequences” – behavioural modifications and public action etc.
Figure 1. Noise annoyance in a “community” setting [from Nelson, 1987 [1]]

Sleep
Another “single health effect model” illustrating the complex links between “night time noise” and the various “components” of the effects of noise on sleep i.e.

- **Acute response** – awakening
- **Reduction in sleep duration**
- **Sleep fragmentation**
- **Next day effects**
- **Chronic (long term effects)**

was described by Porter, Kershaw and Ollerhead in 2000, [2]

Figure 2. From CAA ERCD Report 9964 [2000]
Rijksinstitut voor Volksgezondheid en Milieu (RIVM) general model
The following more general such model was originally proposed by the Health Council of the Netherlands and is taken from the 2005 RIVM Report [3].

Figure 3 Conceptual model – RIVM 2005

Thus, as we move from left to right in the above model, the external environment – noise exposure, is “processed” by the “organism” [centre], and manifests itself in the various categories of effects/outcomes/endpoints on the right.

To quote the RIVM report;

“Long term noise exposure is associated with a number of effects on health and well-being. These include community responses such as annoyance, sleep disturbance, disturbance of daily activities and performance, and physiological effects such as hearing loss, hypertension and ischemic heart disease (Berglund et al., 1999). Although there is much discussion about how noise can affect human health, it is hypothesised that stress plays an important role.\ldots\ldots\ldots The model assumes that health status is determined by a combination of endogenous and exogenous factors such as the physical and social environment and life style. Noise exposure is only one of these exogenous factors. This process may be modified by personal characteristics such as attitude and coping style. Noise exposure induces disturbance of sleep and daily activities, annoyance and stress, which may lead to all sorts of intermediate responses, such as hypertension. In turn, these may affect the risk of cardiovascular disease or psychiatric disorders.”

RIVM 2005

Babisch general model – and more on the stress hypothesis
Another such “model”, proposed by Babisch [4], who describes it as a “reaction schema”, which attempts to show the potential causal pathways through which noise can affect health, is shown in Figure 4 below.
In this case as one moves down the diagram from the top – **Noise Exposure** – through the various possible pathways, to the lower parts of the diagram the “**clinical importance**” of the health effects, or what Babisch describes as the “**disease states**” increases.

Babisch himself summarised the “model” as follows;

> “It simplifies the cause-effect chain i.e.: sound - annoyance (noise) -physiological arousal (stress indicators) - (biological) risk factors - disease - and mortality (the latter is not explicitly considered in the graph). The mechanism works ‘directly’ through synaptic nervous interactions and ‘indirectly’ through the emotional and the cognitive perception of the sound. It should be noted that the ‘direct’ pathway is relevant even at low sound levels particularly during sleep, when the organism is at its nadir of arousal. The objective noise exposure (sound level) and the subjective noise exposure (annoyance) may serve independently as exposure variables in the statistical analyses of the relationship between noise and health endpoints.”
Babisch describes this fundamental “Stress hypothesis” more fully, in more “medical” terms as follows [4, page 10]

“Noise is an unspecific stressor that arouses the autonomous nervous system and the endocrine system. The generalised psycho-physiological concept given by Henry and Stephens can be applied directly to noise-induced stress reaction (Henry 1992). The stress-mechanism as such is genetically determined. It may be modified by experience and environmental factors. Its biological function is to prepare the organism to cope with a demanding stressor. Any arousal of the sympathetic and endocrine system is associated with changes in physiological functions and the metabolism of the organism, including blood pressure, cardiac output, blood lipids (cholesterol, triglycerides, free fatty acids, phosphatides), carbohydrates (glucose), electrolytes (magnesium, calcium), blood clotting factors (thrombocyte aggregation, blood viscosity), leukocyte count and others (Cohen et al. 1995; Friedman and Rosenman 1975; Lundberg 1999). In the long term functional changes and dysregulation due to changes of physiological set points may occur, thus increasing the risk of manifest diseases. Since many of the mentioned factors are known to be classical cardiovascular risk factors, the hypothesis has emerged that chronic noise exposure increases the risk of hypertension, arteriosclerosis and ischaemic heart disease.”

1.2.3 Severity of health effects - Effects and adverse effects.

An important concept for the present project is that of the severity of the effects, for example the issue of whether Annoyance is “real health effect”.

Babisch, in a paper in 2002 [5] summarised the situation as follows;

**Adverse health effect**

The severity of the health outcome, it’s prevalence in the general population, the frequency of exposure considered relevant for health, and the magnitude of effect are important issues in risk impact assessment. The term “adverse” is essential in this context of environmental standard setting. Risk management should ensure that “adverse” health effects cannot occur. Decisions on whether or not any effect is adverse, requires expert judgement. The World Health Organization defines an “adverse effect” as follows [WHO, 1994]:

“Change in morphology, physiology, growth, development or life span of an organism, which results in impairment of the functional capacity to compensate for additional stress, or increase in susceptibility to the harmful effect of other environmental influences.”

It is obvious that the relevance of a noise effect increases with increasing severity and the high prevalence of the considered health outcome Ischemic heart diseases are one of the major causes of premature death in modern societies [Doll R., 1992; WHO Regional Office Europe,1999]. For this reason cardiovascular disorders including hypertension and myocardial infarction have been in the primary focus of epidemiological noise research.”

Babisch then uses the following Figure to illustrate the concept.
He then notes:

The term “internal exposure” at the bottom of the triangle of the Figure is not relevant for noise. In contradiction to such environmental factors like lead, cadmium or benzene, noise is not an exogenous factor that accumulates in the organism. One cannot measure “noise” in the organism, only its effects. However, “internal exposure” may be substituted with “annoyance” here as a “soft” outcome. Next in the triangle comes “physiological changes of unknown significance” followed by “pathological changes”, “morbidity” and “mortality” or “life span”. Effects regarding the top three outcomes of the triangle may be attributed “adverse” according to the WHO criteria. The fact that an organism responds to noise does not have to be per se “adverse”. In noise research, we are looking at endogeneous response variables that are physiological components.

1.2.4 Causality

Causality, in the context of health effects, implies that the effects are a direct consequence of, and are directly related to the noise exposure. The cause, i.e. the exposure, must be prior to, or simultaneous with the effects.

In the 2005 RIVM Report [3] the authors provide a very useful summary:

Evaluation of exposure-effect-relationships is only one of the aspects that can be used to answer questions regarding causality (‘is there any other way of explaining the set of facts before us; is there any other answer equally or more likely than cause and effect’). Next to exposure-effect-relationships, the evidence on the strength of the association, its temporality, biological plausibility, coherence, consistency are also important.
for causality and thus for the assessment of the validity of epidemiological studies for purposes of health impact assessment. In order to get a better feeling of the other causality criteria, we evaluated the causality of the relationships by looking at the underlying studies that assess the impact of noise exposure on the different effects. We looked at the design used (e.g. cross-sectional studies, ecological studies), the characterisation and metric of exposure, the operationalisation of the outcome, the populations under study, alternative explanations for the observed associations in the studies (chance, bias and confounding). As part of this we also looked at the biologic plausibility. How does the exposure-effect relationship relate to what is known about the biological mechanism?

RIVM Report 2005

Babisch [4] provides a similar comment in his 2006 Review.

“Causality in epidemiology can never be completely proven. It is a gradual term of which evidence is increasing with increasing number of facts. However, the magnitude of effect, presence of dose-response relationship, consistency with other studies in different populations and with different methodology, and coherence (biological plausibility) are commonly accepted arguments for a causal relationship.”

[references omitted]

1.2.5 Dose-response relationships, statistical uncertainty.
The ultimate aim of this project is, in effect, to “recommend” a dose-relationship or relationships. It is therefore useful, in this section on “concepts” etc, to consider the “generic form” of such a relationship - see Figure 6 below.

Figure 6. Generic dose-response curve.

Typically, as the dose [exposure] increases from the very lowest levels, we do not see a specific “threshold of effect” but initially the effect increases slowly. Then there might be a range of dose/exposure where a more linear relationship is in evidence.
Finally it is often the case, that as the dose reaches the higher levels, the effect shows a kind of “saturation” as it approaches the maximum.

As we move from this idealised generic form to more “real –life” situation, we need to take account of the issue of “statistical uncertainty” in the dose-response relationship.

a. “individual studies”
For example, the following – Figure 7 - taken from Dr John Ollerhead’s Proof of Evidence for the Terminal 5 Public Inquiry [6] shows the mean value, and 95% confidence intervals of the “effect” – in this case the “Percentage of residents Very Much annoyed” - at each survey site in 3 UK studies of annoyance from Aircraft noise.

![Figure 5.2](image_url)  
**Figure 5.2** Percentage of respondents ‘very much annoyed’ by aircraft noise as a function of 16hr Leq (After Ollerhead, T5 public inquiry DOT/2011, Figure 6.3)

![Figure 7](image_url)  
**Figure 7. Annoyance studies – UK airports**
A “best–fit” curve, through these data points, has been the basis for assessment of Annoyance effects at UK airports for many years.

Another “individual study” example is provided by the RANCH project – Road traffic And Aircraft noise exposure and Children’s’ cognition and Health” [7]. Figure 8 below shows the mean value and 95% confidence intervals for the Reading Comprehension scores, at each of the study sites, plotted against the noise exposure in L_{Aeq} at each site.
Some observers have commented that, because of the “uncertainty” in the results [effect] at each value of noise exposure [dose], differences in effect are only significant for large differences in noise exposure.

b. Combining studies – meta-analyses etc
When we move on from individual research studies and look at a typical “meta-analysis”, where the results of many individual studies are combined, the situation of course becomes more complex. Figure 9 below is taken from the work of Miedema [8] and formed the basis of the EU Position Paper on Exposure-response relationships for transportation noise. [9]

It shows the results for 20 surveys of Annoyance due to aircraft noise, conducted in various countries, in the form of mean values of the effect – in this case – “Percentage Highly Annoyed %HA” plotted against the dose/exposure in terms of the metric Ldn.
Using a complex statistical model, which need not be discussed in detail here, results of the kind shown above, including those from similar collections of surveys on Road Traffic Noise and Railway noise, were combined to generate polynomial functions and related curves, together with estimated uncertainties in the form of 95% confidence intervals about the "mean curves". See Miedema and Oudshoorn Reference 10. These curves are shown below – the central curve in each case being the "mean curve", with the upper and lower curves indicating the uncertainty about the mean curve.

Figure 9. From Miedema, JASA 1998
c. Uncertainty in Noise exposure.

Traditionally attention has been focussed on the Uncertainty in the estimates of “health effect”. One important issue which is often overlooked in considering Uncertainty is that of uncertainty in the noise exposure values associated with the individual studies used in such meta-analyses as that outlined above, as well as uncertainties in the process of combining studies which have used different metrics to quantify the physical exposure. The importance of this issue, and the way in which uncertainty in noise exposure can influence the outcome of analyses of dose-effect relationships has been explained by Berry and Flindell [11] and by Fields [12].
2. PHASE 1 – INITIAL REVIEW
Phase 1 of the project looked at “the initial findings for each health effect” to assist the process of defining further stages of the project. In particular Phase 1 helped decide which effect[s], and associated dose-response relationships, would be the subject of a more detailed study in Phase 2 of the project. An Interim Report was prepared and submitted in time for a meeting on October 28. The following parts of Section 2 of this Final Report summarise the key messages of that Interim Report. It should be noted that a more in-depth assessment is provided in Phase 2 of the project, and the report should therefore be read in its entirety to give the overall picture.

2.1 Review of current evidence and availability of dose-response relationships.

This part of the Interim Report looked at the topic in the light of the “general criteria” that were agreed, which were:
- “quality and depth of evidence”,
- the current “status” or “availability” of dose-response relationships,
- “What noise sources does evidence exist for?” – road traffic, aircraft, railways, industry.

In the next Section, Section 2.2, we consider current evidence and dose-response etc in the light of “additional criteria” which are relevant to the particular kinds of “application” which Defra have in mind.

2.1.1 General background – previous reviews
Over the intervening 10 years since the last authoritative UK review published in 1998 [13] a number of important reviews have been published to update the state of knowledge. Some of these newer reviews deal with **ALL** of the health effects/endpoints, some are **specific to one of the effects, e.g. Cardiovascular**.

The newer reviews include the following documents.


Health Canada 2001
*Noise from Civilian Aircraft in the Vicinity of Airports – Implications for Human Health. I. Noise, Stress and Cardiovascular Disease.* [17]


Other previous reviews which are relevant are as follows;


and the 1999 WHO Community Noise Guidelines [21]

The 1998 NPL Review [13] rated “strength of evidence” as judged by previous reviews in terms of the “standard categories” proposed for the general assessment of epidemiological evidence, by the International Agency of the Research on Cancer (IARC) as;


See Table 1. Below

<table>
<thead>
<tr>
<th>Table 1: IARC criteria for strength of evidence</th>
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<tbody>
<tr>
<td>‘Sufficient’: a relationship has been observed between noise exposure and a specific health effect, chance, bias, and confounding factors can be ruled out with reasonable confidence;</td>
</tr>
<tr>
<td>‘Limited’: an association has been observed between noise exposure and a specific health effect, chance, bias, and confounding factors cannot be ruled out with reasonable confidence;</td>
</tr>
<tr>
<td>‘Inadequate’: the available studies are of insufficient quality, lack the consistency or statistical power to permit a conclusion regarding the presence of absence of a causal relationship;</td>
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<td>‘Lacking’: several adequate studies are mutually consistent in not showing a positive association between exposure and health effect.</td>
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More recently, the regular conference of the International Commission on the Biological Effects of Noise ICBEN, held in the USA in late July 2008, involved nearly 150 scientific papers on new primary studies, as well as “5-year update reviews”, in each of the main “categories”, of noise effect.

These 2008 ICBEN reviews, which can be downloaded from [www.icben.org] include;

<table>
<thead>
<tr>
<th>Author</th>
<th>Review</th>
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<tr>
<td>Mariola Sliwinska-Kowalska</td>
<td>Noise-induced hearing loss in humans – 5 year update</td>
</tr>
<tr>
<td>Hugh Davies, Irene van Kamp</td>
<td>Environmental noise and cardiovascular disease: Five year review and future directions</td>
</tr>
<tr>
<td>Charlotte Clark</td>
<td>The influence of noise on performance and behavior – 5 year update</td>
</tr>
<tr>
<td>Kenneth I. Hume</td>
<td>Sleep disturbance due to noise: Research over the last and next five years</td>
</tr>
<tr>
<td>Truls Gjestland</td>
<td>Research on community response to noise - in the last five years</td>
</tr>
<tr>
<td>Irene van Kamp, Hugh Davies</td>
<td>Environmental noise and mental health: Five year review and future directions</td>
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2.1.2 Summary of reviews
It was decided to study, analyse, extract and “distil” the key messages from the most relevant of these previous and “ongoing” reviews, and to put this information into a set of Tables to provide a broad “overview” for the Interim Report on Phase 1. This provides a summary of all of the previous reviews in terms of the IARC criteria for evidence.

In addition, key relevant parts of the text and Figures of the reviews, on which this Table is based are given in Annex 1 of this Report, to allow convenient access and reference.

For completeness, where possible, and where they are not available online, copies of these key “source documents” were supplied on CDROM to Defra and the Steering Group so that the original source material could be retained. This also provided a valuable resource for later stages of the project, and for future related projects.

This Table 2 is in two parts, covering the periods from 1997-1999/2000 and 2001-2008
It also provides a general, if rather simplified, indication of “What noise sources does evidence exist for?”
### Table 2 – part1

#### REVIEWS of EVIDENCE etc 1997-1999

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<td>Inconclusive</td>
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<td>Inconclusive/Sufficient/ Inconclusive</td>
<td>sufficient</td>
<td>Weak Association</td>
<td></td>
</tr>
<tr>
<td>IHD</td>
<td>sufficient / Sufficient</td>
<td>sufficient</td>
<td>Weak Association</td>
<td></td>
</tr>
<tr>
<td>Biochemical</td>
<td>x</td>
<td>limited</td>
<td>inconclusive</td>
<td></td>
</tr>
<tr>
<td>Immune</td>
<td>x</td>
<td>limited</td>
<td>inconclusive</td>
<td></td>
</tr>
<tr>
<td>Night-time Effects:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep Pattern Awakening</td>
<td>x Sufficient</td>
<td>Sufficient</td>
<td>Sufficient</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Subjective Sleep Quality Mood Next Day</td>
<td>x Sufficient</td>
<td>Sufficient</td>
<td>Sufficient</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Performance next Day</td>
<td>x Inconclusive</td>
<td>Inconclusive</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Immune System</td>
<td>x</td>
<td>Limited, inconclusive</td>
<td>limited</td>
<td>inconclusive</td>
</tr>
<tr>
<td>Hormones</td>
<td>x</td>
<td>Limited</td>
<td>limited</td>
<td>inconclusive</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>x</td>
<td>Limited</td>
<td>limited</td>
<td>inconclusive</td>
</tr>
<tr>
<td>Performance by School Children</td>
<td>Sufficient</td>
<td>Sufficient</td>
<td>Sufficient</td>
<td>Strong enough to warrant further study</td>
</tr>
<tr>
<td>Hearing</td>
<td>Sufficient, sufficient</td>
<td>Not reviewed. “Only in very exceptional cases will environmental noise” exposure induce hearing loss..</td>
<td>SUFFICIENT</td>
<td></td>
</tr>
</tbody>
</table>

**NOISE SOURCES >>**

| ALL          | ALL | AIRPORTS/AIRCRAFT | ALL |

### Table 2 - part 2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annoyance</strong></td>
<td>Not reviewed</td>
<td>Sufficient</td>
<td>Not reviewed</td>
<td>Not reviewed</td>
</tr>
<tr>
<td><strong>Psychiatric Disorders/Mental health</strong></td>
<td>Not reviewed</td>
<td>Not reviewed</td>
<td>Not reviewed</td>
<td>noise is probably not associated with serious psychological ill-health but may affect quality of life and well-being.</td>
</tr>
<tr>
<td><strong>Cardiovascular and Physiological:</strong></td>
<td>Evidence – no significant risk of chronic stress and/or cardiovascular disease from long term exposure to outdoor daily aircraft noise levels above 65 dBA.</td>
<td>Sufficient</td>
<td>IHD [Myocardial Infarction] the evidence of an association between community noise and IHD risk has increased since a previous review.[2000]</td>
<td>consistent evidence for a small but significant effect of transport noise on hypertension and coronary heart disease</td>
</tr>
<tr>
<td>-Ischaemic Heart Disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Hypertension</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Night-time Effects:</strong></td>
<td>Not reviewed</td>
<td>sufficient</td>
<td>Not reviewed</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Sleep Pattern Awakening Subjective Sleep Quality Mood Next Day Performance next Day Immune System Hormones Heart Rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Performance by School Children</strong></td>
<td>Not reviewed</td>
<td>Although the results of this study are robust, the interpretation at population level is difficult.</td>
<td>Not reviewed</td>
<td>Evidence is strong.</td>
</tr>
<tr>
<td>Hearing impairment /TINNITUS</td>
<td>Not reviewed</td>
<td>Not reviewed.</td>
<td>Not reviewed</td>
<td>Not reviewed</td>
</tr>
<tr>
<td><strong>NOISE SOURCES &gt;&gt;</strong></td>
<td>AIRCRAFT</td>
<td>ALL</td>
<td>ROAD TRAFFIC NOISE AIRCRAFT NOISE</td>
<td>ALL</td>
</tr>
</tbody>
</table>
Some GENERAL observations can be made on existing evidence for each effect in turn.

**ANNOYANCE**
Looking across all of the above reviews, and from direct knowledge of the many other newer studies, it is clear that evidence for the Annoyance effect can be regarded as “sufficient”.

The debate continues however on whether it is, in itself, a “real health effect”, or can simply be regarded as a “link in the chain” and part of the complex process by which noise can be a stressor and lead to more adverse effects.

**MENTAL HEALTH**
The summary in the recent Clark and Stansfeld 2007 review [reference 15] is appropriate; “noise is probably not associated with serious psychological ill-health but may affect quality of life and well-being.” However, it should be noted that Clark and Stansfeld’s tentative conclusion may not apply to some individual cases where noise can be a contributory factor to a significant degree of mental distress, particularly where there are disputes between neighbours over noise.

**CARDIOVASCULAR DISEASE**
The key point here is that the “quality and depth of evidence” has increased considerably over recent years. The 2008 review by Berry for the GLA, explains this topic in more detail, and the topic is dealt with later in section 3.


Although strongly based on the 2006 Babisch review, the Berry review also takes into account more recent studies, as well as recent Working Group papers by Babisch and van Kamp for the ongoing WHO Working Group “Evidence review on Aircraft noise and Health”.

The review for the GLA noted that for Road Traffic Noise, an “exposure-response relationship” has been proposed, between noise level and risk of Myocardial infarction MI, and in fact this has been applied by Wolfgang Babisch to estimate the potential number of people at risk of cardiovascular effects from road traffic noise in Germany.

Furthermore it notes that for Aircraft noise, there have as yet been an insufficient number of high quality studies on which to base such an exposure-response relationship but it has been argued by Wolfgang Babisch, that the relationship developed for Road Traffic Noise should be used as an “approximation”.

These relationships are then used by Berry in calculations of numbers of people potentially affected by cardiovascular disease due to noise in the GLA area.

**SLEEP**
It is important here to separate out the various “sub-effects” which are normally considered under the heading of night-time effects.

In general there is sufficient evidence that night-time noise can cause physiological arousal, transient changes in sleep stage, both physiological and behavioural awakening, and next day changes in subjectively reported sleep quality and mood, but there is no statistically conclusive evidence that night-time noise causes significant decrements in performance. Furthermore there is still considerable uncertainty about chronic long-term health effects related to sleep disturbance.

**COGNITIVE IMPAIRMENT**
Evidence was regarded as “sufficient” back in 1997, and so in terms of strength of evidence, the situation is unchanged. There has however been a significant increase in the quantity of
evidence. On the other hand, it could be argued that the scale of effects which have been detected is relatively small in comparison to many other “life-events”, e.g. bereavement, which appear to have much stronger effects on cognitive development.

HEARING
Evidence is sufficient, but see the later discussion in Section 2.2 on “Relevance at environmental noise sound levels”.

2.1.3 Dose-response relationships
A number of national and international organisations have been, and are still involved in the process, of interpreting the outcome of research on the effects of noise on health, in terms of “dose-effect, or exposure-effect relationships”. These organisations include the Dutch National Institute for Public Health RIVM, the Federal Environment Agency UBA in Germany and “multinational” organisations such as WHO. Our own UK Department of Health is close to finalising a new review Report by an Ad-Hoc Advisory Group on Noise and Health, which also addresses this issue.

As with the reviews of evidence on noise and health effects discussed above in Section 2.1, there are a number of key publications which, at various times, have addressed the problem of providing the best available estimates of the relationship between environmental noise and health effects, including dose-response relationships. Some of the review reports outlined in Section 2.1.1 above, have included material specifically on this dose-response issue, and have included “guidance” or “recommendations”.

Some of these are only specific to a particular health effect such as Cardiovascular, [Berry 2008, Babisch 2006] - Some are more general [RIVM 2005].

Review reports involving dose-response relationships, since the year 2000 include;


World Health Organisation [WHO] Working Group – Aircraft noise and health - Chapter on Cardiovascular effects, by Babisch and van Kamp [22]

H Miedema.2007 Exposure-response relationships for environmental noise.[23]


Note – this is referred to as WGHSEA 2005 in later Table 3.


As with the review of evidence in Section 2.1.2 above, it was not felt to be feasible to provide a full “narrative discussion” of all of these earlier “Dose-response” reports with their various recommendations.

Nor was it possible at this stage to assess the “impact” on existing dose-response relationships of any of the newer “primary studies” or re-analyses of specific previous studies or those papers presented at the ICBEN 2008 Conference. It was planned to do this in the phase 2, when the scope of the study was more closely defined.

However, as with the evidence review of section 2.1.2, an attempt was been made to “distil” the key information from the most relevant of these publications into an “overview” Table – Table 3.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychiatric/Mental health</td>
<td>X X X X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Cardiovascular and Physiological:

<table>
<thead>
<tr>
<th>Health effects</th>
<th>Assumed same as AMI</th>
<th>OR for AMI–Lday curve from meta-analysis of 5 Road Traffic studies</th>
<th>AMI-Lden based on Babisch 2006 [2dBA correction]</th>
<th>As Babisch 2006 [but limited evidence]</th>
<th>Babisch 2006 curve Commonly used</th>
</tr>
</thead>
</table>

### Night-time Effects:

<table>
<thead>
<tr>
<th>Health effects</th>
<th>Notes WG HSEA 2004 curve but does not use</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Awakening</td>
<td>X</td>
<td>X</td>
<td>Awakenings and Lnight, See WHO NNGL detail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self rated sleep disturbance</td>
<td>Miedema 2003 and 2004. %HSD-Lnight Based on 8</td>
<td>%HSD-Lnight As EU 2004</td>
<td>%HSD-Lnight</td>
<td>Miedema 2003</td>
<td></td>
</tr>
</tbody>
</table>

**SUMMARY-most commonly used**

- Most use Miedema 2001/EC Position Paper 2002
- Babisch 2006 curve Commonly used
- %HSD-Lnight As EU 2004
- Miedema 2003
<table>
<thead>
<tr>
<th>studies</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Performance by School Children</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>RANCH</td>
</tr>
<tr>
<td>Hearing impairment /TINNITUS</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>If included use ISO1999</td>
</tr>
</tbody>
</table>

**KEY:**
- X = no Dose-response.
- OR = Odds Ratio.
- %HA = % Highly Annoyed, %HSD = % Highly Sleep Disturbed

* NOTE - NNGL Report has detailed explanation of complex relationships involving Lnight etc - discussed on page 105 of NNGL
2.1.4 Some general summary comments on existing dose-response relationships.
The following comments relate to the preliminary assessment during Phase 1. Later parts of this report provide a greater level of detail on some aspects.

ANNOYANCE
The “Miedema / EU curves”, published in various forms, are widely referred to in the above overview and other reviews. However, the topic has become more complex of late, with the UK ANASE study – Attitudes to Noise from Aviation Sources in England [28], which produced dose-response relationships for annoyance which differed considerable from those derived from earlier studies at UK airports. Even before that, in the 2005 RIVM report, the authors noted differences between the Miedema 2001 / EU Position paper curves, and later surveys [2005] at Schiphol in the Netherlands.

See below from the RIVM 2005 report [reference 3].

Figure 4. Comparison between the exposure-effect relationships derived in a survey around Schiphol Airport (Breugelmans et al., 2005) and the Miedema-curve (2001) for aircraft noise annoyance.

Figure 11. Comparison of dose-response curves - from RIVM 2005 Report

CARDIOVASCULAR DISEASE
The “Babisch dose-response relationship”, between risk of Acute Myocardial Infarction AMI [Heart attack] and L_{day}, is the only current “candidate”. See below. The modification of the Babisch relationship in 2007 by Miedema [23] to use L_{den} should also be noted, in any application of that relationship.
However it should be noted that the above curve is based on a meta-analysis of 5 research studies which only involved Road traffic noise. Babisch has proposed that the relationship developed for Road Traffic Noise should be used as an “approximation” when assessing risks from aircraft noise. Thus, in his 2006 Review he states:

Regarding aircraft noise - and particularly the ongoing debate on night-flight restrictions in the vicinity of busy airports - no other alternative exists at present than to take the MI risk curves derived from road traffic noise studies as an approximation for aircraft noise. Since aircraft noise acts on all sides of a building, i.e. different to road traffic noise, the suspicion exists that the effects induced by aircraft noise could be greater than those induced by road traffic (Babisch 2004a; Ortscheid and Wende 2000). This may be due to the lack of evasive possibilities within the home, and the greater annoyance reactions to aircraft noise, which are usually expressed in social surveys (Miedema and Vos 1998).”

Such an assumption was also used by Berry in his study for GLA, although it is only an assumption, not fully supported by actual evidence.


SLEEP
There is ample existing material on dose-response relationships, but one needs to be clear of the distinction between the effects of Awakening and those of Self-reported sleep disturbance. This issue is dealt with fully later in Section 3.4.

Thus the relationships for Percentage Highly sleep Disturbed %HSD, proposed in the 2004 EC Position Paper on dose-effect relationships for night time noise [25] typically take the form;
For road traffic: ¹
%HSD = 20.8 - 1.05Lnight + 0.01486(Lnight)²

**COGNITIVE IMPAIRMENT**
The relationship between “Reading age deficit” and $L_{Aeq}$, from the RANCH study [7] has been used in several “real-life” UK cases of Health Impact Assessment, for example in connection with the proposal by BAA for a second runway at Stansted Airport. [29]

**HEARING IMPAIRMENT**

### 2.1.5 General Summary on Evidence and Dose-response relationships

The following summary can be made, based on the above overviews.

<table>
<thead>
<tr>
<th>EFFECT</th>
<th>EVIDENCE</th>
<th>DOSE-RESPONSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annoyance</td>
<td>Sufficient</td>
<td>YES – various, but see above</td>
</tr>
<tr>
<td>Mental Health</td>
<td>Insufficient</td>
<td>NO</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>Sufficient [increased]</td>
<td>YES – AMI</td>
</tr>
<tr>
<td>Sleep. Awakenings/ Self reported sleep disturbance</td>
<td>Sufficient</td>
<td>YES - %HSD etc</td>
</tr>
<tr>
<td>Cognitive</td>
<td>Sufficient</td>
<td>YES – RANCH or hypothetical curve, see above summary Re WHO</td>
</tr>
<tr>
<td>Hearing</td>
<td>Sufficient</td>
<td>YES, ISO 1999</td>
</tr>
</tbody>
</table>

1 This function is explained in more detail in chapter 3.4
2.2 Status of current knowledge on health effects/impacts and dose-response relationships in the light of “additional criteria”

2.2.1 General
In the discussions at the Inception meeting on September 18 2008, and in subsequent discussions by phone/email etc, a number of “criteria” emerged, against which the health effects/endpoints and available dose-response relationships might be assessed, in order to:

a. guide decisions on which of the several health effects/endpoints would be studied in more detail in the next phases of the project and,
b. guide the planning of future stages of the project in general.

We have already outlined and discussed some of the general criteria in earlier sections, in particular, the “Quality and depth” of the evidence on each health effect(endpoint), existing of dose-response relationships, and the question of “for which noise sources do evidence and dose-response relationships exist?”

The “additional criteria” discussed in this Section are more relevant to the particular kind of “applications” of the results and, by implication, the kind of dose-response functions - which IGCB (N) might be able to use.

In this section we:
1. List and explain the criteria, and briefly assess and summarise current knowledge against each of the criteria.
2. Summarise the overall “picture”, for ALL criteria in a “Matrix”.

2.2.2 Additional Assessment Criteria

List of criteria
A. Criteria related to Health effects/endpoints

- Direct effects, as opposed to indirect effects
- Nature of the effect/endpoint.
- Relevance at typical environmental noise levels

B. Criteria related to Dose-effect relationships

- How “generally applicable” is the Dose-effect relationship
- Use of noise-exposure metrics in the dose-response relationships, which relate to EU policy / END.

Discussion/assessment
A. Criteria related to Health effect/endpoints

Criterion 1 - Direct effects, as opposed to indirect effects.
As set out in Chapter 1 there are various “pathways” which have been postulated, in various “models “, to try to explain the complex links/associations between the external noise exposure or dose, and the effects on human health. One way of simplifying this situation is to classify health effects as;
**Direct** - where there is what some researchers term “ Biological plausibility” of a Causal link or association, or, **Indirect** – where there are other intervening or mediating factors, and the effect in question is only part of a complex pathway.

The earlier Babisch representation - see below - uses the term Direct and Indirect PATHWAYS.

---

**Babisch 2006**

---

**Summary**

From the Babisch “model” it might be considered that the only really **direct effect** is Hearing Impairment, with cardiovascular effects being considered as involving BOTH direct and indirect pathways. In our view, based on wider consideration, only Hearing Impairment and Cardiovascular effects can be considered as **direct** – as summarised below.

<table>
<thead>
<tr>
<th>EFFECT</th>
<th>DIRECT</th>
<th>INDIRECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annoyance</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Mental Health</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Sleep</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Cognitive</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>√</td>
<td></td>
</tr>
</tbody>
</table>

---

**Criterion 2 - Nature of the effect/endpoint.**

This criterion was also expressed as;

“is the effect objectively measureable, tangible–or relies on perception
Summary
Effects/endpoints which can be classed as Objective are;

Cardiovascular effects, where objective medical data such as GP diagnosis, medication use and hospital admission information is used in the epidemiological research,

Sleep - Awakenings, when directly measured in home and laboratory studies

and Hearing impairment – quantified by audiometric tests.

<table>
<thead>
<tr>
<th>EFFECT</th>
<th>OBJECTIVE</th>
<th>PERCEPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annoyance</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Mental Health</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>√ GP diagnosis, Medication, hospital data etc</td>
<td></td>
</tr>
<tr>
<td>Sleep</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Awakenings</td>
<td>√ Lab and other experimental studies</td>
<td></td>
</tr>
<tr>
<td>Self reported SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>√ Measured HL</td>
<td></td>
</tr>
</tbody>
</table>

Criterion 3 - Relevance at typical environmental noise sound levels.
It is generally accepted that not all health effects of noise manifest themselves across the whole range of possible noise levels. Environmental noise sound levels, expressed as L_{Aeq}, and L_{day}, can range from about 20 dBA to 75 dBA.

In simple terms, there can be various “thresholds”, which vary depending which effect is being considered, below which no effects are in evidence. For example, from the work of Babisch and others, we know that Cardiovascular effects from environmental sources are not found below 60-65 L_{Aeq}.

The 1999 report on the Health Impact of Large Airports, by the Health Council of the Netherlands stated;

“It is universally accepted that exposure to high noise levels can induce hearing impairment, however at the levels of environmental noise exposure around civilian airports hearing loss is unlikely”

The 2005 RIVM report stated;

“Although there is ‘sufficient’ evidence for an effect on hearing, it is unlikely that hearing damage occurs at typical levels of community noise exposure. Therefore the effects on hearing were not dealt with in this report.”
To summarise the relevance of various effects at typical environmental noise levels;

<table>
<thead>
<tr>
<th>EFFECT</th>
<th>RELEVANT</th>
<th>NOT RELEVANT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annoyance</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Mental Health</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Sleep Awakenings</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Self reported SD</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Cognitive</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Hearing impairment</td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>

Criterion 4 - Is there a clear approach to being able to “value the endpoint” ?
In the case of Annoyance, since it is already included in various existing methodologies, e.g. IGCB and WebTag, there would have to be a positive answer. Similarly one can envisage an approach to valuing the impact of cardiovascular disease in terms of health costs etc. Similar consideration would apply to Hearing Impairment.

To summarise;

<table>
<thead>
<tr>
<th>EFFECT</th>
<th>Approach to valuation?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YES</td>
</tr>
<tr>
<td>Annoyance</td>
<td>√</td>
</tr>
<tr>
<td>Mental Health</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>√</td>
</tr>
<tr>
<td>Sleep Awakenings</td>
<td></td>
</tr>
<tr>
<td>Self reported SD</td>
<td></td>
</tr>
<tr>
<td>Cognitive</td>
<td></td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>√</td>
</tr>
</tbody>
</table>
B. Criteria related to dose-effect relationships

Criterion 5 - How “generally applicable” is the dose-effect relationship?

This relates to the fact that some known dose-response relationships might in effect, by their very nature, have only a limited area of application. One good example would be the dose-response relationship for Effects on Reading Age arising from the RANCH project which would only be applicable for Schools, and strictly speaking, only for the limited age-group, 9-10 year olds, included in the RANCH study.

Taking each of the effects, and dose-relationship[s] which were discussed in Section 2.1 in turn, we can summarise as follows;

<table>
<thead>
<tr>
<th>EFFECT</th>
<th>Generally applicable</th>
<th>Limited to certain situations/locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annoyance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mental Health</td>
<td>Not applicable no D-R</td>
<td>Not applicable no D-R</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Sleep</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Awakenings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self reported SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive</td>
<td>Schools and other educational situations, only strictly for 9-10 year olds etc</td>
<td></td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>√</td>
<td>Not at lower noise levels</td>
</tr>
</tbody>
</table>

Criterion 6 - Use of noise-exposure metrics in the dose-response relationships which relate to EU policy, END.

Looking back to the summary on dose-response in section 2.1 it can be said in respect of the known existing dose-response relationships that all of them, apart from the possible exception of that applicable to Hearing impairment, are either already expressed in terms of relevant metrics, or could be, given relatively straightforward “conversions”. Normally the “uncertainty” in applying such conversions is much less than the existing statistical uncertainty in the dose-response relationship.

However, with a view to the possible development of other dose-response relationships in the next phases, we should comment that constraining relationships to use existing metrics is non-scientific - but could nevertheless be justified on other pragmatic criteria. It might be that progress could only be made by abandoning the criterion of scientific robustness where this has proved unhelpful. We must however also recognise and accept the resulting uncertainty.
2.2.3 Overall assessment against additional criteria
To provide another “overview” on this topic, we can condense the above 5 individual tables into one. See Table 4 below.
### TABLE 4 – assessment of dose-response relationships against various criteria

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EFFECT/ Dose-response</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>YES</td>
</tr>
<tr>
<td>Annoyance</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>4</td>
</tr>
<tr>
<td>Mental Health</td>
<td>N</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>6</td>
</tr>
<tr>
<td>Sleep-Awakenings</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>4</td>
</tr>
<tr>
<td>Sleep - Self reported Sleep Disturbance</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>3</td>
</tr>
<tr>
<td>Cognitive effects</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>3</td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>3</td>
</tr>
</tbody>
</table>
The final column of the above Table indicates the number of these additional criteria which each Effect/dose-response meets, and so provides a crude indicator of “performance” against these criteria.

We could thus summarise as follows:

Assuming that **ONLY Direct effects** are included in further studies, or are the **PRIMARY focus** – see Column 1 in the above Matrix – this implies focusing on Cardiovascular and Hearing Impairment.

**Cardiovascular effects** are - Direct, Objective, Relevant at typical environmental noise sound levels, have a valuation approach, are generally applicable, and involve metrics which relate to the END. [See Babisch 2006 report which uses L\text{day} etc.]

The only other **Direct effect** - **Hearing impairment** – is judged to be not relevant at typical environmental noise sound levels.

### 2.3 Conclusions and recommendations in phase 1 and decisions for next phase

- The “quality and depth” of evidence for each of the various health effects, has been outlined, based on existing published reviews and other documents, A summary has been provided in the form of Table 2.
- A review of existing dose-response relationships has been given, and summarised in Table 3.
- The health effects and the existing dose-response relationships have been considered in the light of various “additional criteria”, and a further overview, Table 4 is provided. These additional criteria are:
  - Direct effects, as opposed to indirect effects.
  - Nature of the effect/endpoint.
  - Relevance at typical environmental noise levels.
  - How “generally applicable” is the Dose-effect relationship?
  - Use of metrics in the dose-response relationship which link to EU policy.

It was hoped that, by presenting this complex “multi-dimensional” information, on a broad range of health effects/impacts, in this way, it would guide discussion, and inform decisions on the next phases of the project, **as well as providing a fully documented “audit trail” to justify such decisions.**

Taking ALL of the above into account, a number of strategies were possible for the next phase of the project.

For example, if we accept that **only direct health effects** - **Cardiovascular effects and Hearing Impairment** - be considered further, but that, in terms of the criterion of “relevance at typical environmental noise sound levels”, Hearing Impairment should be excluded from further consideration, then the Primary focus of further work should be on **Cardiovascular effects.**

If however the criteria were “relaxed” slightly, there might be some basis for including some aspects of Sleep disturbance i.e. objectively recorded awakenings. However it
was not clear at this stage what approach might be used to the “valuation” of such sleep effects.

Thus from the review work we have became aware of the extent to which there are highly relevant publications concerning ALL of the health effects currently being considered which need to be reviewed and assessed. These include, for example, the newer papers published at the ICBEN 2008 conference. Bearing this in mind, by focussing only on Cardiovascular effects as a subject for more detailed study, the task of taking into account the newer material, which has not been the subject of systematic review, will be reduced to manageable proportions.

Given also the need to study statistical aspects more thoroughly, with the help of our statistical adviser, it would also be advantageous to have a more limited scope. Similar considerations apply to the issue of input from the senior economist.

The key decisions arising were as follows;

- The decision was made to pursue cardiovascular disease and sleep awakenings in more detail in the second stage of the research. This was agreed based upon the evidence presented in the interim report and the criteria which had been discussed previously:

- Cardiovascular disease was agreed because it has a measurable and objective endpoint, with a developed valuation methodology and it is the health effect with the greatest body of supporting evidence to digest.

- Sleep awakenings was agreed because it is an objective endpoint and there is a reasonable body of supporting evidence. There are important policy implications as night noise is frequently raised as an issue and is likely to become more important to policy makers in coming years. Although there is not an established valuation methodology, this assessment could still provide a valuable tool for carrying out quantitative assessments and future work may be carried out to value awakenings.

- it was re-iterated that the final report should still present indicative dose response functions for all of the health impacts considered. Although those health effects outside cardiovascular disease and awakenings will not be fully assessed, indicative dose response function will enable future work to look at the relative order of magnitude of different health effects and inform future priorities. These should be presented with any specific caveats and a comment that they have not been fully assessed.
3. DETAILED REVIEWS

This part of the Technical Report documents the outcomes of work on various parallel “strands” of the project, designed to meet the overall objectives. Therefore it has the following structure:

- Section 3.1 provides a summary of the crucial review by Babisch (2006).
- Section 3.2 summarises of more recent studies on cardiovascular effects, including input from a Statistical Adviser.
- Section 3.3 documents discussions with other experts at RIVM and UBA Berlin.
- Section 3.4 gives a review of dose-response functions for sleep disturbance.
- Section 3.5 briefly reviews other Health effects, and dose-response functions, where available.
- Section 3.6 provides a survey/review of Valuation Methodologies on other countries.
- Section 3.7 gives the views of a senior economist on the dose-response approach.

3.1 Summary of the Babisch review of 2006

Because of the decision to focus on cardiovascular effects in Phase 2 of the project, it is useful to summarise the Babisch review of 2006.

To date, this publication represents the most comprehensive analytical review and Babisch himself first summarises earlier reviews, including those by the Netherlands Health Council, [31], Porter et al [13], van Kempen [3] etc., and his own previous review [32].

He notes that the status of evidence of the relationship between transportation noise and cardiovascular health as concluded in the earlier literature could be summarized as follows:

- **Biochemical effects: limited evidence**
- **Hypertension: inadequate or limited or sufficient evidence**
- **Ischaemic heart disease: limited or sufficient evidence**

Babisch went on to identify 61 epidemiological studies which had investigated the relationship between transportation noise and cardiovascular health endpoints, assessed either objectively or by self-reports. Overall, 20 of these studies refer to commercial aircraft noise, and 32 to road traffic noise. Thirty-seven of those 61 studies had assessed the prevalence or incidence of manifest diseases, including hypertension and ischemic heart diseases (angina pectoris, myocardial infarction, ECG abnormalities).

The various studies and their characteristics are listed in a number of tables, covering each of the health outcomes or endpoints, e.g. Blood Pressure, Hypertension, Ischemic Heart Disease, Drug use etc.

The tables set out risk estimates [Odds Ratio etc] derived from the individual studies, in 5 dB (A) categories of the average A-weighted sound pressure level during the day.

For this present review report, it is convenient to concentrate on the overall picture, firstly for: **Hypertension**, and then for **Ischemic Heart Disease IHD [including Myocardial infarction MI]**.
Aircraft noise studies and Road Traffic studies are dealt with separately.

**Hypertension**

18 studies were considered and analysed by Babisch in this 2006 review. Of these 5 involved Aircraft Noise, but the majority related to road traffic noise. With regard to the association between community noise and hypertension, the picture was said to be “heterogeneous”.

**Hypertension - Aircraft noise**

With respect to aircraft noise and hypertension, studies consistently show higher risks in higher exposed areas. The evidence was said to have improved since the previous review in 2000 [reference 32], but no common risk curve or exposure response relationship could be derived.

The relative risks found in four studies showing significant positive associations ranging between 1.4 and 2.1 for subjects who live in high exposed areas, with approximate daytime average sound pressure level in the range of 60-70 dB (A) or more. Swedish studies found a relative risk of 1.6 at even lower levels (>55 dB (A)).

Babisch went on to show the results of three peer-reviewed studies [references 33, 34, 35] that had been evaluated in another recent review for a 2005 Conference [36].

See Figure 13 below.

He commented, “...regarding aircraft noise the available information is still limited. Although positive associations have been shown in studies, no common risk curve can be derived.”

[see HYENA paper December 2007 discussed later]

![Figure 1: Association between aircraft noise level and the prevalence of hypertension.

Figure 13 – from Babisch 2005 [reference 36].]
**Hypertension - Road Traffic noise**

With respect to road traffic noise, the picture was said to remain unclear. Newer studies tend to suggest a higher risk of hypertension in subjects exposed to higher road traffic noise sound levels, showing relative risks between 1.5 and 3.0. However, the earlier studies cannot be neglected in the overall judgment process. Across all studies no consistent pattern of the relationship between environmental noise and prevalence of hypertension can be seen.

**Ischemic Heart Disease IHD**

Ischemic Heart Disease includes;

- Clinical symptoms of angina pectoris, myocardial infarction (MI), ECG abnormalities as defined by WHO criteria, self-reported questionnaires regarding doctor-diagnosed heart attack – as reported in cross-sectional studies, and,
- Clinical myocardial infarction as obtained from hospital records, ECG measurements or clinical interviews – from longitudinal studies.

The majority of studies of IHD in this 2006 Babisch review refer to road traffic noise, but he discusses a few Aircraft noise studies as follows.

**IHD - Aircraft Noise**

Babisch notes;

**Netherlands**

“The calculation of standardized morbidity ratios (SMR) in an ecological study of 62 municipalities around Amsterdam’s airport Schiphol, using aggregated data from the health registries recording the hospital admissions due to cardiovascular diseases (myocardial infarction, hypertension, ischaemic heart diseases and cerebrovascular diseases), did not show any apparent clustering in areas close to the airport.

A lot of information came from the Amsterdam aircraft noise studies that were carried out in the 1980’s. Significant prevalence ratios of between 1.0 and 1.9 were calculated depending on which IHD endpoint was looked at. The subjects lived in areas exposed to more than approx. 60 dB (A) outdoor noise level. The response rate of the “community cardiovascular survey” was approx. 42%. The “general practice survey” can be considered as an ecological study on contact rates for specific diseases, with general practitioners. Aggregated data of populations, not individuals, were analysed statistically. Multiple consultations were not excluded. The study provides information on the prevalence of cardiovascular disease, which must be viewed as a combination of hypertension and ischaemic heart diseases.

In the study carried out in the four Dutch cities of Groningen, Twenthe, Leeuwarden and Amsterdam, regarding aircraft traffic noise, prevalence ratios greater than 1.0 were found for noise level categories greater than approx. 55 dB (A). However, no dose response relationship was found across the categories, and the relative risk for subjects in the highest noise category was 0.9. The response rate of approx. 43% refers to the subjects that participated in a previous psychological questionnaire survey (response rate there approx. 32%). Subjects that were identified in the questionnaire screening phase as being treated for hypertension were not included in the statistical analysis. This could be a matter of concern regarding selection bias in the study because high blood pressure is a major risk factor for IHD.

**Germany**

The Spandau Health Survey (response rate > 80%), which was primarily conducted with respect to road traffic noise, was also analysed with respect to aircraft noise [#58]. In
the noise zone (according to the German Aircraft noise Act) of Leq(4) > 62 dB(A) the period prevalence (during the past 2 years) with respect to self-reported doctor’s diagnosed angina pectoris was 1.6, and was not significant. However, with respect to the prevalence of myocardial infarction, a lower risk was found in the exposed group (relative risk = 0.4). The preliminary results of an ongoing study around the Stockholm airport showed the opposite [#60]: a higher risk of MI (relative risk = 2.6) in subjects exposed to FBM > 55 dB (A) (the Swedish calculation method of aircraft noise) and a lower risk for angina pectoris (relative risk = 0.9).”

IHD - Road traffic
With regard to IHD, the evidence of an association between community noise and IHD risk was said to have increased since the previous Babisch review in 2000 [Reference 32]. There was said to be not much indication of a higher IHD risk for subjects who live in areas with a daytime average sound pressure level of less than 60 dB (A) across the studies. For higher noise categories, a higher IHD risk was relatively consistently found amongst the studies. Statistical significance was rarely achieved. Some studies permit what Babisch describes as “reflections” on exposure-effect relationships. These studies suggest an increase in IHD risk for noise levels above 65-70 dB (A), the relative risks ranging from 1.1 to 1.5 when the higher exposure categories were grouped together.

By way of overall summary of the “evidence”, Babish notes, on page 48 of the UBA report [4]:

“The evidence for a causal relationship between community or transportation noise and cardiovascular risk, appears to have increased throughout the recent years due to new studies that complement the data base. Compared with earlier conclusions [the 2000 review] this refers, in particular, to hypertension and ischaemic heart diseases.”

Thus

- **Biochemical effects: limited evidence**
- **Hypertension: inadequate or limited or sufficient evidence**
- **Ischaemic heart disease: limited or sufficient evidence**

…now becomes....

- **Biochemical effects: limited evidence**
- **Hypertension: inadequate or limited or sufficient evidence**
- **Ischaemic heart disease: limited or sufficient evidence**

Babisch meta-analysis and exposure-effect relationships

In Section 6 of the 2006 UBA report, on the basis of stringent criteria, five analytic and two descriptive studies were selected that could be used for deriving the relationship between road traffic noise and the risk of myocardial infarction MI. It was found that for sound levels above 60 LAeq, the risk of myocardial infarction increases monotonically.

Based on this, a common risk curve is derived for the relationship between road traffic noise – expressed in L_{day} - and the incidence of myocardial infarction (MI).

Below 60 LAeq for the road traffic sound level during the day (L_{day}; 6-22 hr), no notifiable increase in MI risk could be detected. For sound levels greater than 60 LAeq,
the MI risk increases continuously, with relative risks (odds ratios) ranging from 1.1 to 1.5, with reference to ≤60 LAeq.

A polynomial function was fitted to the pooled data points, and Linear, quadratic and cubic terms were considered. The results and the coefficients of the equations are shown in Figure 14 below [Babisch Figures 9 and 10], for the non-weighted and weighted (number of subjects) data.

**Figure 9.** Polynomial curve fit (non-weighted data points) of the association between road traffic noise and incidence of myocardial infarction.

\[
\text{OR} = 2.210993 - 0.001052*\text{Noise} + 0.00001194531316444*\text{Noise}^2; \quad R^2 = 0.98
\]

(no significant linear term in the equation)

**Figure 10.** Polynomial curve fit (N-weighted data points) of the association between road traffic noise and incidence of myocardial infarction.

\[
\text{OR} = 1.620657 - 0.000613*\text{Noise} + 0.000007356734623455*\text{Noise}^2; \quad R^2 = 0.96
\]

(no significant linear term in the equation)

**Figure 14 From Babisch 2006 – L_day and MI**
In Section 8, Conclusions, of his 2006 Report, Babisch notes;

“Aircraft noise has been less intensively studied in noise epidemiology. The studies focused on high blood pressure. Dose-response assessment was hardly considered. A large European study on the association between aircraft noise and road traffic noise, and blood pressure is currently being conducted (HYENA Jarup et al. 2003). Regarding aircraft noise - and particularly the ongoing debate on night-flight restrictions in the vicinity of busy airports - no other alternative exists at present than to take the MI risk curves derived from road traffic noise studies as an approximation for aircraft noise. Since aircraft noise acts on all sides of a building, i.e. different to road traffic noise, the suspicion exists that the effects induced by aircraft noise could be greater than those induced by road traffic (Babisch 2004a; Ortscheid and Wende 2000). This may be due to the lack of evasive possibilities within the home, and the greater annoyance reactions to aircraft noise, which are usually expressed in social surveys (Miedema and Vos 1998). More research is needed regarding the association between aircraft noise and cardiovascular endpoints.”

In relation to the Babisch work it should also be noted that it has now been published in peer-reviewed journal form, but with no major changes to the main aspects [reference 37].

3.2 Review of more recent studies on cardiovascular effects.

3.2.1 Introduction
This review mainly covers papers on cardiovascular effects, including hypertension and ischaemic heart disease, published since the Babisch report of 2006. The main focus in assessing the papers has been on whether they provide new material which could be used in developing dose-response functions. Some of the studies documented in these papers included the effects of air pollution as well as noise. The papers include some on the HYENA study, where the role of annoyance in cardiovascular effects has been discussed.

A newer “5 year-review paper”, from ICBEN 2008 is also included in this review.

Copies of these newer papers have been provided on CDROM to Defra as an update to the Database of Documents.

As noted in the Interim Report of October 28, since the publication of the extensive Babisch review of 2006, a number of newer papers have been published. These have been identified by various means, including systematic checks on the Proceedings of conferences since 2006, including Internoise 2007, Internoise 2008 which was only held in late October 2008, and ICBEN 2008, held in July 2008.

These papers are briefly summarised below. In reviewing the papers, the main focus has been on whether they provide new material which could be used in developing dose-response functions.

The review is structured into two main sections with papers on Road Traffic Noise and Aircraft Noise, although in a few cases, e.g. the RANCH project, studies involved more than one source.
3.2.2 Summary of papers

ROAD TRAFFIC NOISE

G. Bluhm, N Berglind, E Nordling, M Rosenlund
Road traffic noise and hypertension

Background: It has been suggested that noise exposure increases the risk of hypertension. Road traffic is the dominant source of community noise exposure.

Objective: To study the association between exposure to residential road traffic noise and hypertension in an urban municipality.

Methods: The study population comprised randomly selected subjects aged 19–80 years. A postal questionnaire provided information on individual characteristics, including diagnosis of hypertension. The response rate was 77%, resulting in a study population of 667 subjects. The outdoor equivalent traffic noise level (Leq 24 h) at the residence of each individual was determined using noise-dispersion models and manual noise assessments. The individual noise exposure was classified in units of 5 dB (A), from 45 dB (A) to 65 dB (A).

Results: The odds ratio (OR) for hypertension adjusted for age, smoking, occupational status and house type was 1.38 (95% confidence interval (CI) 1.06 to 1.80) per 5 dB (A) increase in noise exposure. The association seemed stronger among women (OR 1.71; 95% CI 1.17 to 2.50) and among those who had lived at the address for .10 years (OR 1.93; 95% CI 1.29 to 2.83).

Analyses of categorical exposure variables suggested an exposure–response relationship. See Table 3 from the paper – below. The Odds Ratio at the highest noise level category seems very high, with a very large confidence interval [1.27-9.43].

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Association between exposure to road traffic noise and hypertension (n = 608)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
</tr>
<tr>
<td>Continuous (per 5 dB(A) increase)</td>
<td>1</td>
</tr>
<tr>
<td>Category (dB(A))</td>
<td></td>
</tr>
<tr>
<td>≤45</td>
<td>115</td>
</tr>
<tr>
<td>45–50</td>
<td>105</td>
</tr>
<tr>
<td>50–55</td>
<td>281</td>
</tr>
<tr>
<td>&gt;55</td>
<td>107</td>
</tr>
</tbody>
</table>

Adjusted for age, type of residence, occupational status, smoking status and number of cigarettes.

The strongest association between exposure to traffic noise and hypertension was found among those with the least expected misclassification of true individual exposure,
as indicated by not having triple-glazed windows, living in an old house and having the bedroom window facing a street (OR 2.47; 95% CI 1.38 to 4.43).

**Conclusion:** The results suggest an association between exposure to residential road traffic noise and hypertension.

**COMMENT**
The "measure" of hypertension is self-reported - a fact which the authors themselves note as a possible bias - although it does refer to a history of specific diagnosis, rather than self-report of symptoms.

Overall the numbers of subjects with hypertension is small.

Because the numbers of subjects in the 3 highest noise exposure categories [55-60, 60-65 and >65] are small, they are combined into the category of >55. If any of the n=25 subjects in the categories of noise exposure >60, or >65 were those reporting hypertension [n=22], this would skew the apparent link to sound levels being reported as in the category >55.

Y. Kluizenaar, R. T. Gansevoort, P. E. de Jong and H M.E. Miedema. 2007 *Cardiovascular effects of road traffic noise with adjustment for air pollution.* Proceedings of Inter-noise 2007, Istanbul Paper 07-244 CDROM

Also published by the same authors as; *Hypertension and Road Traffic Noise Exposure Journal of Occupational Environmental Medicine.* 2007; 49:484–492

This study investigates cardiovascular effects of road traffic noise, and is one of the few such studies which attempts to account for air pollution. Noise and particulate matter (PM10) exposure was assessed for the City of Groningen, sample (N = 40 856), and a selection of subjects that next visited the outpatient clinic (the *Prevention of Renal and Vascular End-Stage Disease PREVEND* cohort; N = 8 592). Questionnaires and, for the cohort, measurements (e.g. systolic and diastolic blood pressure, BMI, cholesterol) provided cardiovascular endpoints, risk factors and confounders.

For individual exposure assessment detailed spatial data (e.g. traffic characteristics, buildings, screening objects) were used together with geographical information systems (GIS) and state-of-the-art modeling techniques.

Before adjustment for confounders, road traffic noise was associated with antihypertensive medication use in the City of Groningen sample (unadjusted OR = 1.31 per 10 dB increase Lden). It was noted that, after adjustment for confound [age, sex, smoking, family history of CVD, and Socioeconomic status] these odds ratios were smaller and non-significant.

Adjusted odds ratios were significant for the 45-55 year age group in the full model adjusted for PM10 (OR =1.19).

In the Conclusions/Discussion, the authors note, on this issue of the age factor,

"Relative risk estimates for subjects younger than 45 years were not significant."
This might be explained by a lack of power, as a result of low prevalence of hypertension at a younger age. Furthermore, some of the subjects in this age group might suffer from secondary hypertension. At an older age, hypertension is relatively common. It is not clear why the estimated relative risk is not significantly different in subjects older than 55 years, although the risk does seem to be elevated in the respondents between 45 and 55 years old. A possible explanation is that the influence of environmental exposure might become relatively less dominant compared with that of other risk factors, by an overall decrease in health status in the older population. Alternatively, it might be a true effect that subjects who are between 45 and 55 years old might be more sensitive to exposure to road traffic noise, compared with younger and older subjects. This would be consistent with studies on noise annoyance.

Adjusted odds ratios were significant for higher sound levels (Lden > 55 dB; OR= 1.21; with adjustment for PM10 OR = 1.31).

Subsequent email enquiries to the authors have established that this change in Odds Ratio, when the statistical model includes adjustment for PM10, is non-significant.

On this point about higher sound levels the authors note;

“We explored if noise effects were different at higher noise levels. After adjustment for confounders, a stronger association was found for subjects exposed to higher noise levels (Lden >55 dB) in the city of Groningen sample. In analogy, further analysis in the PREVEND cohort showed higher adjusted odds ratios when adjusted for PM10 at higher noise levels for hypertension, although this did not reach significance. A stronger reaction to higher noise exposure may be explained by a threshold for effects, or by a nonlinear exposure effect relationship. However, in further analysis, this could not be conclusively confirmed”

In the cohort the unadjusted odds ratio was 1.35 for hypertension. The adjusted odds ratio was again significant for the 45-55 yr age group

On air pollution it is worth noting the discussion put forward by the authors;

“The present results show that the effects of road traffic noise on hypertension do not wane when we adjust for air pollution; instead, they seem to become even more pronounced. These outcomes strongly suggest that the effects of noise on hypertension cannot be explained by an association between noise and air pollution, and air pollution being the true cause of the effects."

Later in the same Discussion they note;

“When generalizing the relative risk estimates for the population in the city of Groningen to other cities, some aspects need consideration. Results of this study have to be confirmed in different populations. Potentially relevant differences with other cities may include traffic composition, exposure, and population characteristics. Traffic composition in Groningen may be fairly representative for that in an average sized city. Groningen comprises a large variety of road types, including highways, large arterial roads, and a busy ring road. The population of Groningen is relatively homogenous. There is little ethnic variety. More than 95% of the population is white. There was a limited variation in exposure to air pollution (PM10) within the population of Groningen. This may be why no significant contribution to the relative risk for hypertension was found for exposure to air pollution. As far as there were variations in exposure to air pollution, these were accounted for in our most extended models.”
It should be noted however that correlation between physical exposure variable - road traffic noise Lden and air pollution PM10 - was not zero. At $r = 0.72$ it was possibly high enough to mean that the two separate effects could be not fully disentangled in this study.

**COMMENT** – This study, and any plans of RIVM for additional studies were discussed at the visit to RIVM on December 16.

A further paper from the RIVM team, dealing with air pollution and noise was presented at ICBEN 2008, but has been available so far only as Abstract as follows;

*The association of noise and air pollution from road traffic with cardiovascular mortality.*

**Abstract**

“Cardiovascular mortality has been associated with exposure to traffic-related noise and air pollution, but both exposures have previously been studied separately. We investigated associations between cardiovascular mortality and noise and air pollution together.

We used data from an ongoing cohort study on diet and cancer (NLCS, 120,852 subjects) with follow-up from 1987 to 1996. We evaluated cardiovascular causes of death. Exposure to road traffic noise was modelled with a 25 x 25 m resolution. Exposure to black smoke (BS) and traffic intensity on the nearest road were assessed at the home address. We conducted Cox proportional hazard analyses for the association between exposure and cardiovascular mortality.

Traffic intensity on the nearest road was associated with cardiovascular mortality, with highest relative risk for ischemic heart disease mortality. There was an excess of cardiovascular mortality in the highest noise category (> 65 dB Letmaal), which was concentrated in ischemic heart disease and especially heart failure mortality. Relative risk for background BS concentrations were elevated for cerebrovascular and heart failure mortality. After adjustment for BS concentrations and traffic intensity, effects of road traffic noise were reduced. The associations for background BS concentrations and traffic intensity were insensitive for the adjustment of traffic noise.”

Further enquiries to RIVM have resulted in our being sent a copy of the full paper [15 December 2008].
The joint association of air pollution and noise from road traffic with cardiovascular mortality in a cohort study
Rob Beelen, Gerard Hoek, Danny Houthuijs, Piet A. van den Brandt, Alexandra Goldbohm, Paul Fischer, Leo J. Schouten, Ben Armstrong, Bert Brunekreef

OEM Online First, published on November 18, 2008 as 10.1136/oem.2008.042358
http://oem.bmj.com/cgi/rapidpdf/oem.2008.042358v1

**ABSTRACT**

Objectives - The authors investigated associations between cardiovascular mortality and air pollution and noise together.
Methods - Data from an ongoing Dutch cohort study on diet and cancer (NLCS, 120,852 subjects; follow-up 1987-1996) were used. Cox proportional hazard analyses were conducted for the association between cardiovascular mortality and exposure to black smoke (BS), traffic intensity on the nearest road and road traffic noise at the home address.
Results - The correlations between traffic noise and background BS, and traffic intensity on the nearest road were moderate at: 0.24 and 0.30 respectively. Traffic intensity was associated with cardiovascular mortality, with highest relative risk (95% confidence interval) for ischemic heart disease (IHD) mortality: 1.11 (1.03 - 1.20) (increment 10,000 mvh/24h). Relative risks for BS concentrations were elevated for cerebrovascular (1.39 associations were insensitive to adjustment for traffic noise. There was an excess of cardiovascular mortality in the highest noise category (>65 dB(A)), with elevated risks for IHD (1.15 (0.86 - 1.53) and heart failure mortality (1.99 (1.05 - 3.79). After adjustment for BS and traffic intensity noise risks became unity for IHD mortality and slightly reduced for heart failure mortality.

Conclusions - Associations between BS concentrations and traffic intensity on the nearest road with specific cardiovascular causes of death were not explained by traffic noise in this study.

G Belojevic, B. Jakovljevic, V Stojanov, K. Paunovic, J Ilic
Urban road-traffic noise and blood pressure and heart rate in preschool children.
In print form as Environment International. 2008 34: 226-231

Night time noise exposure has very rarely been used in previous studies on the relationship between community noise and children's blood pressure, although children spend a larger part of their night time sleeping at home than adults. For this reason, the study focused on night time noise exposure at children's residences and daytime noise at kindergartens. The aim of this study was to investigate the effects of urban road-traffic noise on children's blood pressure and heart rate. A cross-sectional study was performed on 328 preschool children (174 boys and 154 girls) aged 3–7 years, who attended 10 public kindergartens in Belgrade. Equivalent noise levels (Leq) were measured during night in front of children's residences and during day in front of kindergartens. A residence was regarded noisy if Leq exceeded 45 dB (A) during night and quiet if the Leq was ≤45 dB (A).

Noisy and quiet kindergartens were those with daily Leq > 60 dB (A) and ≤60 dB (A), respectively. Children's blood pressure was measured with mercury sphygmomanometer. Heart rate was counted by radial artery palpitation for 1 min. The prevalence of children with hypertensive values of blood pressure was 3.96% (13 children, including 8 boys and 5 girls) with higher prevalence in children from noisy residences (5.70%), compared to children from quiet residences (1.48%). The difference was borderline significant (p=0.054). Systolic pressure was significantly higher (5mmHg on average) among children from noisy residences and kindergartens, compared to children from both quiet environments (p<0.01). Heart rate was significantly higher (2 beats/min on average) in children from noisy residences, compared to children from quiet residences (p<0.05). Multiple regression, after allowing for possible confounders, showed a significant correlation between noise exposure and children's systolic pressure (B=1.056; p=0.009).

Health effects and major co-determinants associated with rail and road noise exposure along transalpine traffic corridors.

P Lercher, B de Greve, D Botteldooren, L Dekoninck, D Oettl, U Uhrner, J Rüdisser
Proceedings of 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, Foxwoods, Connecticut USA.
This paper includes the main findings from the ALPNAP project - Monitoring and Minimisation of Traffic-Induced Noise and Air Pollution Along Major Alpine Transport Routes


This website includes a comprehensive 335 page report on the ALPNAP project

The study examined the relationship between noise exposure from road and rail traffic and a broad range of health outcomes.

Two geographical areas were investigated, in 3 sub-studies - the Unterinntal and the Wipptal regions of Austria - part of the most important access route for heavy goods traffic over the Brenner Pass which provides the most direct link for central and northern Europe’s traffic to southern Europe. The primary noise sources are motorway and rail traffic, but also include main roads.

All 3 studies were cross-sectional. In the Wipptal (BBT surveys) a phone (N=2,002) and a interview study (N=2,070) were carried out. A pooled sample was created (N=3,630) from both studies (omitting those who participated in both studies: N=442) to get more statistical power and better representation. In the Unterinntal (ALPNAP study) a nearly identical phone survey (N=1,643) was conducted. The participation at the individual level varied between studies (62, 80, 35 % respectively). The research phone study had the lowest participation.

**Noise exposure**

Indicators of day, evening, night exposure and Lden were calculated for each source - Motorway traffic, traffic on main roads and railway traffic. Eventually, total exposure from all or from specific source combinations at several points of the building facade of the participant's home was calculated. In the present analyses Lden of the individual sources at the most exposed façade was utilized.

Extensive air pollution modelling and measurement was conducted with Calculated NO2 and PM10 values for each of the participant's home being assigned by GIS.

The questionnaire covered socio-demographic data, housing, satisfaction with the environment, general noise annoyance, attitudes toward transportation, interference of activities, coping with noise, occupational exposures, lifestyles, dispositions such as noise and weather sensitivity, health status, selected illnesses and medications.

The phone interview took about 15-20 minutes. The longer questionnaire of the face to face interview required about 45-60 minutes.

Health information was based on doctor reported diagnoses and prescriptions. Reporting time was related to the last 12 months. Health status was assessed by a five grade Likert type question. In the analyses only three categories were used: very good, good and less than good (3+4+5 of the 5-point scale). Education was measured in 5 grades (basic, skilled labour, vocational school, A-level, University degree). The top two grades (University and A-level) were combined in the analyses.

**Results**

Of primary interest to our project are the results on diagnosis of hypertension, angina and myocardial infarction
The relation between overall sound exposure (all sources) and hypertension (Figure 5 of original paper) exhibits a mixed picture: The face to face study shows a linear trend (OR=1.28 (1.03-1.58) for 50 to 60 dBA) and reaches a plateau around 60 dBA. The phone study levels off strongly around 60 dBA (OR=1.43 (1.05-1.95) for 65 to 75 dBA) and the analysis for the main valley nearly reaches significance (OR=1.14 (0.98-1.31) for 60 to 70 dBA). The non-linear relation of hypertension medication (Figure 6) with rail noise is quite strong (OR=1.63 (1.12-2.36) for 60 to 70 dBA) while the face to face study shows no relation and the analysis for the inhabitants of the main valley is also not significant.

The same analysis conducted in the phone study by source (Figure 7 of original) reveals a significant relation only with railway and main road but not with motorway noise. Against a reference level of 55 dBA the relative risk (OR) increases to 1.84 (1.15-2.95) for rail and 1.83 (1.17-2.86) for main road at 70 dBA. In contrast to the previous results the combined endpoint angina pectoris/myocardial infarction is significantly associated in the phone study (OR 1.70 (1.16-2.47)(for 60 to 70 dBA) and the main valley analysis (OR=1.34(1.05-1.71) with motorway noise (Figure 8) – but not in the face to face study.
In order to evaluate the possible effect of air pollution, a model without and with adjustment for a specific noise indicator was evaluated. The curves show a small non-significant trend for an increase in poor health with higher level of particulate pollution when noise is not adjusted for (Figure 10 left). However, when an adjustment for overall noise exposure is made, the air pollution effect disappears completely (Figure 10 right). Hence, at higher noise levels, 65 versus 45 dBA, the proportion of persons with poor health is higher, completely independent of the level of air pollution.

**Figure 10:** Proportion with poor health status by education and mean annual PM10 concentration (left) and stratified by high versus low overall noise exposure (right). PM10 modeling by TU-Graz

In the Discussion section of the paper the authors note:

“Within the range of the observed levels air pollution in the studied areas did not make a significant contribution when noise exposure indicators were introduced in the adjusted models. All tests for interaction with noise failed also to reach significance. This is in line with the hitherto only peer reviewed study which has evaluated air pollution in addition to noise with respect to hypertension (de Kluizenaar et al. 2007). This observation is further strengthened by similar experience with other health endpoints (health status, depression, heart disease) in this study.”

**COMMENT** – Further study, and enquiries to the authors are required to enable a proper assessment of how these results, for example Figure 8 above, relate to those of Babisch and others. Thus the measure of “effect” used – proportion with diagnosed angina/myocardial infarction – would need to be expressed as relative risk. Also, no information is provided in the paper on confidence intervals.

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**AIRCRAFT NOISE**

I van Kamp, D Houthuijs, C van Wiechen, and O Breugelmans 2006

*Environmental noise and cardiovascular diseases: evidence from 10 year Schiphol research*  
Proceedings of Intenoise 2006. Paper No.: in07_132, 7 pages

The authors themselves summarise the scope and outcome of this paper as follows; “The monitoring programme around Schiphol Airport, aimed at describing changes in environmental quality and related health effects after opening of a new runway, included several measures for cardiovascular diseases. Before (2002) and after (2005) opening of the runway, information was collected by means of questionnaire surveys. Also two studies with data from medical registries were carried out. Results from the surveys show an inconsistent pattern in the association between aircraft noise and self reported high blood pressure and use of medication for hypertension. There were no indications from the 2005 survey that the change of aircraft noise level, in addition to the noise level itself, had an extra impact.
Medical registries data revealed that the dispensing of anti-hypertensive medication was related to air-traffic noise. There were no indications for an increase of hospital admissions for cardiovascular diseases in relation to aircraft noise. Based on these results and results from earlier studies around the airport, there is a growing evidence for an association between exposure to air traffic noise and the prevalence of high blood pressure around Schiphol Airport.”

Examining the paper in more detail we note that the medical data were based on analysis of routinely collected health data from two sources:
Ten year period data (1995-2004) on hospital admissions from the Dutch national medical registration;
Data about the dispensing of prescribed medication by public pharmacies over a five year period (2000-2004).

Registration data were analysed by means of so called ‘small area health statistics’. The level of analysis is post code area (5,700 inhabitants on average) as opposed to the individual level in the surveys. The incidence and prevalence of the indicators of cardiovascular disease for each postal code area were first standardized using population data stratified by age and sex.

Noise exposure was based on modelled yearly averaged Lden and Lnight levels for aircraft noise provided by the National Aerospace Laboratory (NLR) for an area of 55 by 71 km around the airport. The mean aircraft noise sound level at postcode level was used as exposure indicator.

After adjustment for potential confounding factors at the postal code level and taking into account spatial correlation, the health risk is mapped as standardized morbidity ratio in space and time. In this way, the (changing) spatial pattern around the airport can be visualized and a possible relation with environmental quality quantified.

In addition, surveys (postal questionnaires) of self-reported health were carried out among adults in one year before (2002) and two years (2005) after the opening of the new runway. Questions about health indicators as well as determinants (age, lifestyle, sex etc) were included.

Results of the questionnaire surveys showed that, between 2002 and 2005 no differences were found in the prevalence of self reported cardiovascular disease in the study area. Only self reported hypertension had increased, from 8.6% in 2001 to 9.9% in 2004, but it was noted that this trend is also found at a national level.

In 2005, a statistical significant effect of Lden was found on self reported hypertension. When the sound level increases by 3 dB (A) the odds ratio is 1.2. Also, people who report they are severely annoyed by aircraft noise report hypertension twice as often. In addition, the self reported use of medication for CVD is associated with Lden as well as Lnight although not statistically significant. These associations were not found in 2002.

Changes in Lden and Lnight between 2002 and 2005 did not result in significant changes, either in medication use, or self-reported hypertension

Results from medication registries showed an increase in the dispensing of anti-hypertensive drugs with an increase in aircraft noise sound level. Such an association was not found for hospital admissions. However, the prevalence of dispensing of medication for hypertension (13%) is much higher than the prevalence of hospital admissions for e.g. hypertension (0.2%). The authors suggest that a small effect of aircraft noise in the range of other risk factors for hypertension might not be detectable within the small group of hospital admissions.
Overall the findings in the monitoring programme were said to be consistent with previous estimates of about 1,500 extra persons with hypertension as a result of aircraft noise exposure, and that this could result in “a few additional cases of myocardial infarcts, strokes, and angina”.

**COMMENT**

This study in itself could not used to provide any new numerical information on exposure-response relationships, to add to existing knowledge.

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*Noise exposure and children's blood pressure and heart rate: The RANCH-project.*


http://oem.bmj.com/cgi/content/abstract/63/9/632

[Note – this paper also includes Road Traffic noise effects]

This paper initially comments on the fact that, because of the complexity of the link between blood pressure elevation and stress, and the preponderant influence of lifestyle and genetic predisposition, conclusions from earlier studies investigating the effects of noise exposure on children's blood pressure are limited and inconsistent.

Methodological problems emerging from these earlier studies are noted – including small differences in noise levels between the exposure groups, potential selection bias, a lack of control for socio-economic status factors, differences in insulation and parental history of high blood pressure.

It is also noted that most studies usually only focus on exposure at school when investigating the effects of noise exposure on children. It is questionable whether the health effects could be exclusively attributed to the noise exposure in school. The effect of night-time exposure has been hardly investigated in children.

It was against this background that, in order to investigate the possible association between noise exposure and children's blood pressure and heart rate, data were collected from children living around London Heathrow Airport and Schiphol Airport gathered in the framework of the EU-funded RANCH project.

Out of 118 primary schools available in the British study area, 30 were invited to participate and all but one agreed. In the Netherlands, out of 366 available schools in the selected areas, 77 schools were invited to participate, and 33 agreed. The parents or carers of 2,179 children were approached through the schools by letter and 2,012 children had permission to take part. In the Netherlands all the children who had permission to take part and who were available on the day of testing had their blood pressure measured (n = 730); in the United Kingdom every second participating child was selected from the class list for blood pressure measurement (n = 553). Noise exposure was assessed for each child by linking home and/or school addresses to modelled equivalent aircraft and road traffic noise levels. These predict the average outdoor noise exposure during a specified time interval. In both centres, aircraft noise levels (L\text{Aeq}, 7-23 hr, and L\text{Aeq}, 23-7hr) were obtained from nationally available noise contours for both the home and school situation.
In both centres, road traffic sound levels (LAeq, 7-23 hr) were obtained for the school situation. Road traffic sound levels (LAeq, 7-23 hr) for the home situation were only available for the Dutch sample.

Blood pressure measurements were taken in the afternoon in a quiet room in the school building using automatic blood pressure meters, according to a standard protocol.

Children were given a questionnaire to take home for their mother (preferably), or other carer to complete. The questionnaire provided information on potential confounding factors (e.g. socio-economic status, birth weight, country of birth and parental history of high blood pressure).

The effect of chronic aircraft noise on blood pressure differed somewhat between the samples: In the Dutch sample, chronic aircraft noise exposure at school was related to an increase in blood pressure. Statistically significant increases were estimated for systolic and diastolic blood pressure, respectively. In the British sample, aircraft noise exposure at school was related to small and statistically non-significant increases in blood pressure.

For the pooled data, after adjustment for socio-economic status, ethnicity, cuff-size, room temperature, birth weight, parental hypertension, and pre-maturity only Aircraft noise exposure at home was related to a statistically significant increase in blood pressure.

Chronic aircraft noise exposure during the night (LAeq, 23-7hr) at home was positively associated with systolic blood pressure only.

Due to the difference in exposure metrics and adjustment for confounders, comparison of the results of the RANCH study with other studies was difficult, and it was concluded that “for aircraft noise exposure no consistent findings can be seen”.

Negative associations were found between road traffic noise exposure and blood pressure, which could not be explained.

**COMMENT.**
The authors themselves note that it was not possible to derive an exposure-effect relationship between Noise exposure and children’s blood pressure.


**Summary of study method etc.**
This study investigated the influence of aircraft noise on the incidence of hypertension. A cohort of 2754 men, aged 45-66, in 4 municipalities around Stockholm Arlanda airport was followed between 1992–1994 and 2002–2004. The cohort was based on the Stockholm Diabetes Preventive Program; half of the study subjects had a family history of diabetes.
Residential aircraft noise exposure (expressed as time-weighted equal energy and maximal noise levels) was assessed by geographical information systems techniques among those living near the airport. Noise exposure categories in Lden were 50-55, 55-60, 60-65 and > 65 dB (A).
Incident cases of hypertension were identified by physical examinations, including blood pressure measurements, and questionnaires in which subjects reported treatment or diagnosis of hypertension and information on cardiovascular risk factors. Analyses were restricted to 2027 subjects who completed the follow-up examination, were not treated for hypertension, and had a blood pressure below 140/90 mm Hg at enrollment.

**Results:**
For subjects exposed to energy-averaged levels above 50 dB (A) the adjusted relative risk for hypertension was 1.19 (95% CI 1.03–1.37). Maximum aircraft noise levels presented similar results, with a relative risk of 1.20 (1.03–1.40) for those exposed above 70dB (A).

Stronger associations were suggested among older subjects, those with a normal glucose tolerance, nonsmokers, and subjects not annoyed by noise from other sources. **Conclusion:** These findings suggest that long-term aircraft noise exposure may increase the risk for hypertension.

See Figure 15 - Relative risk for hypertension among men in Stockholm according to different levels of energy-averaged aircraft noise exposure (bars indicating 95% CI), adjusted for age and BMI [Body Mass Index]

**Figure 15** - From C. Eriksson, M. Rosenlund, G. Pershagen, A. Hilding, C-G Östenson, and G Bluhm. 2007

**COMMENT** – there appears to be no variation of Relative Risk as a function of noise level. Also the confidence intervals, in all cases include an OR of 1.0

**NOTE** – a further paper has been published more recently on this same study as;

Aircraft noise and hypertension among men - a study around Arlanda airport.
G Bluhm, C Eriksson, G Pershagen, A Hilding, C-G Östenson
Proceedings of Internoise 2008, paper 0532

**Abstract**
"The number of people living in the vicinity of large airports is steadily increasing and complaints due to aircraft noise are rising. An association between aircraft noise exposure and hypertension has been suggested but there are no longitudinal studies on this relation. Our aim was to investigate the cumulative incidence of hypertension in relation to aircraft noise. A cohort of 2754 men in four municipalities around Stockholm Arlanda airport was followed between 1992-1994 and 2002-2004. Residential aircraft
noise exposure expressed as time weighted equal energy and maximal noise levels was assessed by geographical information systems techniques among those living near the airport. Incident cases of hypertension were identified by physical examinations, including blood pressure measurements, and questionnaires in which subjects reported treatment or diagnosis of hypertension and provided information on cardiovascular risk factors. The adjusted relative risk (RR) for hypertension was 1.19 (95% CI=1.03-1.37) for subjects exposed to energy-averaged levels above 50 dB(A). Maximum aircraft noise levels presented similar results with a RR of 1.20 (1.03-1.40) for those exposed above 70 dB(A). It is expected that the results will strengthen the scientific basis for prevention of adverse health effects related to aircraft noise. Better knowledge about health effects due to noise will be useful in community planning. Conclusions: These findings suggest that long-term aircraft noise exposure may increase the risk for hypertension."

It is interesting to note the following in the Discussion section of this more recent paper;

“Our results suggest that aircraft noise exposure is associated with an increased risk of developing hypertension. Our findings indicate an effect primarily among older subjects. This might be due to a prolonged period of exposure, since most elderly subjects in the cohort have lived more than 10 years at their present address, or it may be that older people are more sensitive to noise. The association between aircraft noise and hypertension also appeared primarily among those with normal glucose tolerance, never-smokers, and those not annoyed by noise from other sources. There are several possible reasons for these results. For example normal glucose tolerance could indicate a lower burden of other cardiovascular risk factors, which were not controlled for. A stronger effect in never-smokers might be due to uncontrolled or residual confounding among the smokers. “

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Greiser, E., C. Greiser, and K. Jannsen, 2007

This paper reports an epidemiological study to investigate primarily the possible impact of night-time air traffic noise on prescription of antihypertensive and cardiovascular drugs in a general population residing in the vicinity of the airport, taking into account, among other potential confounders, social class.

The study region comprised the city of Cologne and two counties adjacent to the Cologne-Bonn Airport. Based on all individual flights from or to Cologne-Bonn Airport in 2004, time averaged spatial aircraft noise levels were calculated – essentially period LAeq. Noise levels were determined for the 6 months of 2004 with highest traffic density for four time periods: day (6.00 a.m.–10.00 p.m.), night (10.00 p.m.–6.00 a.m.) and two night periods (11.00 p. m.–1.00 a.m. and 3.00–5.00 a.m.).

Individual prescription data of 809,379 persons insured with compulsory sickness funds were linked to address-specific noise data (air traffic, road traffic, train traffic).

The main results discussed in detail in the paper are multivariate logistic analyses conducted in relation to a particular two-hour night-time aircraft noise period (3.00–5.00 a.m.). Adjustments were made in the statistical analysis for noise from other sources, age, density of nursing homes etc.
Particular focus was placed on stratifying the results in terms of prevalence of social welfare recipients.

In males there was an increase in the prescribing of anti-hypertensive drugs with increasing aircraft noise [in that two-hour night period] in all strata of social welfare prevalence. However, there were specific differences when comparing effects in different social welfare quartiles.

In females there were significant risk increases over all noise quartiles in all social welfare strata, but in three of four social welfare strata, odds ratios of the fourth noise quartile are lower than of the third. This is a kind of “saturation effect” at the highest noise levels, [2-hour LAeq category of 48 to 61 dBA]. This was discussed as possibly due to self-selection of people living in those regions with the highest noise.

**COMMENT**
Whilst the results are of general interest, because of the way the results are analysed in relation to such a specific night time period, and the way the noise data categories are presented in the publication, it is not possible at present, without additional information, to combine these results with others or use the results in any subsequent calculations.

The following group of papers all relate to the HYENA project – HYENA = HYpertension and Exposure to Noise near Airports).

They are summarised in sequence as they were published.

**Babisch, W., et al., 2007**
Association between noise annoyance and high blood pressure. Preliminary results from the HYENA study.

The EU-funded HYENA study (HYENA = HYpertension and Exposure to Noise near Airports) is a large-scale multi-centered cross-sectional study carried out simultaneously in 6 European countries to assess the relationship between aircraft noise and road traffic noise on the one hand, and the prevalence of high blood pressure on the other.

The study population included 4,861 people (2,404 men and 2,467 women) aged between 45 and 70 years at the time of interview, and who had been living for at least 5 years, near one of the six major European airports (London Heathrow, Berlin Tegel, Amsterdam Schiphol, Stockholm Arlanda, Milan Malpensa) and Athens Eleftherios Venizelos. In Stockholm, the population living near the City Airport (Bromma) was also included to increase the number of exposed subjects. Fieldwork was carried out during the years 2003-2005

This particular paper on the project, the most recent available does not deal with any noise exposure-effect relationship but covers mainly the complex issue of the relationship between annoyance [which the authors sometimes refer to as “subjective exposure”] and hypertension. [See later summary of the full peer-reviewed journal paper on the HYENA project published December 11 2007].

Noise annoyance was assessed using the non-verbal 11-point ICBEN scale, and items covered annoyance from air traffic, road traffic and other community noise or indoor noise sources (e.g. railway, motorcycles, industry, construction, neighbors and indoor
installations). A distinction was made between the annoyance during the day and the annoyance during the night.

Objective blood pressure measurements were carried out in residents’ homes by specially trained staff. Hypertension was assessed from these measurements using standard WHO clinical criteria.

Use of anti-hypertensive medication was assessed and in addition the subjects were asked about the prevalence of doctor-diagnosed hypertension.

A wide range of potential confounding factors were assessed including such as country, age, education, alcohol intake, body mass index, physical exercise and, sex.

Effect modifiers included in the analysis were - noise sensitivity, coping style, belief in authorities and attitude towards the airport. The frequency of usage of noise reducing remedies was assessed (e.g. ear plugs, closing windows, closing window shutters, etc).

The authors expressed the main conclusions on the complex association between Annoyance and hypertension [HT] as follows;

“HYENA subjects who were more annoyed due to aircraft and road traffic noise reported more often that a doctor had ever diagnosed HT, and were more often under medication for HT. This could indicate that chronic noise stress had raised their blood pressure. However, the association can also be interpreted vice-versa. Subjects who were aware of their high blood pressure reported higher noise annoyance. This could either be due to an increased sensitivity to noise as a consequence of their health problem, or due to over-reporting because subjects may tend to blame the environment as being a reason for their health problem. This latter interpretation is supported by the fact that the clinical blood pressure measurements which consider 'mild' (unknown/untreated) HT, did not show much of an association with noise annoyance. More annoyed subjects could also have over-reported high blood pressure. In fact, noise sensitivity was higher in subjects who reported doctor diagnosed HT, but not in subjects where HT was assessed more objectively based on BP readings or medication intake.”

NOTE – the full paper on HYENA follows, published online December 11 2007


Abstract

Background

An increasing number of people are exposed to aircraft and road traffic noise. Hypertension is an important risk factor for cardiovascular disease and even a small contribution in risk from environmental factors may have a major impact on public health. The HYENA study aimed to assess the relations between noise from aircraft or road traffic near airports and the risk of hypertension.
Methods. The study measured blood pressure and collected data on health, socio-economic and life-style factors, including diet and physical activity, via questionnaire at home visits for 4,861 persons aged 45 to 70, who had lived at least five years near any of six major European airports. Noise exposure was assessed using detailed models with a resolution of 1dB (5dB for UK road traffic noise), and a spatial resolution of 250 x 250m for aircraft and 10 x 10m for road traffic noise.

Results. We found significant exposure-response relationships between night-time aircraft as well as average daily road traffic noise exposure and risk of hypertension after adjustment for major confounders. For night-time aircraft noise, a 10dB increase in exposure was associated with an odds ratio of 1.14 (95% confidence interval: 1.01-1.29). The exposure-response relationships were similar for road traffic noise and stronger for men with an odds ratio of 1.54 (95% CI: 0.99-2.40) in the highest exposure category (>65dB); (ptrend = 0.008).

Conclusions. Our results indicate excess risks of hypertension related to long term noise exposure, primarily for night-time aircraft noise and daily average road traffic noise.

The key figures from this paper on the HYENA study are shown below.

Figure 16. Odds ratios (OR) of hypertension in relation to aircraft noise (5dB categories). LAeq, 16h (left) and Lnight (right) separately included in the model. Adjusted for country, age, gender, BMI, alcohol intake, education and exercise. The error bars denote 95% confidence intervals for the categorical (5dB) analysis. The unbroken and broken curves show the OR and corresponding 95% confidence interval for the continuous analysis.
Figure 17. Odds ratios (OR) of hypertension in women (left) and men (right) in relation to road traffic noise (LAeq, 24h, 5dB categories) separately included in the model. Adjusted for country, age, BMI and alcohol intake, education and exercise. The error bars denote 95% confidence intervals for the categorical (5dB) analysis. The unbroken and broken curves show the OR and corresponding 95% confidence interval for the continuous analysis.


This paper deals with the acute effects of short-term changes of transportation or indoor noise levels on blood pressure (BP) and heart rate (HR) during night-time sleep in 140 subjects living near four major European airports. Non-invasive ambulatory BP measurements at 15 min intervals were performed. Noise was measured during the night sleeping period and recorded digitally for the identification of the source of a noise event. Exposure variables included equivalent noise level over 1 and 15 min and presence/absence of event (with LAmx . 35 dB) before each BP measurement. Random effects models for repeated measurements were applied. An increase in BP (6.2 mmHg (0.63–12) for systolic and 7.4 mmHg (3.1, 12) for diastolic) was observed over 15 min intervals in which an aircraft event occurred. A non-significant increase in HR was also observed (by 5.4 b.p.m.). Less consistent effects were observed on HR. When the actual maximum noise level of an event was assessed there were no systematic differences in the effects according to the noise source.
It was concluded that effects of noise exposure on elevated subsequent BP measurements were clearly shown. The effect size of the noise level appears to be independent of the noise source.

A further paper on the HYENA study was also included in the ICBEN 2008 conference Hypertension and exposure to noise near airports - results of the HYENA study Wolfgang Babisch, Danny Houthuijs, et al.,

This paper from July 2008 is a “re-working” of earlier papers, and provides no new data. However the Abstract is given here for completeness.

“Hypertension is an important risk factor for cardiovascular disease. Even a small contribution in risk from environmental factors may have a major impact on public health. The HYENA study aimed to assess the relations between noise from aircraft or road traffic near airports and the risk of hypertension. Blood pressure was measured, and data on health (history of hypertension, medication), socio-economic, life-style factors and potential effect and exposure modifiers (personality factors, remedies to reduce the noise) were collected via questionnaire at home visits for 4,861 persons aged 45 to 70, who had lived at least five years near any of six major European airports. Aircraft noise contours and road traffic noise levels were modeled using the Integrated Noise Model (INM) and national calculation methods. The noise levels were linked to each participant's home address using graphical information systems. Significant exposure-response relationships between night-time aircraft as well as average daily road traffic noise and risk of hypertension were found after adjustment for major confounders. For night-time aircraft noise (Lnight), a 10 dB(A) increase in exposure was associated with an odds ratio of 1.14 (95% confidence interval: 1.01-1.29). For 24h road traffic noise (Leq,24h), a 10 dB(A) increase in exposure was associated with an odds ratio of 1.10 (95% confidence interval: 1.00- 1.20). The exposure-response relationships for road traffic noise was stronger for men with an odds ratio of 1.54 (95% CI: 0.99-2.40) in the highest exposure category (>65dB); (ptrend = 0.008). The results indicate excess risks of hypertension related to long term noise exposure, primarily for night-time aircraft noise and daily average road traffic noise.

CONCLUSIONS

The Hyena study supports previous studies that have suggested an effect of long-term road traffic noise on high blood pressure (Babisch 2006, 2008). In particular, the prevalence of hypertension increased with increasing noise exposure. The findings also indicate an effect of night-time aircraft noise on hypertension. Stratified analyses (subgroups) suggested that annoyance due to aircraft noise during the day could be an effect modifier of the association between aircraft noise during the night and hypertension(larger odds ratio in annoyed subjects), and that closing the windows was an effect modifier of the association between road traffic noise and hypertension (smaller odds ratio in subjects who kept the windows closed). Type of housing and belief in the authorities were also found to have a potentially effect modifying impact on the association between road traffic noise and high blood pressure.*

The HYENA project was also the subject of a paper at the Internoise 2008 conference in October 2008.

However, in reviewing this it was noted that it is simply a summary of the two main previous papers discussed above.


This Internoise 2008 paper is thus noted for reference, and is included in the Database of relevant publications but is not summarised here.

3.2.3 Comparison of studies of Hypertension and aircraft noise – including HYENA
In his review report for the GLA, published on the GLA website,


Berry noted a comparison of various studies made by Babisch and van Kamp in the January 2008 Draft Chapter on Aircraft Noise and Health, in the Report of the WHO Working Group on “Evidence Review of Aircraft Noise and Health”. This Group was established by the Noise and Health programme of WHO/Europe European Centre for Environment and Health late in 2007.

This comparison was described at the time as follows;
“Only a very few epidemiological studies are available on adults, in which the association between aircraft noise and clinical states of cardiovascular diseases were assessed. Five studies appear reasonably valid for further consideration because minimum requirements regarding the validity of the assessment of exposure, outcome and the statistical control for confounding factors were fulfilled . However, noise level related data pooling (‘categorical approach’) is difficult due to the fact that different (national) exposure indices were used. A graphical presentation of results using approximations with respect to the common noise indicator $L_{dn}$ is shown in Figure 1. No conclusions regarding possible threshold values or noise level related risks (in absolute terms) can be made.”
Some aspects of the results plotted for Stockholm are included in the papers already reviewed earlier in this section. Experts believe that little reliance can be placed on the Okinawa results because of serious doubts over the noise exposure information used. Noise predictions from the 1970s, when the airport involved was still a US Air Force base in the Vietnam War, were compared to health data from the 1990s.

The comparison noted above was one of the main topics discussed in the January 27 2009 visit to Babisch in Berlin. We were advised that a paper entitled “Exposure-response relationship of the association between aircraft noise and the risk of hypertension” had been submitted to the journal Noise and Health based on the as yet unpublished Chapter for the WHO Report on Practical Guidelines for Risk Assessment of Environmental Noise. We were supplied with a copy of the submitted paper. It notes that;

“No single, generalised and empirically supported exposure-response relationship can be established yet for the association between aircraft noise and cardiovascular risk due to methodological differences between studies and the lack of continuous noise data. However in spite of these limitations an attempt has been made to derive a best-guess estimate which can be used for quantitative risk assessment until more data become available”.

The suggested approach uses a calculated relative risk of 1.13 for a 10 dBA increase in Lden, with an onset of 55 dBA. However, until the full paper is peer reviewed and published, and in view of the comments in the paper itself it is recommended that the proposed exposure-response relationship is noted but not used as part of a methodology. Another reason for this is the prospect of “double counting” of numbers of people affected if relationships for BOTH hypertension and myocardial infarction were included.

3.2.4 New review paper July 2008
In addition to the papers on “primary studies” reviewed here, there has also been another key review paper, presented at the ICBEN 2008 conference.

*Environmental noise and cardiovascular disease: Five year review and future directions.*
Under the heading “Blood pressure/Hypertension” the paper discusses research since 2003 under two sub-headings;

Environmental studies - road traffic
Environmental studies – aircraft traffic

The road traffic studies reviewed are those by Belojevic 2008, van Kempen 2006 [RANCH project], Bluhm 2007 and de Kluizenaar 2007 which have already been outlined above in this annex. This confirms that our own “coverage” of newer research is as complete as it could be.

Of the de Kluizenaar paper which included air pollution, these reviewers note;

“This study was perhaps the first to consider the joint-effects of air pollution. In the fully-adjusted noise models, further adjustment for PM10 did not affect noise-effect estimates; this was taken to mean that PM10 was not confounding the noise-HT relation, but the authors point out there was very limited contrast in PM10 exposure”.

The aircraft traffic studies reviewed were those by Eriksson 2007, van Kempen 2006 [RANCH project] and Greiser 2007. Again these have already been reviewed in this section. On the Greiser 2007 study, Davies and van Kamp note;

“.. exposure-response curves were not consistent.”

It is worthwhile noting the Conclusions of this Davies and van Kamp 2008 review in full, as follows;

“The past five years has seen a number of high quality studies that addressed many of the past concerns of study design, power, analytical approach, exposure assessment and outcome classification. While these studies have largely supported the hypothesis that noise and mediating factors such as noise sensitivity are causally associated with cardiovascular diseases including hypertension, there remain several areas that require future attention.

First is the issue of the joint effects of air pollution and noise on CVD (Schwela et al. 2005). A number of studies have begun to examine this; one is reviewed in this paper (de Kluizenaar et al. 2007), and others (Jarup et al. 2005; Babisch et al. 2008) reported on the study design of HYENA and its early results, which will be the first large multi-center study to investigate modifying effects of air pollution on road and air traffic effects around 6 major EU airports. Other studies are in progress (Davies et al. 2008) and will be reported in the next few years.

Other key issues that have surfaced or remain are the effects of noise on susceptible populations, the inconsistencies found in studies of noise and blood pressure/hypertension among children, and gender effects. This effort will require continued improvements in exposure assessment techniques, improvements in case definitions (eg objective measures of HT), analytic designs that better cope with the limitations of existing exposure assessment and systematic adjustment for confounding factors.”

The 2005 paper by Schwela et al., referred to is ;

3.2.5 Statistical adviser input
Following the meeting on October 28, the Statistical Adviser, John Bates, was fully briefed in a series of emails and was asked to review the 2006 Babisch UBA report to look into the process used to estimate dose-response functions based on meta-analyses, and to assess robustness etc and suitability of the dose-response function for application in the UK.

His report is reproduced below.

In summary, apart from essentially minor criticisms, he feels it is an important and authoritative review and interpretation of the literature in this area. In his view the implications are, no more and no less, that a significant correlation exists in the most reliable data indicating that the probability of ischaemic heart disease is higher when road traffic noise sound levels are higher. This does not, of course, imply anything about causation. To give a simple example, if persons with heart disease could only afford cheaper housing and cheaper housing was predominantly in noisy streets, this could lead to the observed pattern.

Reflections on the Paper by Babisch W (Transportation Noise and Cardiovascular Risk: Review and Synthesis of Epidemiological Studies, Dose-effect Curve and Risk Estimation)


I have read the main text of this Report, and in general I find it to be thorough, painstaking and even-handed. Not being an expert in this field, I cannot comment on the extent of coverage of existing work, but the Report gives the impression of being wide-ranging and critical. It is important to note that the Report is essentially an interpretation of existing literature, and does not have access to any data beyond that available from the published literature.

It appears that the works reviewed contain mixed messages, in terms of supporting a relationship between transport noise and cardiovascular illness of various types. In itself this is not too surprising, given a) the relatively low incidence, and b) the intrinsic measurement problems (in particular the fact that noise is typically measured for a fixed location – e.g. residence – without allowing for the movement of the potentially affected respondent both within and outside the location). The author’s approach, therefore, is to attach reasonably stringent qualifying criteria for individual studies, so that only the most reliable are taken into serious consideration. This is a conservative approach, but in my view it is appropriate (though a counterargument exists in terms of the “cautionary principle” discussed on p 48 of the article).

The core of the Report is a meta-analysis of qualifying studies. For this, four “necessary” criteria were defined for studies:
(1) peer-reviewed in the international literature
(2) reasonable control of possible confounding
(3) objective assessment of exposure and
(4) objective assessment of outcome.
Additional criteria for the ranking were:

(5) type of study and
(6) dose-response assessment.

Approximately 50 studies were considered, out of which only 8 were judged to qualify for the meta-analysis. Of this, 6 were described as “observational analytic studies”, and the other 2 as “descriptive studies on individuals” (though these terms are not entirely clear to me). In the former, it appears that three studies relating to Caerphilly and Speedwell have been pooled.

It turned out that, as a result of the evaluation process, all these studies referred to the road traffic noise during the day (Lday: 6-22 hr) and the incidence or prevalence of myocardial infarction (MI) as the outcome. Accordingly, for both sets of studies, the meta-analysis is presented as a relationship between the “odds ratio” for MI and the road traffic noise level.

Unfortunately, there are some confusing aspects of the description. Table 1 sets out the data clearly, but introduces a distinction between “prevalence” and “incidence” data in a way which is not clearly related to the previous distinction between “analytical” and “descriptive” studies. By some detective work, it appears that the two “descriptive” studies are #42 (#27) and #43 (#28), and that the remaining four “analytical” studies are ## 44, 32, 33, 61. The numbers in brackets have the same sample sizes as the numbers which they follow, and relate to the same areas, but appear in the Table A5 as “Studies on effects of community noise on the prevalence of ischaemic heart disease”. All the other numbers appear in Table A6 as “Studies on effects of community noise on the incidence of ischaemic heart disease.” However, only the last four have been used.

This seems to suggest that “descriptive” is aligned with “prevalence” and that “analytical” is aligned with “incidence”. Figures 7 and 8 plot the raw and pooled data for “prevalence” and “incidence” respectively.

I am not familiar with the statistical program used to carry out the meta-analysis, but it appears that two stages are used: firstly, the data is pooled taking appropriate account of the reported range for the individual estimates (Figures 7, 8), also producing confidence intervals for the pooled estimates (Figures 13, 14). Secondly (in this case, only for the “incidence” results), a curve is fitted to the pooled estimates, presumably taking account of the confidence intervals.

In the course of reporting this, there is reference to “statistical weights” which are presumably being used to reflect the confidence intervals appropriately – higher weights corresponding with narrower confidence intervals. A little more explanation would be helpful.

Based on the information provided in the text, the following figure summarises the position. The pooled estimates are plotted, with their confidence intervals (taken from Table 1), and in addition, the two fitted curves are shown (taken from Figures 9 and 10).
Figure 19. Babisch curves

It can be seen that the confidence intervals are quite wide, particularly for the highest noise level. If the unweighted fit is used, the curve is drawn upwards to the highest observation. However, the weighted fit reflects the relative lack of confidence for the highest point, and the curve sits closer to the more reliable estimates. It should certainly be concluded that the weighted fit is more appropriate.

Of course, while the fitted curve represents a “best estimate”, the confidence intervals for the underlying data should still be kept in mind. Nonetheless, the way in which the (weighted) curve has been fitted has taken appropriate account of the error in the data. It would have been useful if statistics for the coefficients of the polynomial curves had been provided.

In Section 7 of the Babisch report, the results of the meta-analysis are used to predict the level of MI risk, using data for exposure to Road Traffic noise for the whole of Germany. The calculations set out in Table 5 suggest that, if the hypothesis is accepted, then 3.2% of the MI in Germany is due to traffic noise. The total number of MI cases (133115 for 1999) is given in Table 2. The conversion of the odds ratio obtained from the meta-analysis to a measure of “relative risk” is not explained, it being merely noted that “odds ratios are estimates of the relative risk”.

Note that, for non-experts, the difference between an odds ratio and a relative risk measure is merely a technicality. For example, Wikipedia notes that “The odds ratio, while in itself difficult to interpret, is …used as an estimate of the relative risk. This, however, is only valid when dealing with low-probability events”. The relative risk, which is easier for the layman, is the ratio of the probability of the event occurring in the exposed group to the probability of the same event occurring in a non-exposed group. For example, if the probability of developing lung cancer among smokers was 20% and among non-smokers 1%, then the relative risk of cancer associated with smoking would be 20. Smokers would be twenty times as likely as non-smokers to develop lung cancer.

Essentially the baseline for the odds ratio is the control group (non-exposed). In practice the definition of the control group is likely to depend on the hypothesis being investigated. There are places in the text where the conclusions could be made clearer, and the Report ends slightly abruptly. Nevertheless, these are essentially minor criticisms of an important and authoritative Review and interpretation of the literature in this area.
In my view, the implications are, no more and no less, that a significant correlation exists in the most reliable data indicating that the probability of ischaemic heart disease is higher when road traffic noise levels are higher. This does not, of course, imply anything about causation. To give a simple example, if persons with heart disease could only afford cheaper housing and cheaper housing was predominantly in noisy streets, this could lead to the observed pattern.

As noted, the confidence intervals are wide, and, indeed, cross the value of 1.0 for the odds ratio in most places. This means that any particular value of the (higher) noise levels cannot be confidently associated with a increased probability of disease. Nevertheless, taken together, the increase in mean probability is significant. Of course, an odds ratio even of 1.5 (highest noise level) only means that the probability of developing the disease is 50% higher.

3.2.6 Interim conclusions on cardiovascular effects

For Ischaemic heart disease, including myocardial infarction, although there have been some new studies, for example the ALPNAP study in the ICBEN 2008 paper by Lercher discussed in this review, further study, and enquiries to the authors are required to enable a proper assessment of how these results relate to those of Babisch and others.

The Babisch review has been evaluated by an independent statistical adviser whose report, whilst raising a few minor questions did not note any significant problems with the work.

Thus it can be concluded that the dose-response Babisch relationship proposed by Babish in 2006 between Lday and myocardial infarction still provides an adequate basis for a methodology to value health effects.

The present review indicates that, in the case of hypertension, although there have been interesting new results, and additional analyses, as in the HYENA project, the overall picture is still “mixed”, with no firm agreement on a single dose-response relationship. The recent best-guess proposal of Babisch and van Kamp has been noted but it is suggested that it is premature to base a methodology on this, and problems could arise over “double counting”

Results from the limited number of studies which have included air pollution as well as noise do not as yet provide a clear picture on this issue.
3.3 Discussions with other experts at RIVM Netherlands and Federal Environment Agency in Berlin.
In order to survey the views of international experts on number of issues relating to health effects and dose-response relationships it was decided to visit a limited number of experts. Therefore visits to Dr Irene van Kamp of RIVM and to Dr Wolfgang Babisch were arranged. This section documents the key outcomes of those visits.

Visit to RIVM, Bilthoven, Netherlands – December 16 2008

General

Contacts met:
As well as Dr Irene van Kamp from RIVM, those involved were Dr Hans Nijland and Mr Ton Dassen from the Netherlands Environmental Assessment Agency, Dr Elise van Kempen and Mr Wim Swart from RIVM. Later in the day a separate discussion was held with Mr Danny Houthuijs from RIVM.

Agenda
1. WHY WE ARE THERE.
2. CARDIOVASCULAR EFFECTS [Primary focus]
   - Recent Dutch / German studies and reports, Hypertension, IHD etc. e.g. the 10-year Schiphol studies, HYENA
   - Differences in approach between Babisch and RIVM
   - Air pollution + Noise issues – the Groningen study/ Kluizenaar etc
   - Dose-response issues
   - Vulnerable groups
   - Obstacles and “institutional problems affecting the adoption of dose-response functions”
   - Any work in progress to be noted / suggestions for new research?
3. OTHER HEALTH EFFECTS – Sleep Awakenings and Self-reported sleep disturbance, Annoyance
   - Dose-response issues
4. MONETARY VALUATION / APPRAISAL METHODS in use in Holland/Germany – and what RIVM know of other countries.

Discussions.
These followed the main points of the planned Agenda but not in the original order, due to time constraints of some of those invited to attend:

Bernard Berry explained in detail the origin and nature of our UK project. The meeting moved on then to discussions of the methods developed in Holland for evaluating major infrastructure projects. A number of publications were supplied. It was emphasised that Noise was a relatively low-priority issue compared to such things as employment, social cohesion etc. The Netherlands do not specifically include health effects, just annoyance through hedonic pricing etc. A new survey is being planned within the EU INTARESE project – http://www.intarese.org/ – This will include some element of asking residents about “perceived health”.

We discussed the valuation method published in reports from Switzerland, which relied on dose-response functions for cardiovascular effects. Dr van Kamp offered to provide
We discussed the MSR [Rotterdam] report. See Section 3.6. It was noted that the authors of that report had originally planned to do a more complete estimate of the numbers of people affected by cardiovascular disease, but had changed their minds before final publication, so that only very rough estimates were published.

I was advised that RIVM had been involved in a WHO project led by the WHO Regional office in Rome to produce “Guidelines for Cost-Benefit Analysis of Transport related Health effects”. A report was imminent.

We had detailed discussions on the comparison of the Babisch dose-response functions and those arising from the RIVM meta-analysis of 2002. It transpired that Dr Elise van Kempen had updated the meta-analysis and that this forms part of her published PhD thesis from January 2008, of which we have a copy. [now online at http://igitur-archive.library.uu.nl/dissertations/2008-0122-203944/index.htm ]

Related to this is a recent direct comparison, only just published as an RIVM report, which has been made between a new RIVM dose-response curve for risk of Myocardial Infarction, and the 2006 Babisch curve. The new RIVM report also includes new numerical risk-assessment type comparisons of the numbers of people potentially affected by Myocardial Infarction, made using the two different, but quite similar curves. This provides a very useful practical indication of the implications of using one curve rather than another, as well as information on how the large confidence intervals influence the comparisons.

Babisch and van Kempen are to produce a joint paper on this new work to emphasise, as Elise van Kempen put it – “that they are not in competition”.

It also transpired that RIVM had produced a short unpublished report on the ICBEN 2008 Conference, based on the session of papers on cardiovascular effects, including the resulting conference discussions on issues such as the role of air pollution. We had a discussion on “obstacles to agreement on dose-response etc”. This is dealt with in the next section, 3.3.1.

Reference was made to a new overall review on dose-response functions undertaken within the EU INTARESE project. http://www.intarese.org/about-us.htm Efforts are in hand to acquire the relevant reports. We had a brief discussion about “vulnerable groups”. The general view was that people who were “noise sensitive” as rated by various psychological scales, were more susceptible to cardiovascular effects. This ties in with the role of annoyance as a mediating factor.

A separate discussion was held with Danny Houthuijs of RIVM who was in Utrecht on that day. The main points arising concerned “projects in progress” and these are detailed elsewhere in the report in Annex 2.

Visit to Dr Babisch at Federal Environment Agency Berlin, January 27 2009
Both Ian Flindell and Bernard Berry attended.

3 This has subsequently been published – “Economic valuation of transport-related health effects” http://www.euro.who.int/transport/policy/20090115_2
Again, after an initial introduction about the work of the Agency, and our own outline of the NEE 0102 project, the discussion generally followed the items on the above planned agenda.

We began by discussing the basic “stress model” and the issue of direct physiological effects and their influence on cardiovascular disease effects as opposed to the role of annoyance and the perception of sounds and noise in such effects. Babisch suggested that there were two main “pathways”;

a. During daytime exposure, there was a link between physical exposure in terms of L_{day}, via perceived annoyance through to cardiovascular effects.

b. During night-time exposure, effects during sleep could manifest themselves as cardiovascular effects.

He placed strong emphasis on a various research studies that had showed a stronger association between cardiovascular outcomes and L_{night} than with L_{day}. In particular he cited the work of Alain Muzet in France which showed effects of night-time noise stimuli on blood pressure and heart rate, when no EEG effects were observed.

In general he explained his own “belief” that the case for cardiovascular effects being caused by noise rested on the combined evidence from 3 main “columns”;

1. Laboratory studies such as those by Muzet and Maschke in Germany on short-term effects
2. Studies on animals with long-term exposure which showed real effects on arteries etc.

Babisch made the point that it seemed odd that in the case of Air Pollution the link between exposure and effects was more widely accepted when in many cases the strength of evidence was less than for noise.

He explained particular outcomes of the HYENA project where, on the one hand there were significant associations between various “non-acoustic factors” such as attitudes to an airport, belief in authorities etc and annoyance, whereas no such associations were found between the same factors and hypertension.

We discussed the related issue of “Double counting” when one considered effects of annoyance as well as cardiovascular. He was of the view that they could be treated independently.

In respect of the general philosophy to be used in considering noise policy he pointed out that cardiovascular effects, unlike some other health effects were NOT reversible. Thus one could not plan future noise policy in the hope it might make up for some of the mistakes of the past.

On “Vulnerable groups” he felt that the only sub-set of the population we need consider would be those with pre-existing illness.

Later in the day we returned to this general area with a discussion about the interconnected roles of the human nervous system and the endocrine/hormonal system and the implications for the question of “causality”.
The general impression we had was that there are still a number of uncertainties, about the biological mechanisms underlying cardiovascular effects, some of which might never be fully resolved by any practical research approach but that Babisch firmly believed that one should concentrate on the directly observed outcomes in terms of cardiovascular health and that such effects were attributable to noise exposure.

We took the opportunity to raise some of the points raised by John Bates in his paper and Babisch was able to clarify, for example, his use of the terms “analytic” and “descriptive”, and this confirmed our understanding of the terms.

I raised the direct question of whether he planned to modify the dose-response curve for myocardial infarction from the 2006 review in the light of any new research. He indicated that he had looked at newer material in terms of the strict acceptance criteria and decided that there was no suitable new material.

On hypertension we discussed prospects for a single dose-response curve. He informed us that the chapter on Aircraft noise and Hypertension which he and Irene van Kamp of RIVM had drafted for the September 2008 WHO Draft, had now been submitted for review to the journal Noise and Health. He gave us a copy.

In relation to ongoing research he noted several items of direct relevance;

- A new project involving a sample of 2000 addresses in Berlin where noise and air pollution were being quantified, and several health outcomes studied. Houses were being specifically chosen which had no “quiet side”. Urban and suburban locations were involved with an attempt to disentangle the correlation between air pollution and noise.
- He was planning a new meta-analysis on the effects of road traffic noise on hypertension to parallel the new publication on aircraft noise and hypertension referred to above. This would leave only Aircraft noise and Myocardial Infarction as an “unfilled cell” in a 2 by 2 matrix of noise source and health effect.
- Data from the HYENA study was still being re-analysed in terms of specific issues, such as “room orientation”.
- There is material on air pollution for 4 of the 6 airports in the HYENA study and this will be analysed.

As far as actual Methodologies for Valuation were concerned, Babisch was of the opinion that no “national method” was used in Germany, but pointed to the work of Dr Friedrich at the IER institute in Stuttgart which has been noted in our second Interim Report. We discussed the way his research had been interpreted in the Swiss valuation method, and we noted that the specific curves pre-dated his 2006 review.

We discussed “obstacles and institutional problems”. He expressed the view that the German Government fully accepted the scientific evidence for cardiovascular effects and the related dose-effect relationships, and even published leaflets for the general public making reference to such effects. He felt the only opposition came from the aircraft industry.

Finally we discussed ideas for new research. In addition to possible additional analyses of HYENA data two items emerged;

- The need for studies on railway noise, where air pollution effects would be minimised compared to road traffic
- The need for studies on cardiovascular effects of combined stressors, for example work stress and environmental stress.

Conclusions on visits
Taking both of the above visits together it is clear that they were very valuable to the project as a whole. There was the chance to clarify specific aspects of the published work of some of the most relevant experts in the field, as well as an opportunity to discuss some of the issues which do not find their way into publications. Highly relevant ongoing projects were identified, as well as new contacts. New research requirements also emerged.

3.3.1 Structural challenges
One of the aims of the research was to identify any “structural challenges” to developing a robust dose-response relationship. This requirement arose from the acknowledged situation that, despite considerable effort by a number of influential parties, principally the World Health Organisation, to assimilate the large amount of scientific information on the effects of noise on health into “globally agreed” dose-response relationships, no such general agreement has been reached to date. Hence the interest in what structural challenges, or non-scientific reasons, might underlie this lack of progress. The most recent effort in this regard was the formation of a group of experts to develop a document giving “Practical Guidance for Risk Assessment of Noise”. The group met in Bonn in May 2008. Individual chapters of the document were drafted by pairs of experts in specific areas, e.g. cardiovascular, sleep etc. Because of problems in developing a coherent text, the WHO employed a consultant, who had not been part of the original group, to produce an agreed text. Such a text appeared in draft form in September 2008. However it generated a considerable amount of negative comment. The document remains unfinished. The same fate has befallen a report on “The effects of Aircraft Noise on Health” which was developed by a similar expert group who started work in October 2007.

Several of the experts involved in our visits to RIVM and to Berlin were closely involved in the various WHO initiatives and its seemed logical to base our look at this issue of structural challenges on the discussions with Irene van Kamp and colleagues at RIVM and with Wolfgang Babisch in Berlin which have been described in the previous section.

Our discussions and deliberations indicated 5 main aspects;

*Differences in basic methodology, including regression analyses*
Different approaches have been used by RIVM and by Babisch in their respective meta-analyses to assess estimates of effects when data are pooled and exposure-response relationships in order to carry out a quantitative risk assessment. RIVM calculate uniform regression coefficients across all noise categories within individual studies (‘regression approach’). The regression coefficients are then pooled over all studies. Babisch calculates pooled relative risks for individual noise categories from different noise studies, which were then considered for an exposure-response relationship (‘category approach’). Both approaches have advantages and disadvantages. However, because the two approaches were developed from different organisations, so far the differences have not been resolved. But we were informed that a joint paper is being prepared for the journal Noise and Health which will show the implications of using the different curves. It is not known as yet if the paper will propose some compromise, but this matter should be followed up.

*Basic differences in “belief”, about causality*
By “belief” in this context, we mean that experts in any field over many years tend to build up an “integrated view” of the underlying causes of the various factors that they are measuring, studying and discussing with other experts in the field. In this particular field, where many or even most of the individual research studies are inconclusive or subject to considerable uncertainty, and where contradictory and/or negative results are
not unusual, it is likely that many experts, when put under pressure to come up with informed opinions, will tend towards forming overall judgements based on general trends and overviews and might possibly tend to place a little more weight on pieces of evidence that support their personal beliefs than on pieces of evidence that do not. Comparing Babisch with the experts at RIVM, it was clear that, even on the basis of largely the same evidence, RIVM tend to have a marginally more cautious view when interpreting the evidence, although they still make practical use of the observed relationships for health impact analysis. In general, and when looking through the various papers reviewed herein, it is clear that different authors often take a more or less cautious view when inferring the possibility of causal relationships from what is often statistically inconclusive or experimentally confounded data. It is perhaps unfortunate that future research funding often depends on having obtained 'successful' or conclusive results in previous research, whereas in fact negative results (i.e., no relationship found) should be of equivalent value even though they often are not perceived as such.

Institutional inertia where methods already exist
This is a normal situation which can apply to a range of issues in noise regulation and legislation. Within a given country, considerable effort may have been put into individual research projects and the reviewing of research outcomes leading to the development of local methods for assessing noise effects. Such methods are then embedded in legislative documents. In very few cases are mechanisms maintained on a long-term basis for periodic review. To some extent the Netherlands is an exception to this, through its National Health Council. The proposal in the new HPA review report for a Standing committee would go some way to resolve this issue.

A bias towards methods based only on national research in a particular country.
Particularly where health issues are concerned, there is sometimes reluctance to "import" findings from other countries, with an innate and probably irrational belief that the population of one's own country is somehow unique, or that some of the factors potentially involved, for example the degree of industrialisation, mean that results from one country cannot be generalised to others. It might be argued that the WHO should provide a suitable forum for sharing information and hence resolving such issues, but this does not seem to have been the case so far. The setting up of a new EU-funded "European Research Network on Noise and Health" due to start in September 2009 might contribute to reducing such national bias.

Conflicting views of stakeholders
In a complex topic such as this, it is inevitable that just as different researchers may have different views, so also may different stakeholders have different views on the level of evidence required as a justification for action. Industry, with a view to the major economic implications of any action will often take one view, whilst environmental groups will generally tend to take a more "precautionary" line.

In some cases it is possible that a particular global industry, for example the aviation industry, can have (or appear to have) a disproportionately strong voice in key international forums such as the WHO. Amenity groups can argue equally forcefully for an opposing point of view. These kinds of adversarial situations do not help the 'truth' to emerge, although in this particular field, because of uncertain, confounded and sometimes even contradictory evidence, it can sometimes be difficult to identify exactly what the truth really is.
3.4 Dose Response Relationships for Noise induced Sleep Disturbance

3.4.1 Introduction
Section 2 described the many potential health effects of noise and rated the strength of evidence for each of those effects. This section focuses on noise-induced sleep disturbance effects for which it was shown that there was sufficient evidence.

The overall output of this work is to facilitate the informing of future policy on the adverse health effects of environmental noise. This primary aim of the work is to identify robust dose-response relationships, which define a direct quantitative link between the exposure (i.e. the dose) and the effect that it has on human health, wherever these can be justified on the basis of existing evidence.

To recap, sleep disturbance has been identified as a potential adverse health impact of environmental noise. The objective of this work is to examine the type of sleep impacts for which there are dose-response relationships and comment on their general applicability to policy appraisal in the UK in relation to health impact assessment.

In the first instance, the general impacts of noise on sleep are summarized below. In order to meet timescales, it was agreed that the review work should use, as a basis, previous reviews of noise-induced sleep disturbance. The next section therefore identifies the key reviews and sets out their context. Added to the existing review data, is information derived from team discussions and project consultations. This chapter then presents the dose-response relationships. It then sets out a number of criteria for robust dose-response relationships for policy application in relation to health consequences. Information relating to these criteria from the scientific research reviews is discussed. Finally, using these criteria, the chapter concludes how/if a dose-response relationship could be selected, applied and used to inform on health consequences for policy purposes.

It is worth noting here the terminology adopted in many of the references. The relationships are termed dose-response, exposure-effect, dose-effect and exposure-response and these definitions tend to be used almost interchangeably. This is unfortunate because, strictly speaking, exposure refers to the sound that is present, dose refers to what is actually absorbed by the body, response refers to the instantaneous response of an organism, and effect tends to refer to longer term response to that stimulus. Most research is addressed to exposure-effect or exposure-response relationships, because individual dose is hardly ever measured and might not be particularly relevant for legislative or regulatory control anyway.

3.4.2 Understanding Noise and Sleep Disturbance
Many models for sleep disturbance have been proposed which are all very similar. To help summarise noise and sleep disturbance effects, a model derived by Porter et al (27) will be used. For a full discussion of this model, please refer to full reference.

The model framework is shown in Figure 20 on the next page. Although it uses as its basis the effects of noise from aircraft, it is generally applicable to all noise sources. The model recognizes four levels of effect:

1. acute responses that include immediate or direct disturbances caused by noise events,
2. total night effects that are aggregations of (1) over the whole night,
3. next day effects that are a result of (1) and (2), and
4. chronic effects that are pervasive long-term consequences of (1), (2) and (3).
Responses and effects which are objectively measurable are shown in green; subjective reactions in red. The model recognises that all of these are dependent on many modifying factors - demographic, behavioural, sociological, situational and so on. Modifying factors have a substantial, sometimes dominant influence.

For this work, we are interested in identifying the key exposure-response or exposure-effect relationships which maybe robust enough for policy application when assessing health effects. This model shows that noise can directly lead to acute effects and then through a chain to health consequences. However, it also shows that there are feedback mechanisms and modifying factors which means that noise can lead to health consequences through indirect paths, highlighting the complex web of interactions which makes it difficult to successfully quantify any simple exposure-response relationship between noise exposure and health effects.

Team discussions and consultations have led to consideration of the role of other factors in determining the extent of a response or effect. In particular the role of familiarity with the noise and how the brain function reaction time could determine the extent of a response such as awakening. If a subject recognizes a noise then the brain can determine whether it is necessary to awaken for a ‘fight or flight reaction’. This brain function has a response time, and in considering the manner in which the sound level increases over time – the rise time – this could help to explain the magnitude of a response. If the rise time is short, then the brain may not have sufficient time to recognize the source and assess its level of threat, and therefore the subject may waken. If the rise time is longer, the brain may have time to identify the source and its level of threat, and it may not be necessary to awaken if there is no threat level. It could therefore be hypothesized that the magnitude of a response is not necessarily...
proportional to the total energy of an event but is proportional to the method and associated time it takes for the body to respond to the increase in sound energy. Neurone activity is a relatively fast response to a stimulus whereas the release of hormones is comparatively slower. We will return to this point later.

It is helpful to consider briefly here how the exposure and response/effect can be measured before reviewing studies into the derivation of any relationships for sleep disturbance. The effects of noise on sleep disturbance can be studied through either field studies (using actual community noises) or laboratory studies (using simulated noise exposures). Historically, the noise exposure has been measured indoors or outdoors (or both), using short-term measures such as SEL or Lmax, and/or longer term averaging over set time periods such as Lnight. Techniques for measuring the sleep disturbance vary depending on the responses/effects being studied (as shown in the model above). Immediate or acute responses have been measured using

- EEGs (Electroencephalograph arousal response) – this can be used to indicate the disturbance in terms of changes to the depth of sleep, awakenings and prevention from getting to sleep.
- Actimetry - this is a wrist worn device that monitors body movement.
- Behaviourally confirmed awakenings (BCA) – subject presses a button to indicate an awakening from sleep.

After effects (non-acute) are usually measured subjectively using questionnaires on sleep quality, tiredness, and annoyance. Objectives measures of after effects include excretion of hormones, and sleepiness, task performance tests, and cognitive functioning tests.

3.4.3 Key Reviews
The previous section has summarized a general ‘cause-effect’ model linking noise to sleep disturbance and has indicated a number of measures used to describe the dose and response. This section now looks at some of the work that has been conducted in deriving exposure-response relationships for noise and sleep disturbance. In order to meet timescales, it was agreed that the review work should use as a basis previous reviews of noise-induced sleep disturbance. The next section below therefore identifies the key reviews and sets out their context.

Table 5: Chronological List of Review Papers on Noise and Sleep since 2000.

<table>
<thead>
<tr>
<th>Date</th>
<th>Ref</th>
<th>Author</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>27</td>
<td>N Porter et al</td>
<td>Adverse effects of night-time aircraft noise, R&amp;D Report 9964, National Air Traffic Services. This report was part of a continuing UK government funded programme intended as background to future UK studies of night-time noise. It reviewed the ‘state of the art’ at that time including dose-effect relationships, causal models and areas of uncertainty and led to the commissioning of 2 exploratory projects.</td>
</tr>
<tr>
<td>2004</td>
<td>25</td>
<td>EC Working Group on Health and Socio-Economics Aspects</td>
<td>Position paper on dose-effect relationships for night-time noise. Following the introduction of the Environmental Noise Directive, dose-response relationships were provided as a general set to give the effect of a general population exposed to a well defined range of noise levels. The first</td>
</tr>
</tbody>
</table>
set was intended to assessing annoyance using Lden. This report reports on the Working Group examining the dose effect relations for Lnight. The main emphasis is on longer term relationships although more short term effects are reviewed using indicators such as SEL and Lmax.

<table>
<thead>
<tr>
<th>Year</th>
<th>Page</th>
<th>Author</th>
<th>Reference</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>38</td>
<td>HCN, Netherlands</td>
<td>The Influence of Night-time Noise on Sleep and Health, No. 2004/14E, The Hague, 22 July 2004 (corrected version, 27 January 2005)</td>
<td>The Netherlands has regulations designed to limit public exposure to environmental noise, primarily with a view to managing the associated nuisance. Most of the limits relate to exposure over a complete twenty-four-hour period and do not therefore focus specifically on the period during which most people sleep. At the time of writing regulations are presently being prepared at EU level that concentrate on night-time noise exposure. The Health Council were asked to provide advice regarding the influence of night-time noise on sleep, health and well-being and were specifically asked a list of key issues to address the effects and how these are quantified, how each effects compares with others in terms of health consequences, high risk groups, specific rules for night-time.</td>
</tr>
<tr>
<td>2004</td>
<td>39</td>
<td>H Miedema</td>
<td>Self reported sleep disturbance caused by aircraft noise, TNO-INRO, Delft</td>
<td>As a basis for the EC paper above, this paper was prepared and financed by the Dutch government.</td>
</tr>
<tr>
<td>2005</td>
<td>3</td>
<td>EEMM van Kempen et al</td>
<td>Selection and evaluation of exposure-effect relationships for health impact assessment in field of noise and health, RIVM report 630400001/2005.</td>
<td>This report is a background document that can be used to assess the health impact attributable to noise in the Netherlands. To this end the available exposure-effect-relationships in the field of noise and health are reviewed and evaluated, using data published in the epidemiological literature as well as previous reviews. Only the relationships describing the association between noise and annoyance, sleep disturbance and cardiovascular disease are considered to be suitable for health impact assessment purposes. Finally, recommendations are made for the applicability of these exposure-effect-relationships.</td>
</tr>
<tr>
<td>Year</td>
<td>No.</td>
<td>Author(s)</td>
<td>Title</td>
<td>Notes</td>
</tr>
<tr>
<td>------</td>
<td>-----</td>
<td>----------------------</td>
<td>----------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
</tr>
<tr>
<td>2006</td>
<td>40</td>
<td>B Griefahn et al</td>
<td>Noise emitted from road, rail and air traffic and their effects on sleep, JSV 2006.</td>
<td>This reports on a study of noise from road, rail and air traffic and tested the applicability of leq for the evaluation of sleep disturbance. This is not a review paper.</td>
</tr>
<tr>
<td>2006</td>
<td>41</td>
<td>L Finegold et al</td>
<td>Sleep disturbance due to transportation noise exposure, Chapter 24………..</td>
<td>This is a review chapter of a book looking at the subject of sleep disturbance. It examines the different metrics, effects and their evaluation and existing criteria and their shortcomings.</td>
</tr>
<tr>
<td>2007</td>
<td>42</td>
<td>D Michaud et al</td>
<td>Review of field studies of aircraft noise-induced sleep disturbance, JASA 2007</td>
<td>This is a literature review of 5 field studies of aircraft noise-induced sleep disturbance. It finds that sleep disturbance effects are non dramatic on a per-event basis and that links between exposure and disturbance are tenuous. It concludes that predictions of sleep disturbance due to aircraft noise should not be based on an over-simplification of the findings of reviewed studies.</td>
</tr>
<tr>
<td>2007</td>
<td>43</td>
<td>H Miedema and H Vos</td>
<td>Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies, Behavioural Sleep Medicine 3(1), 1-20, 2007.</td>
<td>This study looks at relationships that specify self-reported sleep disturbance and exposure to nighttime transportation noise. It is based on reanalyzing pooled data from 28 original datasets obtained from 24 field studies. Functions are given in terms of percentage highly sleep disturbed, sleep disturbed, and a little sleep disturbed with average nighttime outdoor noise exposure.</td>
</tr>
<tr>
<td>2007</td>
<td>23</td>
<td>H Miedema</td>
<td>Exposure-response relationships for environmental noise, Internoise 2007, 28-31 August 2007, Istanbul, Turkey</td>
<td>This paper presents an overview of exposure-response relationships that can be used for assessing the impact of environmental noise including Lnight and self reported sleep disturbance.</td>
</tr>
<tr>
<td>2007</td>
<td>24</td>
<td>WHO</td>
<td>Night noise guidelines for Europe</td>
<td>In 2003, the WHO Regional Office for Europe set up a working group of experts to provide scientific advice to the European Commission and its Member States for the development of future legislation and policy action in the area of control and surveillance of night noise exposure. In 2006, all draft reports were compiled into a draft</td>
</tr>
<tr>
<td>Year</td>
<td>ID</td>
<td>Author(s)</td>
<td>Title</td>
<td>Publication Details</td>
</tr>
<tr>
<td>------</td>
<td>----</td>
<td>-----------------</td>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2007</td>
<td>44</td>
<td>M van den Berg</td>
<td>Night noise guidelines for Europe, Internoise 2007, 28-31 August 2007, Istanbul, Turkey</td>
<td>In 2003 the WHO received a grant from the European Commission to provide expert support on developing future legislation on the control of night noise exposure. This paper describes the process of collection of the scientific data and the outcomes in terms of health and the related uncertainties.</td>
</tr>
<tr>
<td>2008</td>
<td>45</td>
<td>K Hume</td>
<td>Sleep disturbance due to noise: Research over the last and next five years, 9th ICBEN 2008, Foxwoods, CT</td>
<td>This paper is a brief review of the fundamental issues concerning noise and sleep disturbance, it outlines some of the developments over the past 5 years (2003-2008) and considers emerging issues and suggests some research developments for the future.</td>
</tr>
<tr>
<td>2008</td>
<td>46</td>
<td>WHO</td>
<td>Practical guidance for risk assessment of environmental noise. Draft</td>
<td>The use of risk assessments incorporating EBD (environmental burden of disease) methodology and of the metric Disability-Adjusted Life Year (DALY), developed by WHO, can be used to help quantify the noise problem. The WHO European Centre for Environment and Health, Bonn office has organized several meetings to further develop approaches to quantify the effect of noise on health and overcome the difficulties related to the gaps in knowledge. The outcomes of these meetings are summarized in this document, which aims to provide guidance to those wishing to undertake their own risk assessments of environmental noise. This documents provides synthesized reviews of evidence on the relationship between environmental noise and health effects in order to better inform policy makers and the public about noise exposure and it’s effects. It also provides the best available estimates of the relationship between environmental noise and health effects, including the exposure-response relationships, exposure prevalence, and disability weights. Finally it provides practical guidance for risk assessment of environmental noise exposure including burden of disease calculations.</td>
</tr>
</tbody>
</table>
3.4.4 Key Exposure-Response Relationships derived from Scientific Research

Previously it was agreed that the focus of this work would be on awakenings from sleep rather than the other effects. In examining the reviews outlined in the previous section, a number of exposure-response relationships have been identified and are reproduced below.

**US Sleep Disturbance Relationships**

In 1995, Pearsons et al (47) compiled a comprehensive database of laboratory and field studies on noise induced-sleep disturbance. This formed the basis for an interim curve which was later adopted by the U.S Federal Interagency on Noise (FICON) (48). Following additional studies in the US, BBN Laboratories developed an exposure-response relationship which was recommended in the 2000 US ANSI standard S12.9. Part 6, (Methods for Estimation of Awakenings Associated with Aircraft Noise Events Heard in the Home) (49) as reproduced below.

![Figure 21: ANSI S12.9-2000/Part 6 relationship between prevalence of awakening and indoor sound exposure level](image)

The ANSI 12.9 standard did not include a later study by Passchier Vermeer in 2003 (50) and the following figure adds the data in to the figures.
Figure 22: ANSI S12.9-2000/Part 6 relationship between prevalence of awakening and indoor sound exposure level with Passchier Vermeer 2003 observations.

The meta-analysis was redone by Finegold and Elias in 2002 (51) with then available data (not Passchier Vermeer of 2003). The exposure-response curves are shown below in Figure 23. The more recent work was primarily based on behaviourally confirmed awakenings and focused on aircraft noise although 3 out of 8 included road traffic noise, with only 1 containing information on railway noise.

Figure 23: Finegold and Elias (51) sleep disturbance prediction curve and earlier FICON interim curve (48).

Additionally, in 1997 Powell developed a curve that was published by FICAN (Federal Interagency Committee on Aviation Noise) (52) which was only a recommendation intended to protect the public from sleep disturbance in any degree and therefore is not intended as a exposure-response relationship but simply as an upper limit on some of the behavioural awakening data. This is reproduced below.
UK work on Dose-Response for sleep disturbance

The Porter et al. review of adverse effects of night-time aircraft noise describes CAA studies on night-time aircraft noise (27). That report follows the progress of research from 1977 through to 2000 and focuses many of its conclusions on the UK 1992 Field Study (53). Of specific importance to this study was the main finding that at outdoor noise events below 90 dBA SEL (approx 80 dBA Lmax), average sleep disturbance rates were unlikely to be affected and, at higher noise event sound levels, the chance of the average person being awakened from an aircraft noise event was about 1 in 75. This relationship was primarily derived from actimetric arousals. This finding is reproduced below together with Elias and Finegold data (and some of the original datasets from the US) described above and some other criteria adopted in Europe at that time. Note that several criterion values are shown below. A criterion value can be referred to a specific sound level above which a definite response is expected, e.g. an awakening. In the past, the UK has used, for aircraft noise, a criterion of 90 SEL dB(A) (the value for one aircraft noise event) above which 1/75 of the exposed population is predicted as being likely to be awakened by that event.
European noise induced relationships for sleep disturbance

Below, we take a look at some of the exposure-response relationships derived in other European countries, some of which have been used at a European level.

Netherlands dose-response relationship on noise-induced awakenings

In 2003 Passchier-Vermeer reviewed 9 studies (50) on awakening by noise (focusing on BCA), with rail noise, ambient (probably road) noise, and aviation noise (civil and military). For civil aviation noise, there was sufficient data to derive a dose-response relationship as shown below:

**Figure 26: 2003 Passchier Vermeer Meta-analysis (50)**

The following figure is taken from the same reference and uses Lmax and motility.

**Figure 27: 2003 Passchier Vermeer**

In 2007, Miedema pooled data on self-reported sleep disturbance (not objectively measured) and derived the following set of exposure-response functions which have been used at an EU level (23).
Figure 28: Miedema meta-analysis by source using subjective sleep disturbance measures (23).

Sweden
In 2004, finding from the Swedish Soundscape Research Programme (54) derived the following exposure-response relationship for traffic noise (y-axis is percent of population).

World Health Organisation – European Region
In 2003, the WHO Regional Office for Europe set up a working group of experts to provide scientific advice to the European Commission and its Member States for the development of future legislation and policy action in the area of control and surveillance of night noise exposure. In 2006, all draft reports were compiled into a draft document, reviewed and presented as a final document in 2007 (24). The first figure below shows how the responses increase with increased Lnight for road traffic noise.
Figure 29: Increase in effects on sleep increase due to road traffic noise, taken from WHO (24)

The next figure shows how this relationship changes for aircraft noise.

Figure 30: Increase in effects on sleep increase due to aircraft traffic noise, taken from WHO (24)

Finally the following exposure-response relationship is reproduced from the most recent field study in 2006 of aircraft noise by Basner et al (55).
Figure 31: Basner et al findings on sleep disturbance from aircraft field study using EEG, reproduced from WHO (24).

The table below summarises how these of the exposure-response relationships can be objectively classified.

Table 6: Objective Classification of Exposure-Response Relationships

<table>
<thead>
<tr>
<th>Dose</th>
<th>US d-rs</th>
<th>UK d-rs</th>
<th>Netherlands (50)</th>
<th>Netherlands/EU (25)</th>
<th>Swedish (54)</th>
<th>Basner (52)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor</td>
<td></td>
<td>estimate</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lnight</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lmax or SEL</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effects</td>
<td>Awakenings</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>EEG</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motility</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjective</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sources</td>
<td>Mainly aircraft</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Only aircraft</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.4.5 Application of exposure-response relationships at a policy level for health impact assessment

To recap, the objective of this work is to examine the type of impact for which there do exist exposure-response relationships and then comment on their general applicability to policy appraisal in the UK in terms of health impacts. Having presented a series of exposure-response relationships in the previous section (without comment), this section now discusses general application of these for policy purposes.

It is important first to present a set of criteria against which the exposure-response relationships can be judged in order to determine whether they are suitable for informing on policy on the adverse health effects of environmental noise. The first 2 relate to metrology issues, the second 2 relate to sampling issues, the last 2 relate to the strength and usability of the relationship our policy purposes.
Robust measures of noise exposure – does the measure cover all the input factors that are relevant and does it really measure what the researcher intended?

Robust measures of response/effect.

Representativeness to all types of noise - in terms of applying it outside the narrow context for which it was derived.

Representativeness to wider population.

Strength of relationship.

Usability of relationship for policy purposes in relation to monetary valuation of adverse health effects.

The following section presents some of the information from the reviews and team consultations with respect to sleep disturbance relationships.

Robust measures of noise exposure

Ideally the best noise exposure measures are those with the ability to predict an effect, as well as one which does describes all the input factors that are relevant and accurately describes what the researcher intended. More practically the best noise indicators should be easy to explain and easy to measure and apply for a specific purpose (in this case for informing policy on health effects of noise).

The reviews have shown that there appears to be no single noise exposure metric or general measurement approach that is generally agreed upon for noise-induced sleep disturbance. Most of the reviews suggest that the clearest and most consistent relationships are those between indoor sound levels and BCAs. Long-term measures of outdoor levels were not generally found to be reliably associated with any measure of acute sleep disturbance. The measures used have been short-term instantaneous values such as Lmax and SEL, which have traditionally been used to be associated with the acute responses, or the longer term averages such as Lnight. Some reviews suggest that SEL is a better predictor of sleep disturbance across the studies than Lmax, whereas other reviews show that measures of peak sound pressure level are a better predictor than an average sound pressure level. Griefhan carried out work in 2004 to test the hypothesis that human response to transportation noise during sleep corresponds to daytime annoyance. This work found that LSeq appeared to be a suitable predictor for subjective evaluation but not for the physiological disturbances of sleep.

Lnight has been adopted by EU for the measure of dose, but it is accepted that information may be lost on acoustical properties of the noise, number of events, time of events, and it is therefore recommended in the Environmental Noise Directive that it may be advantageous to use Lmax or SEL as a supplementary measure for night protection. Lnight is simple to use, easy to administer for strategic use, and additionally, data is being collated on this measure through the END. However, the END relates to describing the exposure, but is not necessarily specifically related to the aim of this project which is focused on health consequences.

However, let us return to the issue. The best noise indicators are those with the ability to predict an effect and to do this they may have to reflect the earlier discussion of the role of rise time, familiarity with a noise and the response time of the brain to prepare for a fight or flight and a need to awaken. As this work has led to the hypothesis that a noise effect is not necessarily simply proportional to the overall energy an event but actually proportionally to the method and speed at which a body responds, this highlights some shortcomings of the SEL metric. For the same SEL level, the rise time may be long with a lower Lmax, or the rise time may be short with a higher Lmax. It is
hypothesized that the latter case maybe more likely to result in an awakening as the brain may not have sufficient time to identify the source. Therefore it would follow that Lmax or Lpeak could be a better predictor of the awakening response. However, this hypothesis does require further research as no suitable scientific data is currently available. Research studies have not been designed with distinguishing between these two generic types of metric as an aim.

It has been suggested that an overall effect on health, is a more long term effect (it falls at the end of the chain of cause-effect link in our model framework) and could be considered as an aggregated effect cumulating from the cause-effects leading to it. It may therefore only be possible at this stage to suggest that such an aggregated effect on health should only be described by an aggregated noise exposure measure such as Lnight. Although SEL has been shown to relate in some way to individual awakenings, it is unclear at present how such a response leads to overall clinical health effects, and therefore with our current level of understanding, using an SEL based measure may not be useful to placing a value on overall health effects unless one event alone can cause a huge health impact. Lnight on the other hand does at least help to describe both the energy and number of events in a time period.

Robust measures of effect/response
There are many different measures of response dependent on the type of response as well as the equipment used; for example awakenings can be measured through EEG sleep changes, actigraphy (motility/movements), or pressing buttons (BCAs). The choice of measurement methods and sleep disturbance indicators is still controversial. Only one study has cross-validated actimetric and EEG data (56). EEG provides the most detailed information is often regarded as the gold standard. Motility provides information on movements that could indicate a stress response and be an indicator of an awakening. Behavioral awakenings do provide a clear and unambiguous indicator of an awakening but there could be some noise intrusions that do not provide a sufficient impetus to push a button, or an awakening could have already occurred when a noise heard and the button then used. The reviews have shown that the diversity of end point analysis (choice of that based on EEG, motility or BCAs) can detract from the clarity of any results.

Non-acute or next day effects are often ‘measured’ subjectively. There are many factors that influence subjective evaluations of sleep. In general it has been found that subjective self-reports of awakenings do not correlate well with more objective measures.

It is true that there is most data on awakenings and as this is an acute reaction, it is more likely to be more robust with less intervention from the modifying factors. For the purposes of this work it can concluded at present that although there are a number of successful measures of awakenings and of sleep structure changes, it is not clear how these in turn relate to overall impacts on health. This means that we can either adopt a relationship based on awakening and recognize that it is unclear how these lead to overall health effects, or recognize that our current level of understanding of the overall causality chain to health effects is not known, so using awakening as an indicator for overall health effects for policy purposes is not reliable at this time.

Representativeness to all types of noise
Miedema (39) found from his pooled data of subjective evaluations of sleep disturbance that at the same average night-time noise exposure level, aircraft noise is associated with more self-reported sleep disturbance than road traffic noise, which is associated with more self reported sleep disturbance than railways.
However, if we focus on objectively measured awakenings from noise, the findings vary. Griefahn (40) carried out work in 2004 to test the hypothesis that human response to transportation noise during sleep correspond to daytime annoyance. This work found that Leq appeared to be a suitable predictor for subjective evaluation but not for the physiological disturbances of sleep. It also found that aircraft noise, rail and road noise caused similar after effects but physiological sleep parameters were most severely affected by rail noise. Comparing types of source, the number of events varies considerably as well as the character and connotation of the noise source, it can be expected that the dose-response relationships may vary according to the type of noise source. However, the main databases of sleep study data consist largely of data from aircraft noise studies. In adopting any dose-response relationship for policy purposes, it should be recognized that there is a limit to applicability and non-aircraft noise sources may not have the exact same response function as that given.

Again, let us look at the hypothesis that the magnitude of response is proportional to the method and speed at which the body responds and how this may help to explain differences in responses to different sources. Trains tend to be more regular, following the same path, are predictable and slow – the brain has time to recognize a train and may chose to ignore the stimulus and an awakening may be less likely to occur. The path and noise of an aircraft is less predictable, less regular, usually has a faster energy rise time than that of train and therefore it may take the brain longer to recognize and the passage of an aircraft may therefore by more likely to result in an awakening.

It therefore can be concluded that the existing exposure-response relationships are not fully representativeness for all types of noise and cannot necessarily be applied outside the narrow context for which they were derived.

**Generally applicable to whole population**

Any tools used in policy application should be applicable to the general population unless it is stated that the policy is to protect a specific subset of the population. The reviews of the research have identified a number of factors that limit the applicability of the dose-response relationships to the general population and therefore limit their use for general policy purposes.

These factors can be what are termed modifying factors which include perceived predictability, perceived control, trust and recognition, general attitudes, personal benefits, sensitivity to noise, habituation (the process by which one becomes accustomed to one’s environment) – it has been suggested that if people do not habituate completely to their acoustic environment, health disorders can be expected in the long term.

Vulnerable groups may have a requirement for increased protection and a general population based dose-response relationship may not be applicable for policy purposes. Children have a higher awakening threshold than adults and therefore are often seen to be less sensitive at night but they are in bed longer (including the shoulder hours) so may be seen as an at risk group. With age, sleep structure becomes more fragmented; so elderly people are more vulnerable to disturbance. This is also applicable to pregnant women and people with ill health. Shift workers are also at risk as their sleep structure is under stress. The reviews highlighted that a small proportion of the population is 60% more disturbed than the ‘average’ population. This may be those people who have such personality factors which can lead to higher sensitivity to those and these people, could be the main ones seriously affected.

Many of the relationships have focused on awakening from sleep once asleep but there are uncertainties over shoulder hours, noise can delay sleep onset, and/or hasten final
awakening. Several studies have shown that a noise induced awakening occurs more often during the later than the earlier part of the night.

The reviews summarized an effect of age on response. From pooled data on subjective evaluations of sleep disturbance, it was found that the association of noise induced sleep disturbance with age has an inverse u shape, with the strongest reaction found between 50 and 56 years of age.

Ambient sound levels in bedrooms were found in several studies to be inversely related to awakenings. This suggest that people sleeping in quieter quarters maybe more likely to experience disturbance (or movements) when exposed to intruding noise than those accustomed to sleeping in noisier quarters.

Therefore, in considering using any exposure-response relationship for policy purposes, all these factors have to be taken into account, or caveats clearly set out ring fencing its use.

Strength of Relationships
The pathways linking noise exposure and its effects are complex and subject to many extraneous influences. The original framework model given in Figure 20 shows the links from noise to health effects. Longer-term health effects have many causes, of which noise disturbance is only one. In practice it is very difficult to identify all the cause effect links, let alone disentangle them. The model indicates how the ‘modifying factors’ intervene at each stage such that moving from left to right in the diagram, the relationship between noise and its effects are increasingly ‘scrambled’ and therefore difficult to determine by simply correlating the effects with some measure of noise exposure. In fact the Finegold and Elias curve (41) actually only predicts 22% of the variance in the data so that it has been recognized that it is still not possible to make very accurate predictions of sleep disturbance at the community level.

Michaud et al (42) usefully reflect the findings from this section when they summarize the relationships for aircraft noise induced sleep disturbance between indoor sound levels and arousal, motility and awakening. The findings differ between measure of sleep disturbance and study as highlighted above. The most consistent relationships between measures for aircraft sound levels and sleep disturbance was observed between indoor sound levels and BCAs. Although, one of the more consistent findings was that a single event descriptor such as SEL or Lmax could be used to describe the effect of aircraft noise on sleep, these relationships had such a shallow curve and do not account for more than 20% of variance, and that review recommended that such a relationship cannot be used robustly for regulatory purposes. Relationships between motility and indoor sound levels are inconsistent with each other and are further complicated by methodological differences e.g. ambient sound levels, time, time of sleep onset. That paper concludes that the use of this tool for regulatory purposes is therefore hindered.

Unfortunately, it is only really possible to conclude here that none of the relationships that have been scientifically derived to date, account for a high level of variance and therefore cannot be reliably used for policy purposes.

Usability of relationship for policy purposes in relation to monetary valuation of adverse health effects.
The reviews have shown that there appears to be no exposure-response relationship that sufficiently meets all above criteria for a robust dose-response relationship for noise induced sleep disturbance applicable for policy application in relation to monetary valuation of adverse health effects. Whilst SEL and awakenings seem to give the most
reliable relationships, and may be usable for strategic applications other than cumulative health effects, SEL is not a aggregated measure and it is unclear the precise links between awakenings and longer term clinical health effects.

This chapter has examined the existing dose-response relationships for noise induced sleep disturbance. However, one of the main points of this research project is the link of the relationships to longer-term health consequences. So, even if we could find reliable, robust and all applicable dose-response relationships between noise and awakenings, how do we relate this to final health consequences?

The model framework shows the complex web of links between noise and longer term health effects. Our work here has focused on the direct link between noise and awakenings as this has been the most research and sufficient evidence has been found to link the two. However, this is only a small part in the chain as in practice it is very difficult to identify all the cause effect links, let alone disentangle them. The model indicates how the ‘modifying factors’ intervene at each stage.

The reviews generally concur that there is very little known about the long-term cumulative effects of intermittent sleep disturbance from community noise exposure.

Only one review paper (46) refers to disability weights used for the calculation of DALYS for what is termed ‘primary insomnia’ which is given as 0.100 with the definition as below:

‘Difficulty falling asleep, remaining asleep, or receiving restorative sleep for a period of no less than one month. This disturbance in sleep must cause significant stress 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’.

Noise could be considered as ‘other substances’ and may be excluded but Van Kempen (ref 3) reported a severity of -0.1 for severe sleep disturbance, although some other studies have found values of 0.01, 0.55 and 0.9.

General consensus that there is a need for more insight into the mechanisms causing the effects and interrelations between effects. It is not known the mechanisms though which noise effects sleep and the interrelations between self-reported sleep disturbances sleep disturbance, extra motility, cardiovascular response, EEG arousals and changes in EEG pattern. In addition it is unclear how these relate to actual longer-term clinical health consequences.

One most recent advance in 2004 (57) has been work into the establishment of the level and nature of normal values of spontaneous arousals and perturbation that occur in sleep. This can help to identify ‘significant’ in terms of sleep disturbances due to say noise, although it is still unclear which level of perturbation that can lead to a long term clinical health effects.

To conclude, there does not exist at present any reliable dose-response relationship for noise and sleep disturbed related health effects that could be used for policy purposes in relation to monetary valuation of adverse health effects. However, it is recognised that there may well be situations where one is concerned more with Quality of Life, or amenity issues and where a requirement exists to assess the sensitivity of outcomes such as sleep disturbance to various options and assumptions. Possible approaches to a dose-response relationship for such situations are dealt with in the next section.
3.5 Other Health effects
As noted previously, at the end of Phase 1 of the project it was agreed that the Final Report should “present indicative dose-response functions for all the health effects considered”. Accordingly this section of the Report considers other effects apart from Cardiovascular effects and Awakenings from sleep, which have been discussed in detail above, and puts forward possible dose-effect functions, without providing a detailed review. The effects considered are:

- Self-reported sleep disturbance
- Mental Health
- Cognitive effects on school children
- Hearing impairment

3.5.1 Self-reported sleep disturbance
[NOTE- the more detailed review in Section 3.4 indicates that the dose-response curves discussed below do not meet the strict criteria discussed earlier, but are outlined here in view of their use by others]. The most “reputable” dose-response curves for self-reported sleep disturbance are those included in the EU Position paper of 2004 [25];

The functions are based on analyses of 15 data sets with more than 12000 individual observations of exposure-response combinations, from 12 field studies which had included a questionnaire containing questions regarding sleep disturbance. The curves are based on data in the Lnight (outside, maximally exposed facade) range 45-65 dB(A). The polynomial functions are close approximations of the curves in this range and their extrapolations to lower exposure (40-45 dB(A)) and higher exposure (65-70 dB(A)).

The formulae of these polynomial approximations for road traffic are as follows:

\[
\%HSD = 20.8 - 1.05L_{\text{night}} + 0.01486(L_{\text{night}})^2
\]

\[
\%SD = 13.8 - 0.85L_{\text{night}} + 0.01670(L_{\text{night}})^2
\]

\[
\%LSD = -8.4 + 0.16L_{\text{night}} + 0.01081(L_{\text{night}})^2
\]

in which SD=Sleep Disturbed; H=Highly; L=Lowly

For aircraft;
For railways:

\[ \%HSD = 11.3 - 0.55L_{\text{night}} + 0.00759 (L_{\text{night}})^2 \]
\[ \%SD = 12.5 - 0.66L_{\text{night}} + 0.01121 (L_{\text{night}})^2 \]
\[ \%LSD = 4.7 - 0.31L_{\text{night}} + 0.01125 (L_{\text{night}})^2 \]

The functions are shown graphically below.

**Figure 7. Percentages of highly disturbed when exposed to rail and road traffic noise**

**Figure 32 Self reported sleep disturbance and Lnight**

The Position Paper notes that the above relations represent the current best estimates of the influences of Lnight on self-reported sleep disturbance for road traffic noise and for railway noise, when no other factors are taken into account. For aircraft noise it
notes that the variance in the responses is large compared to the variance found for rail and road traffic. This means that the uncertainty regarding the responses for night-time aircraft noise is large, and such responses can be considered as indicative only. They could be used however for various “sensitivity analyses”.

**Industrial and impulse noise**

The Position Paper also notes that for industrial noise there is an almost complete lack of information, although there are some indications that impulse noise may cause considerable disturbance at night.


For this project, due to the limited frequency of military training activities, which were one source of sounds, it was not feasible to conduct a study in residential areas around military firing ranges or training fields. Due to the poor predictability of the occurrence of the sounds of interest, and the uncertainty about the availability of a sufficient number of participants, the feasibility was low for designing a conventional field survey also for the other more civil sounds. As an alternative, the sounds were presented by means of loudspeakers in the bedrooms of 50 volunteers. The shooting sounds had been produced by a small and a medium/large firearm, and the sound fragments consisted of individual bangs or volleys of ten isolated or partly overlapping impulses. The civil impulse sounds had been produced by slamming one of the doors of a van, and by transshipment of a container. Again, the sound fragments consisted of single or multiple events. Aircraft sound was included as a reference source. The sounds were presented during a six-hour period that started 75 min after the beginning of the sleeping period. The time period between the various stimuli varied between 12 and 18 min. Each subject participated in 18 nights to be completed within four weeks.

A composite form of the results is shown below which indicates the Probability of awakening as a function of the A-weighted sound Exposure level of the impulse sounds
5.1 Comparison of results from military and civil groups

![Graph showing probability of awakening as a function of A-weighted sound Exposure level of impulse sounds.](image)

**Figure 34.** Data replotted from Figure 14 and Figure 25. For shooting (single and volley), the data are averaged across the rifle and machine-gun conditions; for civil impulses (single and multiple), the data are averaged across the door-slam and container-transshipment conditions.

**Figure 33.** Probability of awakening as a function of the A-weighted sound Exposure level of impulse sounds

3.5.2 Mental Health
The most recent comprehensive review on this topic was published in the Proceedings of the ICBEN 2008 conference. *Environmental noise and mental health: Five year review and future Directions* by Irene van Kamp and Hugh Davies.

The review comments that, “New evidence leans towards the conclusion that there is no direct association between environmental noise and mental health”. Furthermore it notes – “Noise annoyance is consistently found to be an important mediator.”

In another recent review, Clark and Stansfeld concluded [15]; “Overall, studies suggest that for both adults and children noise exposure is probably not associated with serious psychological illness but there may be effects on well-being and quality of life”.

3.5.3 Cognitive effects on schoolchildren

The large scale RANCH study, which compared the effect of road traffic and aircraft noise on children’s cognitive performance in the Netherlands, Spain and the UK, found a linear exposure-effect relationship between chronic aircraft noise exposure and impaired reading comprehension and recognition memory, after taking a range of socioeconomic and confounding factors into account (Stansfeld et al., 2005, reference 7). No associations were observed between chronic road traffic noise exposure and cognition, with the exception of episodic memory, which surprisingly showed better performance in high road traffic noise areas. Neither aircraft noise nor road traffic noise affected attention or working memory.

In terms of the magnitude of the effect of aircraft noise on reading comprehension, a 5dBA increase in aircraft noise exposure, expressed in L_{Aeq, 16h}, was associated with a 2 month delay in reading age in the UK and a 1 month delay in the Netherlands. The mean results for reading comprehension scores across all schools in all countries were presented as Z-scores in the following diagram- Figure 34. The 2 month reading delay corresponds to approximately 0.1 units on the Z-score scale.

![Figure 1: Adjusted mean reading Z score (95% CI) for 5 dB bands of aircraft noise (adjusted for age, sex, and country)](image)

**Figure 34.** RANCH study

3.5.4 Hearing Impairment

The ISO standard 1999 (ISO 1990, reference 30) gives a method of calculating noise-induced hearing impairment in populations exposed to noise. This is universally accepted for estimating occupational noise-induced hearing impairment, and is the basis of assessments under the UK Noise at Work Regulations. It has been argued by some, including WHO that it is also applicable for environmental and leisure noise-induced hearing impairment. For values of noise exposure below 75dB LAeq for an 8-hour day, no effect is predicted. For values above that level, coefficients are given to enable the estimation of 2 factors – a hearing threshold level based on the age of the person, plus an estimate of the noise-induced permanent threshold shift.

The formulae are not amenable to graphical representation.
3.6 Valuation Methodologies on other countries

3.6.1 Email survey

Introduction
It was considered a useful exercise to investigate how other countries have adopted dose-response relationships for assessing health effects of noise. This section reports on an exercise to collate such information by means of an email survey to European equivalents of Defra Noise Policy sections. The email request is set out below.

Email Survey
The following email was sent to various government departments to collate information. This was firstly sent on 25th November 2008 with a follow up email on 16th December 2008. There were 36 recipients identified.

Box 1: Email survey

Dear Colleague

Estimating Dose-Response Relationships Between Noise Exposure And Human Health Impacts In The UK

The UK Government is funding research to inform future policy on the adverse health effects of environmental noise. I am working with Bernard Berry from Berry Environmental Ltd and Ian Flindell on this topic. A project summary is attached giving more information including the main aims.

Dr Rokho Kim of the World Health Organisation is acting as a Special Adviser to the project, particularly following the WHO related work on Environmental Burden of Disease, see http://www.euro.who.int/Document/NOH/Noise_EDB_2nd_mtg.pdf .

Current UK Practice
There is growing evidence of a number of adverse health outcomes which are caused by noise pollution. These include: cardiovascular disease, hypertension, tinnitus, hearing impairment, cognitive development and sleep disturbance. At present, there is no agreed UK methodology for putting an economic valuation on these impacts to inform policy decisions in the UK. Project appraisal for UK government policy is carried out through the use of cost benefit analysis (CBA) where possible, which feeds into business cases and impact assessments, and is used to inform the policy decisions. Currently in England, monetary CBA can only be undertaken to assess the annoyance element of certain transport noise. These values were developed by UK Department for Transport (DfT) for road and rail transport appraisal (known as the Webtag values), which are based upon the effect of noise on house prices, as measured in the a Birmingham study in 2004 . In conclusion, the health effects of noise, and their economic implications are not fully taken into account in the appraisal of UK policy.

Help needed
As part of this work, I am reviewing how other countries are assessing and also putting an economic valuation on noise and its health effects. We were advised that you may be the best contact in your country to seek advice and therefore would really appreciate your help in answering the questions below, preferably by Friday December 19th 2008.

1. Does your country have an agreed method for (1) assessing the health effects of noise and (2) a methodology for monetary evaluation of these effects?
2. If not, why not? Can you mention any particular obstacles preventing adopting a method? Are there any plans to develop such a methodology?
3. If you do have such a methodology, what health effects are included (Annoyance/Sleep/Cardiovascular/Cognitive/Other)?
4. What dose-response relationship is used for each health effect in the methodology?
5. What approach is used at the stage of “economic or monetary valuation” of the health effects/impacts?
6. Please refer me to any relevant publications, studies or websites.

If you feel that there is someone else in your country who may also be able to assist, please could you pass this email on and let us know that you have done so.

Our final report is due in the Spring of next year, and should be published on the UK government website, and we will advise when our findings are published. Many thanks for your help.
Response
The final response rate was unfortunately lower than anticipated. Out of the 36, 4 email addresses were no longer valid, 4 recipients were on annual leave or maternity leave, 3 gave holding responses, 3 recipients suggested other contacts, 3 gave full or partial responses. This represents 17 of the 36 (approx 50%) of the recipients. Despite a follow up and forwarding of the email to the other suggested recipients, no additional information was obtained. This may have been due to the time of year the survey was conducted which fell at the end of the year and the Christmas season.

Findings
The email survey did not reveal any information about agreed methods of assessment, apart from some work carried out in Denmark. The information is summarized below.

Flemish Region of Belgium
There is no agreed method for assessing the health effects of noise. There have been regular assessments of the health effects of noise ((severe) annoyance, (severe) sleep disturbance, and to a lesser extent hypertension and DALY’s) based on noise exposure models and dose-effect-relations, but no standard for doing this has been agreed to date. Apart from calculated numbers, on a regular basis a population survey is carried out to obtain numbers on annoyed and sleep disturbed people. For general noise annoyance, there has as an official policy aim to restrict the number of "severely annoyed" people. This number is obtained by applying the dose response relationship’s for road, rail and air traffic agreed in the WG-AEN (Miedema) to a calculated noise model. For air traffic, the Brussels Airport has to report the number of the highly annoyed people in the surroundings of the airport in the framework of their environmental license. This number is also based on the dose response relationships for air traffic agreed in the WG-AEN (Miedema).

There is no methodology for monetary evaluation of these effects. A major obstacle is the lack of international standardised dose response relationships and/or monetary evaluation schemes. This leaves individual researchers to discuss which dose response relationships or schemes should be used. As a consequence, research outputs will vary depending on which dose response relationships or scheme is used. European efforts to offer a standard dose response relationships for airport and sleep disturbance are considered helpful.

In the preparation of action planning for road and rail (in the framework of the END), a working group uniting several administrations has been discussing health effects in order to extract possible limit values to be used in the action planning process. Next year, a study will be organised to gain more information about the suitability of these limit values (and to propose possible mitigation measures). This study will also review possible monetary evaluation schemes in order to get a full cost-benefit analysis.

In the past there have been regular assessments of the health effects of noise (annoyance, sleep disturbance, and to a lesser extent hypertension and DALY’s).

More information can be found at the general homepage of the noise division of the Environmental Department of the Flemish government:

Denmark
In 2002-03 there was a study made on the health impact of road traffic noise and the costs associated. It was led by Søren Peter Lund from the Institute of Labour Protection.
and the study is reported in the Danish EPA Working Report no. 53/2003 (in Danish). The focus was on hypertension and ischaemic heart diseases, and it was found that 200-500 Danes die prematurely each year caused by road traffic noise. The "health-related" costs from premature deaths and disease was added to the "annoyance-based" cost, and information was used from the decrease of house prices due to road traffic noise. The entire study was the background for the Road Traffic Noise Strategy issued by the Government in 2003. Currently there is a new project starting where the strategy is to be reviewed.

**Portugal**

The country does not have an agreed method for assessing the health effects of environmental noise and or a methodology for monetary evaluation of these effects? In the context of the Portuguese Environment and Health Action Plan, such methodology may be developed. The Plan is under development and it due for completion by 2013. Other relevant information can be found on Portuguese Environment and Health Action Plan at:


**Summary**

An email survey has been conducted to investigate how other countries have adopted dose-response relationships for assessing health effects of noise. Unfortunately, despite follow up reminders, there was a very low response rate. Information has been collated on 3 countries. However, the email survey did not reveal any definitive information about agreed methods of assessment, apart from some work carried out in Denmark. Due to the low response from our email survey, information was sought from other contacts. The additional inquiries found out more detailed information for Denmark, Switzerland and the Netherlands which is set out below.

### 3.6.2 Valuation methods in other European countries: Review of publications

**Introduction**

This section provides a "commentary" on various relevant publications which have come to light in the course of the "Review of Methods in other countries" element of the NEE0102 project. It does not constitute a comprehensive review of all of these publications, but focuses instead on the direct issue of the extent to which Health effects other than annoyance have been considered in valuation/appraisal methods or in the development of noise policy in general [NOTE- the MSR 2008 report discussed later is an example of a "noise policy" application].

Thus, some of the 12 publications deal only with "conventional" methods, based on hedonic pricing or contingent variation, where annoyance, nuisance or other negative perceptions are involved in the valuation process.

The publications have been identified by various means - searches, suggestions from personal contacts such as at RIVM in the Netherlands, by cross reference from other publications etc.

The publications deal with “methodologies” and also in some cases with examples of the way such methodologies have been applied.

This commentary should be seen as complementary to the email survey on this topic, described above.
Publications identified
Table 7 provides an overview of the initial set of 12 publications, and includes a summary derived from that in the original publication.

The commentary which follows also deals with other publications which have been identified through reviewing this initial set.
Table 7. Chronological List of Selected Publications on Valuation Methods in other countries

<table>
<thead>
<tr>
<th>Date</th>
<th>Author/Title/Reference</th>
<th>Summary from Report, but see Commentary which follows</th>
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<tbody>
<tr>
<td>2008</td>
<td>H. Nijland, B. van Wee <em>Noise valuation in ex-ante valuations of major road and railroad projects</em> European Journal of Transport Infrastructure Research EJTIR Issue 8(3) September 2008 pp. 216-226 <a href="http://www.ejtir.tbm.tudelft.nl/">http://www.ejtir.tbm.tudelft.nl/</a></td>
<td>Noting that, in many European countries, the impact of new road and railroad infrastructure is assessed by performing a cost-benefit analysis, monetising as many relevant effects as possible, this paper <em>systematically reviews</em> the guidelines for monetising ROAD AND RAIL noise in different European countries. The study shows, firstly, that there are guidelines for monetising noise in most western and northern European countries and secondly, but that not all noise effects are dealt with. Usually <em>only annoyance</em> in a residential context is included. Thirdly, the different prices being attached to noise in various countries are mainly due to different unit values applied to the same impacts. Fourthly, a gap has been shown to exist between the theoretical guidelines and their application in practice.</td>
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<tr>
<td>2008</td>
<td>K. Ohlau and R. Friedrich <em>External costs of traffic noise: Assessment of noise impacts in using the example of air traffic in Germany</em> Proceedings of Internoise 2008. Paper 0307</td>
<td>This paper presents an assessment approach of <em>air traffic noise</em> and underlines its future meaning. Methodologies for assessing noise including aircraft noise have been developed, improved and applied, which focus on the impact pathway approach, i.e. in the first step noise levels are estimated, as a second step dose-response functions are applied to calculate health impact and annoyance level distributions. The third step is evaluated by transforming the impacts into monetary values. New studies for assessing annoyance have been carried out with the contingent valuation method. Realizing an integrated assessment approach, in a fourth step, measures can be deduced for the reduction of noise. As a fifth step, this information will be adapted in the calculation of the noise level estimation (see step one). Examples for the applied assessment methodologies can be found in several EC funded projects like HEATCO (Developing Harmonized European Approaches for Transport COsting and Project Assessment), GRACE (Generalisation of Research on Accounts and Cost Estimation), ASSET (ASsessing SEnsitiveness to Transport) and HEIMTSA (Health and Environment Integrated Methodology and Toolbox for Scenario Assessment). Future research will aim at developing a harmonized assessment approach for traffic noise. Results of the monetary valuation will be shown for a potential harmonized assessment approach in using the example of the seven biggest German airports.</td>
</tr>
<tr>
<td>2008</td>
<td>Z. Wadud <em>Depreciation of Property Prices around Airports: A Meta-Regression of Hedonic Price Studies.</em></td>
<td>The external costs of <em>aviation noise</em> are an important input for policy assessment for cost-benefits analysis. The Noise Depreciation Index (NDI) is used to capture the externality costs through measuring the depreciation of property prices exposed to aviation noise. Existing NDI estimates from Hedonic Price studies range from no statistically significant effect to a 2.3% decrease in property prices for every dB of increase in noise exposure. This</td>
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<tr>
<td>2008</td>
<td>MSR Rotterdam – Theme Group Noise</td>
<td>Noise, Health and Money - The price of noise</td>
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<tr>
<td>2008</td>
<td>Jan Jabben</td>
<td>Benefits of noise measures in the Netherlands.</td>
</tr>
<tr>
<td>2007</td>
<td>L.C. den Boer and A. Schroten</td>
<td>Traffic noise reduction in Europe. Health effects, social costs and technical and policy options</td>
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</tbody>
</table>
to reduce road and rail traffic noise
CE Delft Report 07.4451.27
http://www.ce.nl/pdf/07_4451_27.pdf

- Noise reduction options
- Recommendations for action

Appendix B deals more fully with “Social costs for traffic noise”, and points to the INFRAS 2004 reports and the UNITE project.

<table>
<thead>
<tr>
<th>2007 Feb</th>
<th>M. Maibach et al</th>
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<tr>
<td>Handbook on estimation of external costs in the transport sector</td>
<td></td>
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<tr>
<td>CE Delft report 07.4288.52</td>
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The IMPACT study

In the light of this mandate from the EU legislator, the European Commission has commissioned the IMPACT study in order to summarise the existing scientific and practitioner’s knowledge. The central aim of the study is to provide a comprehensive overview of approaches for estimation and internalisation of external cost and to recommend a set of methods and default values for estimating external costs when conceiving and implementing transport pricing policy and schemes. The study also provides technical support to the Commission services to carry out an Impact Assessment of strategies to internalise transport external costs.

Handbook on external costs

This Handbook presents the state of the art and best practice on external cost estimation to make this accessible for those who are not familiar with the issue. It covers all environmental, accident and congestion costs and considers all transport modes. The focus is on marginal external costs of transport activity as a basis for the definition of internalisation policies such as efficient pricing schemes. The handbook does not include information on the existing taxes and charges and does not include information on Infrastructure costs. The handbook is based on the existing scientific and expert work mainly done at EU level and within European countries. It has been reviewed by a panel of more than thirty experts, including experts who were designated by Member States. The handbook recommends:

- Methods for calculating external cost figures.
- Best available input values for such calculation (e.g. value of one life year lost).
- Estimated default unit values of external cost for different traffic situations (e.g. air pollution cost of a vehicle in Euro per kilometre).

Methods for estimating external costs

Although the estimation of external costs have to consider several uncertainties, there is a wide consensus on the major methodological issues. The best practice estimation of congestion costs is based on speed-flow relations, value of time and demand elasticities. For air pollution and noise costs, the impact pathway approach is broadly acknowledged as the preferred approach, using Values of Statistical Life based on Willingness to Pay. Marginal accident cost can be estimated by the risk elasticity approach, also using Values of Statistical Life. Given long-term reduction targets for CO2 emissions, the avoidance cost approach is the best practice for estimating climate cost. Other external costs exist, e.g. costs related to energy dependency, but there is for the time being no scientific consensus on the methods to value them.

Available input values and EU default unit values

It is concluded that external costs of transport activities depend strongly on parameters like location (urban, interurban), time of the day (peak, off-peak, night) as well as on vehicle characteristics (EURO standards). Within the same Member State, the cost of one lorry kilometre in urban areas at peak hour can be at least five times higher than the cost of an interurban kilometre by the same vehicle at off-peak time. The handbook provides typical European and Member State input values, based on the literature assessment made by the study. These input values can be used to produce own output values, with relatively high level of accurateness. Alternatively, the
output values provided for each cost category can be used directly, considering the value transfer approach proposed. These values have lower accuracy, but still provide reliable bandwidths and could be used for policy purposes.

### 2006

**G. Debrezion et al.**

*The Impact of Rail Transport on Real Estate Prices: An Empirical Analysis of the Dutch Housing Markets*

TI 2006-031/3

Tinbergen Institute Discussion Paper

http://www.tinbergen.nl/discussionpapers/06031.pdf

A hedonic pricing model is estimated to analyse the impact of railways on house prices in terms of distance to railway station, frequency of railway services and distance to the railway line. Correcting for a wide range of other determinants of house prices we find that dwellings very close to a station are on average about 25% more expensive than dwellings at a distance of 15 kilometres or more. A doubling of frequency leads to an increase of house values of about 2.5%, ranging from 3.5% for houses close to the station to 1.3% for houses far away. Finally we find a negative effect of distance to railways, probably due to noise effects. Two railway station references were used in the analysis: the nearest and most frequently chosen station in the post code area. This distinction indicates that railway station accessibility is a more complex concept than one might think. It involves competition between railway stations.

### 2005 Jan

**T. Odgaard [COWI Denmark], Kelly and Laird [ITS].**

*Developing Harmonised European Approaches for Transport Costing and Project Assessment HEATCO Deliverable 1*

*Current practice in project appraisal in Europe Analysis of country reports*

HEATCO project Report

http://heatco.ier.uni-stuttgart.de/

The primary objective of the HEATCO project is the development of harmonised guidelines for project assessment and transport costing at an EU level. Work Package 3 contributes by collecting, compiling, analysing and comparing the existing practice of project appraisal in EU Member States and Switzerland. This report presents the overall findings of the analysis and country comparison. Most of the country specific details are presented in Annexes I-XII. See Annex VIII Noise - Table VIII.1 Elements included in valuation ...etc

Noise is included in a cost-benefit analysis in around half of the surveyed countries. There are clear regional differences on how to treat noise effects. None of the countries in the South region include noise in a cost-benefit analysis, whereas all but three countries in the North/West region include noise in a cost benefit analysis. Around half of the countries in the East region include noise effects in a cost-benefit analysis. All countries, which include noise with a money value, include noise annoyance, whereas only a few include health costs related to noise. The money value of noise annoyance is in all countries except one, based on hedonic pricing. The recommendation of UNITE that values should grow over time is not consistent with country practice.

### 2004

**Van Praag et al**

TI 2004-024/3

Tinbergen Institute Discussion Paper

*Using Happiness Surveys to value Intangibles; the Case of Airport Noise*

http://www.tinbergen.nl/discussionpapers/04024.pdf

Inhabitants of houses near Amsterdam Airport are complaining of noise nuisance, caused by aircraft traffic. The usual assumption is that the effect of the externality will be perfectly reflected by house price differentials. This is based on the implicit assumption that there is a well-functioning housing market. If that is not true, we need a correction method in order to assess the intangible damage. We assess the monetary value of the noise damage, caused by aircraft noise nuisance around Amsterdam Airport as the sum of hedonic price differentials and a residual cost component. The residual costs are assessed from a survey, including an ordinal life satisfaction scale, on which individual respondents have scored. The derived compensation scheme depends on, among other things, the objective noise level, income, the degree to which prices account for noise differences, and the presence of noise insulation.

### 2003

**WG HSEA**

*VALUATION OF NOISE-POSITION PAPER*

This paper;

- Summarises current understanding of the benefits of noise reduction;
- Recommends an interim money value which could be used to represent...
<table>
<thead>
<tr>
<th>Year</th>
<th>Author(s)</th>
<th>Title</th>
<th>Details</th>
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<tr>
<td>2003</td>
<td>J. Lambert and D. Oboki</td>
<td>Noise valuation practices in road project appraisal in Europe.</td>
<td>Many European countries developed and implemented tools for the socio-economic assessment of road projects. Among the environmental assessment criteria, noise constitutes a major aspect. Noise values are now usually used in several European countries, in particular within the framework of cost-benefit of road projects. This paper presents an overview of the European practices as regards valuation of noise and use of monetary values in the assessment of road projects. This paper mainly focuses on the scientific basis of the noise values used in practice. A comparison of the practices by the Road administrations in France, Sweden, Germany and Norway is proposed. Finally, the harmonization of these practices at the European level is discussed.</td>
</tr>
</tbody>
</table>


The benefits of reducing noise exposure; and
• Recognises the need for further research and studies if more robust guidance is to be provided – including on differences between transport modes.


<table>
<thead>
<tr>
<th>Source</th>
<th>Details</th>
</tr>
</thead>
</table>

SEE OTHER PUBLICATIONS DESCRIBED IN TEXT IDENTIFIED FROM THE ABOVE
Commentary on certain publications [most recent first]

It should firstly be recalled, that many of these publications listed in Table 7 deal with “conventional” monetizing approaches based on hedonic pricing, contingent variation etc., which have some link to annoyance and other “negative perceptions”.

Several of these publications provide interesting comparisons, meta-analyses etc. of different techniques and might be noted for later study, but are not considered in detail here since the focus is on the extent to which the publications comment on situations where health effects other than annoyance have been considered in valuation/appraisal methods.

Thus the publications which have been listed but NOT considered in any more detail are those by:

- Wadud, 2008
- Jabben, 2007
- Maibach, 2007
- Debrezion, 2006
- van Praag, 2004
- EU WG HSEA, 2003

This commentary documents the situation as at December 18 2008. A number of publications require further study.


This paper, which is a summary of a PhD thesis by Hans Nijland, asks two basic questions;

1. Which European countries are monetising noise effects and which price do they attach to noise?

2. Are differences in price (partly) due to artefacts, like different noise impacts considered or different monetisation methods used?

Information on “geographical coverage”, i.e. in relation to Question 1 above, is based directly on the earlier work of Thomas Odgaard in the HEATCO project – see later.

The information was presented graphically in the following figure;
The authors note that: “there is a clear regional tendency in the treatment of noise. Most countries in the northern part of Europe and about half of them in the eastern part include costs due to noise in their ex-ante evaluation. All of the southern and some of the eastern countries do not consider noise effects in monetary terms. They only do qualitative assessments, or do not assess noise impacts at all.”

The above Figure also shows monetary valuation of road traffic noise to be more common than this valuation of railroad noise. Most countries that monetise noise impacts for railroad traffic apply lower values to railroad traffic than to road traffic at equal noise levels. It is noted that “this is consistent with much research showing that at equal noise levels annoyance due to road traffic will be higher than annoyance due to railroad traffic (for example Miedema et al., 2001)”.

It is noted that very few studies do valuations on rail noise. The Eliasson et al. study is cited one of the few that values both road and railroad noise.

On the issue of **WHICH noise effects** are monetised, the Nijland paper puts forward, by way of overview, the “conceptual model” shown below [Figure 3 of original].

![Conceptual model of transport noise valuation](image)

It notes that, on the basis of the Odgaard report of 2005 from the EU HEATCO project;

“Only France and Denmark take **other health effects of noise** into account by adding additional health costs to the cost of noise annoyance. In France, the cost of noise levels above 70 dB is increased by 30% (Lambert and Lamboki, 2003). In Denmark, it is pragmatically assumed that annoyance costs comprises two third of the total health costs due to noise (Odgaard et al., 2005).”

[NOTE - see later in this Commentary under the heading of the Odgaard study.]

Possible reasons suggested by Nijland for not including other health effects apart from annoyance are given as follows;

- “Noise impact assessment deals with noise loads before and after construction of a (rail) road. Noise exposure before and after is calculated and noise effects are estimated on the basis of dose-effect relationships. These dose-effect relationships are only available for annoyance (Miedema et al., 2001) and sleep disturbance (Miedema et al., 2007, van Kempen et al., in press), both in residential context only.

- Monetisation of noise in the CBAs takes people’s behaviour as a starting point. As noise has no price tag, monetisation of noise is often done by estimating implicit prices for
noise on parallel markets, like the housing market. The higher price of dwellings in a quieter neighbourhood is, ceteris paribus, the price people are willing to pay to avoid negative impacts of noise. As most people are not aware of other noise effect than annoyance (and possibly sleep disturbance), they will not include other health impacts in their market preferences. Consequently, only annoyance (and possibly sleep disturbance) is implicitly monetised. Furthermore, as the method (called hedonic pricing) focuses on houses, its range is limited to the residential context.

Further enquiries on Valuation Methods in France and Denmark

France
Examination of the Lambert and Oboki 2003 paper [Noise valuation practices in road project appraisal in Europe. Proceedings of Euronoise 2003.] shows the following table;

<table>
<thead>
<tr>
<th>Daytime LAeq at the façade</th>
<th>55 – 60</th>
<th>60 – 65</th>
<th>65 – 70</th>
<th>70 – 75</th>
<th>Beyond 75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation index / dB(A)</td>
<td>0.4 %</td>
<td>0.8 %</td>
<td>0.9 %</td>
<td>1.1 %</td>
<td>1.1 %</td>
</tr>
<tr>
<td>Extra costs for long term health effects</td>
<td>+ 30 %</td>
<td>+ 30 %</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It has been established by email enquiries, on 4 December 2008, to Jacques Lambert at INRETS in France that;

1. The basis of the 30% figure for “extra costs for long-term health effects” in France is something of a political compromise between 0% and the higher figure of 50% used in Denmark, and does not have any significant scientific basis.

2. The approach is still in current use in France.

Denmark.

Since the 2008 paper by Hans Nijland is based on the 2005 report, produced within the EU HEATCO project, by Thomas Odgaard from the Danish consultancy COWI, additional email enquiries were made at COWI. Anne Ohm at COWI provided [on December 11] a very useful update on Methods used in that country.

She indicated that;

“A new assessment of the noise price - including a new assessment of annoyance with a hedonic pricing approach and a new assessment of health costs based on a dose-response function - was made in connection with our work with the Danish Noise strategy for the Danish Environmental Agency, published in 2003, unfortunately in Danish:"

Miljøstyrelsen - Forslag til strategi for begrænsning af vejtrafikstøj.htm

She also supplied copies of two related publications in English, from which the relevant paragraphs have been extracted, and presented below, with key text in bold.

A.


“Two main illnesses were selected for further analysis on the indication that these seemed the most important: Hypertension (high blood pressure) and cardio-vascular disease. Based on an epidemiological literature review a dose-response relation was established for this specific purpose, i.e. a relationship between exposure to noise and the risk ratio (increased risk) for the mentioned diseases. The main sources used for establishing the dose-response relationship were Babisch et al. 1999, Maschke 2002 and van Kempen et al. 2002.

A recent analysis carried out by Babisch (2006) confirms that a dose-response curve could be derived and thus underpin the importance of including and quantifying these costs in the valuation of social costs of noise. (See Babisch Chapter 6)”

B

MARGINAL COSTS OF TRAFFIC NOISE - GENERALISED VALUES FOR PRICING POLICIES (NOISE VALUES AET) Presentation at ETC 2004, Strasbourg, France

Health costs
“Some attempts to estimate health costs have been made using available study results, e.g. Schmid (2001) and TRL (2002). As part of the work with development of the Danish noise strategy a first rough estimate of health costs has been made, Danish Environmental Agency (2003b). The estimate is based on an international literature review, Miljøstyrelsen (2003b), Babisch (1999, 2000 and 2002), Maschke (2002), van Kempen (2002) and estimate costs for the selected end-points hypertension and ischaemic heart disease.

The epidemiological documentation for health effects caused by traffic noise is generally weak and without convincing evidence and further research is needed. Recent research points to the importance of night time noise as an important factor, Maschke (2002). For the purpose of the update of health costs the increased risk rates for ischaemic heart disease from the van Kempen (2002) meta-analysis seem to be the best available source and constitute the basis for the estimate. A threshold value of 55 dB(A) is chosen and the same risk rates are assumed to apply to hypertension as well.

The new estimate thus assesses the health costs associated with increased risk for ischemic heart disease and hypertension and include costs of medicine, doctors, hospital costs and a valuation of the premature deaths by a value of a statistical life. The increased risk of death has been valuated by using a WTP approach. Relating the estimated total costs to the total SBT, this results in a unit value of 21.250 DKK per SBT.”

Comment - This recent information on methods used in Denmark provides strong confirmation of, and support for, the emphasis on Cardiovascular effects proposed in the Interim Report on the NEE 01012 project, produced for the October 28 2008 meeting and also confirms that the 2006 review report by Babisch and the 2002 meta-analysis by RIVM provide a good basis for any new methodology.

Further study and enquiries are required to ascertain the exact form of the dose-response function used, and the way the function is incorporated into the overall Danish methodology.
K. Ohlau and R. Friedrich

*External costs of traffic noise: Assessment of noise impacts in using the example of air traffic in Germany. Proceedings of Internoise 2008.*

The paper is somewhat “tantalising” in that it refers initially to the fact that;

“Two major impacts are usually considered when assessing noise impacts:

- Annoyance, reflecting the disturbance which individuals experience when exposed to (traffic) noise.

- Health impacts, related to the long term exposure to noise, mainly stress related health effects like hypertension and myocardial infarction and secondly sleep disturbance like subjective sleep quality.”

It then notes that;

“2.2 Valuation of Health Effects

For the assessment of health effects, analysed in the Study of Schmid (2005), monetary values for health risks are used, which were resulted from the sum of following components (after Hunt 2001):

- Costs for resources: Medical costs, which are covered by the health service or insurances and further personal expenses of individuals or the family.

- Opportunity costs: costs by productivity failure (Working time failure or by performance reduced) and by loss of leisure time, e.g. honorary activity.

- Use loss: Further social and economic costs, inclusive restrictions or pleasure reduced of leisure activities, own discomfort and circumstances of one’s own (pain and suffering), fear of the future and discomfort, worry and circumstances of the family and other.”

However it then comments;

“But for further calculations of external costs in air traffic noise the health effects didn’t play an important role for the total costs (see Schmid 2005), which was also the case for the other traffic noise categories (road, rail and ship). “

Email enquiries have been made to Ohlau and Friedrich at the IER Institute in Stuttgart for more information, but remain unanswered.

The Schmid 2005 papers - in German – have not as yet been followed up.

Neither has the somewhat imprecise Reference 6 from the Ohlau et al. paper.


A link is given in the Ohlau paper to a relevant Deliverable in the UNITE project – UNIfication of accounts and marginal costs for Transport Efficiency


This report, dated 24 January 2003 is “Environmental Marginal Cost Case Studies”- Section 3.3 of the Report deals with the Methodology for Noise.

Relevant parts are extracted below, with key points in bold text.
“3.3.2 Noise impact assessment

Consequences resulting from exposure to transport noise, which affects human life and human health are quantified by the use of exposure-response functions. A large amount of scientific literature on health and psychosocial effects considering a variety of potential effects of transport noise is available. The scientific basis used within UNITE relates to the state of the art summary by De Kluizenaar et al. (TNO Report for UNITE 2001). In their review work, they report risks due to noise exposure in the living environment. Quantitative functions for relative and absolute risks are proposed for the effect categories presented in Table 6.

<table>
<thead>
<tr>
<th>Category</th>
<th>Measure given</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress related health effects</td>
<td>RR</td>
<td>Hypertension and ischaemic heart disease</td>
</tr>
<tr>
<td>Psychosocial effects</td>
<td>AR</td>
<td>Annoyance</td>
</tr>
<tr>
<td>Sleep disturbance</td>
<td>AR</td>
<td>Awakenings and subjective sleep quality</td>
</tr>
<tr>
<td>RR = relative risk; AR = absolute risk</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Eight endpoints for concrete health effects were identified for stress related health effects and exposure-response-functions were constructed. The endpoints are defined in a way appropriate for economic valuation. They are listed, together with the ER-functions used, in Table 7. They were applied as well for road as for rail traffic noise.

<table>
<thead>
<tr>
<th>Endpoint</th>
<th>Expectancy value * (per 1000 adults exposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myocard infarction (MI), fatal; Years of life lost (YOLL)</td>
<td>0.084 $L_{DEN} = 5.25$</td>
</tr>
<tr>
<td>Myocard infarction (non-fatal), days in hospital</td>
<td>0.504 $L_{DEN} = 31.5$</td>
</tr>
<tr>
<td>Myocard infarction (non-fatal), days absent from work</td>
<td>8.960 $L_{DEN} = 56$</td>
</tr>
<tr>
<td>Myocard infarction, expected cases of morbidity</td>
<td>0.028 $L_{DEN} = 1.75$</td>
</tr>
<tr>
<td>Angina pectoris, days in hospital</td>
<td>0.183 $L_{DEN} = 10.5$</td>
</tr>
<tr>
<td>Angina pectoris, days absent from work</td>
<td>0.684 $L_{DEN} = 42.75$</td>
</tr>
<tr>
<td>Angina pectoris, expected no. of morbidity days</td>
<td>0.240 $L_{DEN} = 15$</td>
</tr>
<tr>
<td>Hypertension, days in hospital</td>
<td>0.063 $L_{DEN} = 4.5$</td>
</tr>
<tr>
<td>Sleep disturbance, road traffic</td>
<td>0.62 ($L_{Aeq,23,0.07} = 43.2$)</td>
</tr>
<tr>
<td>Sleep disturbance, rail traffic</td>
<td>0.32 ($L_{Aeq,23,0.07} = 40.0$)</td>
</tr>
</tbody>
</table>

* Threshold is 70 dB(A) $L_{DEN}$ except for b) 43.2 dB(A) and c) 40 dB(A); Other assumptions: MI, 7 years of life lost per fatal heart attack in average; base risk of MI: 0.005; survival probability of MI: 0.7; MI, morbidity; 18 days in hospital per MI, 32 days absent from work; Angina pectoris, base risk: 0.0015; days in hosp.: 14 / severe episode; 20 days of morbidity per episode; $L_{Aeq,23,0.07}$ as assessed outside at the most exposed façade.

Sleep disturbance is quantified by calculating the percentage of the exposed population expected to react highly sleep-disturbance annoyed. The functions are derived from noise effect surveys on self-reported sleep disturbance and night time equivalent sound level at the most exposed façade of the dwelling.
Although ER-functions to predict annoyance reactions on the population level were available, they could not be used in this study. For the valuation of annoyance impacts, expressed as the share of the population reacting little annoyed, annoyed and highly annoyed, no corresponding monetary value was available, where the use of the same definition of annoyance levels was assured. Therefore, another method to value amenity losses due to noise was used based on hedonic pricing.

Section 3.3.3 of this UNITE project Report, which follows on from the above extract deals with Monetary valuation and considers 3 elements:

(a) Resource costs, i.e. medical costs paid by the health service  
(b) Opportunity costs, i.e. mainly the costs in terms of productivity losses  
(c) Disutility, i.e. other social and economic costs of the individual or others

The methods are applied in this UNITE Deliverable 11 Report to 3 countries, Finland, Germany and Italy – and the results are given below.

<table>
<thead>
<tr>
<th>Impact</th>
<th>Finland</th>
<th>Germany</th>
<th>Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myocardial infarction (fatal, 7 YOLL) Total per case</td>
<td>535 000</td>
<td>564 000</td>
<td>528 000</td>
</tr>
<tr>
<td>Myocardial infarction (non-fatal, 8 days in hospital, 24 days at home)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical costs</td>
<td>4 800</td>
<td>4 700</td>
<td>3 700</td>
</tr>
<tr>
<td>Absentee costs</td>
<td>2 900</td>
<td>3 500</td>
<td>2 700</td>
</tr>
<tr>
<td>WTP</td>
<td>15 400</td>
<td>16 300</td>
<td>12 900</td>
</tr>
<tr>
<td>Total per case</td>
<td>23 100</td>
<td>24 500</td>
<td>19 400</td>
</tr>
<tr>
<td>Angina pectoris (severe, non-fatal, 5 days in hospital, 15 days at home)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical costs</td>
<td>3 000</td>
<td>2 900</td>
<td>2 300</td>
</tr>
<tr>
<td>Absentee costs</td>
<td>1 800</td>
<td>2 200</td>
<td>1 700</td>
</tr>
<tr>
<td>WTP</td>
<td>9 700</td>
<td>10 200</td>
<td>8 100</td>
</tr>
<tr>
<td>Total per case</td>
<td>14 500</td>
<td>15 300</td>
<td>12 100</td>
</tr>
<tr>
<td>Hypertension (hospital treatment, 6 days in hospital, 12 days at home)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical costs</td>
<td>1 900</td>
<td>1 800</td>
<td>1 500</td>
</tr>
<tr>
<td>Absentee costs</td>
<td>1 600</td>
<td>2 000</td>
<td>1 500</td>
</tr>
<tr>
<td>WTP</td>
<td>600</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Total per case</td>
<td>4 100</td>
<td>4 400</td>
<td>3 500</td>
</tr>
<tr>
<td>Medical costs due to sleep disturbance (per year)</td>
<td>200</td>
<td>210</td>
<td>200</td>
</tr>
<tr>
<td>WTP (per year)</td>
<td>400</td>
<td>430</td>
<td>400</td>
</tr>
<tr>
<td>WTP for avoiding amenity losses (€/dB/person/year)</td>
<td>20</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

**COMMENT** – the main point to note at this stage is the fact that health effects other than annoyance are included, and that Ischaemic Heart Disease forms the main basis of the valuation of such effects, with sleep disturbance also being included.
This report includes a section on the economic consequences of noise [Section 6. Economy]. However this deals with conventional approach of using Noise Sensitivity Depreciation Index NSDI.


Figure 3 of the MSR Report, based on that 2005 RIVM report shows the number of DALYs per 100,000 inhabitants due to severe annoyance and severe sleep disturbance resulting from transport noise in the Netherlands in 2000 and 2020. It is noted that road traffic plays an important role and is responsible for by far the highest burden of disease: approximately 165 DALYs per 100,000 inhabitants in 2000. The figure also shows that the burden of disease resulting from severe annoyance and sleep disturbance will increase, for road traffic the number of DALYs will rise to almost 200 per 100,000 inhabitants in 2020. When calculating the DALYs, the basis is the annoyance and sleep disturbance calculated based on the exposure-response relationships of Miedema.

In addition, in Sections 4.8 and 4.9, the report goes on to provide some additional examples of use of health effects - annoyance and sleep disturbance - in calculating DALYS and in deriving a valuation based on these.
Based on the calculated number of people suffering severe annoyance and severe sleep disturbance, the number of Disability Adjusted Life Years (DALYs) resulting from noise has been calculated for Rijnmond. Table 5 and Figure 20 show the total number of DALYs and the number of DALYs per 100,000 inhabitants. Every year in Rijnmond, the equivalent of approximately 2,630 life years (260 per 100,000 inhabitants) are lost as a result of people suffering severe annoyance and severe sleep disturbance due to noise caused by transport (road, rail and air) and industry. Road traffic noise makes the largest contribution: the equivalent of 1,880 life years (185 per 100,000 inhabitants) annually. This is somewhat higher than the average in the Netherlands: in the Netherlands road traffic noise is responsible for approximately 165 DALYs per 100,000 inhabitants (Knol 2005).

<table>
<thead>
<tr>
<th></th>
<th>RIJNMOND</th>
<th>DALYs per 100,000 inhabitants (20 years of age and older)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Severe annoyance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road traffic</td>
<td>1,251</td>
<td>123</td>
</tr>
<tr>
<td>Rail traffic</td>
<td>52</td>
<td>5</td>
</tr>
<tr>
<td>Air traffic</td>
<td>51</td>
<td>5</td>
</tr>
<tr>
<td>Industry</td>
<td>608</td>
<td>61</td>
</tr>
<tr>
<td><strong>Severe sleep disturbance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road traffic</td>
<td>629</td>
<td>62</td>
</tr>
<tr>
<td>Rail traffic</td>
<td>39</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2,630</td>
<td>260</td>
</tr>
</tbody>
</table>
Based on the calculated number of people suffering severe annoyance and severe sleep disturbance, the number of DALYs resulting from noise has been calculated for the three cities.

The method uses the Miedema dose-response functions for annoyance and sleep disturbance [2001 2003 etc]

To calculate the DALYs due to noise levels in Rijnmond and in Rotterdam, Amsterdam and Utrecht, the following data are used:

- The number of people who suffer from severe sleep disturbance and the number of people who suffer from severe annoyance due to noise:
- The weighting factors for severe sleep disturbance and severe annoyance:

The weighting factor of 0.02 is derived from the RIVM 2005 report by Knol. It is noted that this weighting factor has a relatively large uncertainty (0.01-0.12 for annoyance and 0.01-0.1 for sleep disturbance) (Knol 2005).

In fact it was not possible to calculate the burden of disease resulting from severe sleep disturbance for Amsterdam, as the required information regarding noise levels was unavailable. Table 6 from the MSR Report – below- gives the number of DALYs per noise source and per city. Table 7 is corrected for the number of inhabitants of 20 years of age and older in the three cities (DALYs per 100,000 inhabitants). Road traffic noise is responsible for the largest burden of disease. Furthermore, the table shows that in Amsterdam aircraft and in Utrecht rail traffic make a relatively large contribution.
Figure 22 of the MSR report, below gives the burden of disease due to road and rail traffic noise in Rotterdam, Utrecht and the Netherlands per 100,000 inhabitants. The burden of disease in Rotterdam and Utrecht is of the same order of magnitude. When compared to the Netherlands, the burden of disease in the two cities is higher. In Rotterdam, road and rail traffic noise is responsible for a burden of disease of 253 DALYs per 100,000 inhabitants and in Utrecht for 264 DALYs per 100,000 inhabitants, while on average in the Netherlands road and rail traffic noise are responsible for a burden of disease of 175 DALYs per 100,000 inhabitants.
NOTE - Although the authors of the Report do not take these calculations of DALYs to the next step of estimating an “economic cost” at this point in the Report, the above data are in fact used in the extensive summary on pages 5 and 6. See below.

Extract from MSR Report summary

Every year in Rijnmond, approximately 2,630 life years (260 per 100,000 inhabitants) are lost as a result of severe annoyance and sleep disturbance due to road traffic, rail traffic, aircraft and industrial noise. As a comparison: for all of the Netherlands this is approximately 170 DALYs per 100,000 inhabitants. Of these sources, in Rijnmond road traffic with 1,880 DALYs is by far the most important. However, the DALYs mentioned resulting from the annoyance caused by noise are the result of using a conservative calculation method, and in reality they could be higher. The reason for this is that the calculation method uses exposure-response relationships and not the data from surveys into annoyance. For the Netherlands, it is estimated that 4% of the people are severely annoyed by road traffic noise, while the surveys using questionnaires show that approximately 25% experience severe annoyance. It should be clear that, in addition to human distress, this also represents an enormous loss due to visits to the doctor, hospital admissions and the like. An amount of € 78,500 can be assumed for every lost year of life. For the given figures of 2,630 DALYs, this means a loss to society of more than € 200 million.
NOTE: From a study of an earlier report, the CE Report by den Boer et al, see 3.4 below, it seems this figure of 78,500 euros derives from the following publication;


On cardiovascular disease the MSR Report comments in the summary as follows;

"With respect to the exact correlation between exposure to noise and cardiovascular disease, there is still considerable discussion. However, it is clear that noise has an influence on high blood pressure and on the chance of a heart attack. Knowledge in the area of noise and health is still developing and it is expected that in the future a generally accepted calculation method will become available to establish this relationship. For the time being, the data related to cardiovascular disease are presented with a degree of caution."

Later in Section 3.4 it notes

3.4 Cardiovascular disease

"Long-term exposure to noise can lead to cardiovascular disease. This mainly concerns effects such as high blood pressure and heart attacks (Berglund 1999, Kempen 2005, RIVM 2008). There are also indications that noise pollution leads to more visits to the doctor, increased use of medication for high blood pressure and more hospital admissions. It is assumed that these health effects are the consequence of stress reactions to noise. In the same way as for annoyance and sleep disturbance there are indications that non-acoustic factors influence the stress effects of noise. Research shows that predictability and controllability have a major influence on people’s reaction (Woudenberg 2006). The influence of road traffic noise on the occurrence of heart attacks and of aircraft noise on the occurrence of high blood pressure has now been sufficiently scientifically established. The degree to which road traffic noise influences high blood pressure is still being discussed in scientific circles. This is among other things because in studies into the effects of noise on cardiovascular disease, air pollution has a disruptive effect. This is because high noise levels often go hand in hand with air pollution, which also has an effect on the occurrence of cardiovascular disease. It is possible that effects could be attributed to noise, while they are actually caused by air pollution, but the reverse is also possible. It is expected that in the coming five to ten years many new results will become available with respect to the relationship between noise and cardiovascular disease. This will possibly lead to more insight into the exact relationship between noise and cardiovascular disease.

The ‘High Blood Pressure and Heart Attack’ appendix indicates the way in which the available scientific information is used to calculate the number of inhabitants of the Rijnmond area who suffer from high blood pressure or have had a heart attack due to transport noise. The numbers for cardiovascular disease that are presented in this report must be considered to give a rough indication of the reality."

And then in section 4.7 it states

4.7 Cardiovascular disease in Rijnmond

As there is ongoing scientific discussion regarding the exact risks (numerical) of exposure to noise, no exact numbers are given in this subsection. Only orders of magnitude are given. As described in the previous chapter, the relationship between exposure to road traffic noise and suffering a heart attack is scientifically proven. The relationship between road traffic and high blood pressure is (still) under discussion, but research indicates that such a relationship exists. When, with this reservation, calculations are made for cardiovascular disease, it
appears that thousands of people have raised blood pressure levels in Rijnmond due to road 
traffic noise. High blood pressure can lead to more serious effects such as a stroke or a heart 
attack. A proportion of the people who suffer a stroke or heart attack will die as a result. For 
Rijnmond this would mean that several tens of people die annually due to noise.

Appendix 6 of the MSR Report, on DALYs notes

Until recently, mortality resulting from high blood pressure due to noise was also calculated 
in DALYs (RIVM 2005, Woudenberg 2006). However, there is scientific discussion 
concerning the influence of road traffic noise on high blood pressure and with it the 
calculation of DALYs from this effect. Therefore mortality resulting from high blood pressure 
is not calculated in DALYs in this report.

Noise Action plans

The Report is also relevant to the present Defra project in that it discusses how “indicators” 
related to the effects of noise on health might feature in the Noise Action Planning process.

The relevant section, from Section 8. Recommendations, page 37, is quoted in full below;

Via the implementation of the action plans, the coming years will see a lot of work being done 
to make Rijnmond quieter. It is possible that this report can play a role in detailing or 
implementing the plans. If this is too late for this year’s action plan, in 2013, the public 
authorities must draw up a new action plan. Around this time, repeating this research on the 
basis of new insights into the health effects resulting from noise could be very useful. In this 
report we recommend that the possibilities available at the supralocal level should also be 
used. It is for instance possible to jointly, in collaboration with other stakeholders such as the 
Ministry of Housing, Spatial Planning and the Environment and EUROCITIES, request that 
Brussels pays more attention to accelerating the (obligatory) replacement of the existing 
 tyres by quieter tyres and to requirements related to the noise production of cars, trucks and 
aircraft. The Central Government can be encouraged to accelerate the payment and 
execution of ISV2 projects and to introduce a system to check the permanent noise 
requirements of the road traffic (periodic motor vehicle test for noise).

The effects of the measures taken must be monitored. A number of possible indicators that 
can be used here have been mentioned in the theme report, such as the (geographic) 
calculation of the noise levels in Rijnmond, the health damage and the economic effects. To 
allow the economic effects and the related cost-benefit analysis of measures to be correctly 
calculated, it is necessary for a study to be made in collaboration with the Tilburg University. 
In addition to these and other indicators, it is necessary to keep up to date with more general 
developments, such as the use of quieter tyres and the European obligations with respect to 
making passenger cars and commercial vehicles quieter.

Indicators have been formulated, based on the opportunities. However, indicators are also 
required that give a picture of the existing or future situation. The indicators do not give a 
complete picture, but give the initial impetus for those aspects that must be monitored in the 
coming years. Unless stated otherwise and if possible, the indicators will be included in the Noise chapter of the main report. Indicators that are already monitored and that are in line 
with the content of this report are:

- Noise levels in Rijnmond (see chapter Space);
- Quiet environmental protection area;
- Reports concerning noise;
- Annoyance due to noise (environmental perception survey);
Higher limit value exemptions;
Progress of remediation of the houses on the A-list and the rail list.

These indicators must continue to be monitored.

New indicators can be:

- Health effects of noise;
- Economic effects of noise levels;
- Noise barriers along national trunk roads and provincial roads
- Quiet asphalt on national trunk roads (ZOAB - very porous asphalt);
- Quiet asphalt on provincial and municipal roads (DGD - thin noise reducing top layers);
- Clean and quiet vehicles for various government organisations (see also the trend analysis in the chapter concerned with social context);
- Clean and quiet vehicles for companies and private individuals;
- Indicators that are in line with the implementation of the various (municipal) action plans;
- Indicators that are in line with the noise aspect of the environmental objectives for companies.

Proper monitoring provides insight into the noise situation and can also provide insight into the effects of the measures (from the action plans) that are taken to combat noise pollution. It is therefore important to link the measures from the action plans to MSR. In the coming years, MSR will work on the development and further substantiation of these and other (improved) indicators. In this way, MSR can serve as a good basis for drawing up the 2013 action plan, as there will then be insight into the effectiveness of the measures that have already been taken.

Health effects, social costs and technical and policy options to reduce road and rail traffic noise
CE Delft 07.4451.27
http://www.ce.nl/pdf/07_4451_27.pdf

This is a wide ranging if somewhat superficial review report, covering;
- The health effects of traffic noise,
- The social costs, including section 3.1 “Valuing the health effects of traffic noise”
- Noise reduction options
- Recommendations for action

Section 3 on “Social cost of noise” is of most direct relevance to the current Defra project.

Most of Section 3 deals with conventional WTP method and, for Western Europe, draws heavily on two earlier valuation studies;

H. Link, et al. 2000
The Accounts Approach. UNITE (UNIficaton of accounts and marginal costs for Transport Efficiency)

INFRAS/IWW, 2004
External Costs of Transport, Update Study
Comparing INFRAS/IWW and Link

Both INFRAS/IWW (2004) and Link (2000) have estimated the social costs of noise due to road and rail traffic. However, their results vary rather widely. The main reasons for these differences are:

- The number of people reported to be exposed to traffic noise differs between the two studies because of the different data sources used. Since the total estimated costs are the sum of the costs for all individuals exposed to noise, the estimated numbers of people exposed to traffic noise directly affects the cost estimates reported.

- Both studies use comparable Willingess to Pay (WTP) figures derived from hedonic pricing studies for noise reduction: about 0.1% of per capita income. However, INFRAS/IWW use these figures to estimate the loss of well-being due to annoyance and sleep disturbance, while Link uses the same figures to estimate the loss of well-being due to annoyance only. In the latter report the monetary value of sleep disturbance due to traffic noise is estimated separately.

- An important difference between INFRAS/IWW and Link is the way fatalities due to traffic noise are valued. INFRAS/IWW (2004) estimate the increased mortality due to health risk and value each fatality using the so-called Risk Value, based among other things on the value of a statistical life, the latter from the literature on valuing the victims of traffic accidents. This method has been criticised because victims of traffic accidents are much younger than victims of heart attacks. For this reason, Link evaluates only the ‘years of life lost’ (YOLL), using a ‘value of a life year lost’ (VLYL). This method, for its part, can be criticised for ethical reasons, because it claims that the lives of elderly people are ‘worth less’ than those of younger citizens.

- Medical costs are estimated in the two studies in entirely different ways. INFRAS/IWW provides estimates for the medical costs of cardiovascular diseases only, thereby assuming that 8% of all the economic costs associated with cardiovascular disease are due to traffic noise. This figure of 8% represents the share of the costs of these diseases attributable to traffic noise of 65 dB(A) and upwards and it is consequently on the basis of the population exposed to this noise level that medical costs are calculated.

Link, on the other hand, uses a series of exposure-response functions to estimate the number of people suffering various health effects due to traffic noise. To value the health effects in these people, Link uses monetary values from ExternE.

The medical costs associated with sleep disturbance are estimated in a similar way.

Details of the exposure-response functions referred to above in connection with the report by H Link et al 2002 are in fact in the UNITE deliverable 11 report summarised above in Section 3.2 on the Ohlau and Friedrich paper.

Examination of the report on the INFRAS/IWW 20004 report,

External Costs of Transport, Update Study

indicates that it deals with “Valuation of Health risks” [ section 2.4.2 ] and that it bases its methodology on Ischaemic heart disease. The studies on which this is based and the values used derived from such studies are given in table 9 of the INFRAs report.

COMMENT – the CE Report of 2007 by den Boer, and the related publications it uses from INFRAS 2004 and the UNITE project, again provide strong confirmation of, and support for, the emphasis on Cardiovascular effects proposed in the Interim Report on the NEE 01012 project, and the use of the Babisch data.

Odgaard, Kelly and Laird. 
*Developing Harmonised European Approaches for Transport Costing and Project Assessment HEATCO.*

*Deliverable 1- Current practice in project appraisal in Europe. Analysis of country reports* 
[http://heatco.ier.uni-stuttgart.de/](http://heatco.ier.uni-stuttgart.de/)

Within the EU HEATCO project Work Package 3 dealt with “Current practice in project appraisal in Europe.” The main categories of the “effects” of infrastructure projects considered as part of project appraisal are listed in Table 3.1 of the report.

<table>
<thead>
<tr>
<th>Table 3.1</th>
<th>11 main categories of effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Construction costs</td>
<td>• Benefits to goods traffic</td>
</tr>
<tr>
<td>• Disruption from construction</td>
<td>• Safety</td>
</tr>
<tr>
<td>• System operating cost and maintenance</td>
<td>• Noise</td>
</tr>
<tr>
<td>• Passenger transport time savings</td>
<td>• Air pollution - local/regional</td>
</tr>
<tr>
<td>• User charges and revenues</td>
<td>• Climate change</td>
</tr>
<tr>
<td>• Vehicle operating costs</td>
<td></td>
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</tbody>
</table>

This part of the HEATCO project is essentially a data collection exercise. The work is reported on 3 levels. The first level is this main report presenting an overview of findings across countries and summarising the actual trend of appraisals in the EU. The second level is the annexes to this report offering more detailed data at country level but in a form of tables making it easy both to study the situation in the countries and compare across the countries. The third level is the full database with all collected data in the form of the country reports. This is delivered to IGCB as a CD-ROM in addition to the main report.

Noise is covered in Section 7 with data tables in Annex VIII.

Thus on page 54, we read;

“All countries, which include noise with a money value in the appraisal, include the effect of noise annoyance. All these take into account the effect of annoyance in dwellings, whereas around half (France, Germany, Lithuania, Slovenia, Sweden and Switzerland) also include the annoyance at other locations.

Only five countries (Denmark, France, Lithuania, Poland and Switzerland) include health related costs related to noise with a money value. Only Lithuania and Switzerland bases
health related costs on a dose-response assessment. [see table VIII.3 of the Odgaard Report below]

This is in fact one of the special features of Swiss practice of project appraisal. The approach is based on a recent study, which showed that noise is related to ischaemic heart diseases and to hypertension related diseases, which both lead to premature deaths (measured in years of life lost) and hospital treatment. In Switzerland health costs are equivalent to one seventh of the costs of noise annoyance (measured by hedonic pricing).”

Typical data tables are as follows

<table>
<thead>
<tr>
<th>Region</th>
<th>Country</th>
<th>Dose-response based on exposure</th>
<th>Other</th>
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</thead>
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<td>North/West</td>
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<td>Spain</td>
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</tbody>
</table>

Codes:
\* No information
\* Not relevant

* Correction made compared to country report: as noise not included with a money value.
NOTE- Differences have been identified between the way the more recent 2008 paper by Nijland and van Wee summarizes the Odgaard 2005 paper, as compared to the way the material is presented in the Odgaard report itself. Thus Nijland only lists Denmark and France as including other health related costs, whereas Odgaard in the 2005 report lists Denmark, France, Lithuania, Poland and Switzerland.

Recent email exchanges with Hans Nijland indicates that, in his view this represents a difference between “practice and theory”, with some countries claiming to have methods which are not used in practice.

**Swiss methods – update**
Because the Swiss method makes specific reference to ischaemic heart diseases and to hypertension related diseases, this matter has been followed up and after email enquiries to Mr Christoph Lieb at the Swiss consultants Ecoplan, detailed reports have been obtained.

**Table VIII.5  Estimation of health related costs**

<table>
<thead>
<tr>
<th>Region</th>
<th>Country</th>
<th>Stated preference/contingent valuation</th>
<th>Hedonic pricing</th>
<th>Other</th>
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<tbody>
<tr>
<td>NorthWest</td>
<td>Austria</td>
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* Codes:
- No information
- Not relevant

* Correction made compared to country report as noise not included with a money value.
The 2008 report is a relatively minor update of the 2004 report, with no changes to the treatment of ischaemic heart diseases and hypertension-related diseases. These very detailed reports, each of the order of 200 pages are in German, but have extensive English summaries.

The summaries do not however give details of the dose-response functions.

These have been extracted from the relevant Section 5 of the report, and are shown below, with an approximate translation of the caption.

**Figure 5.3** [of Swiss Report] Noise level and relative risk for Ischaemic Heart Disease
Examination of section 5 of the Swiss report indicates that the dose-response function for ischemic heart disease is derived both from the work of Babisch, and that of van Kempen at RIVM with the following references being cited. Van Kempen et al. (2002), The association between noise exposure and blood pressure and ischemic heart disease: A meta-analysis. Babisch (2000), Traffic noise and cardiovascular disease: Epidemiological review and synthesis.

The dose-response function for Hypertension appears to derive both from the work of van Kempen and that of Maschke. Maschke et al. (2003), Epidemiologische Untersuchungen zum Einfluss von Lärmstress auf das Immunsystem und die Entstehung von Arteriosklerose.

In both the above cases the original dose-response functions from the research papers have been simplified into linear functions.

As an indication of how the dose-response functions are applied, the relevant parts of the English summary are given below.

It would appear that the method uses the same general approach used by Babisch in his 2006 report, and by Berry in his 2008 report on work for the GLA on Noise and Physical Health Risk in London. In both cases calculations of numbers of people potentially affected by AMI and IHD were made using a dose-response function combined with data on the distribution of the population in various noise exposure bands, to give an estimate of
Population Attributable Risk. The estimates of numbers of people affected are then the basis of the monetary evaluation of health costs etc.

Noise-induced health problems: number of cases
The impact of noise on cases of illness and death has been determined using the concept of the attributable proportion. This is a measure of the proportion of cases of illness and death by which the total would be reduced, if the noise pollution was eliminated. International studies were analysed to derive the dose-response function between noise pollution and the incidence of individual illnesses. The findings are summarised in Table 3 below. Noise leads first and foremost to a relatively sharp rise in illnesses related to hypertension, but also to additional cases of ischaemic heart diseases (myocardial infarction, angina pectoris, etc.). The total of 1,226 years of life lost (983 are due to road traffic, 243 to rail traffic) can be attributed to 143 cases of premature death (114 and 29 respectively).

| Table 3: Overview of years of life lost and illness caused by noise in the year 2000 |
|-----------------------------------------------|-----------------------------------------------|
|                                              | Ischaemic heart diseases                      | Hypertension-related diseases                  |
|                                              | owing to daytime noise                        | owing to nighttime noise                       |
|                                              | Road  | Rail  | Total *) | Road  | Rail  | Total *) |
| Years of life lost                          | 274   | 56    | 330   | 708   | 188   | 896   |
| Working years lost                          | 21    | 4     | 26    | 31    | 8     | 40    |
| Hospital admissions (inpatient)             | 82    | 17    | 99    | 272   | 72    | 344   |
| Hospital admissions (part-inpatient)        | 7     | 1     | 9     | 15    | 4     | 19    |
| Number of days in hospital (inpatient)      | 757   | 153   | 910   | 3,647 | 966   | 4,613 |
| Lost working days (hospital inpatient days only) | 192   | 39    | 231   | 517   | 137   | 653   |
| Outpatient treatments                       | 101   | 20    | 121   | 10,569| 2,800 | 13,369|
| Daily doses of medication (1000s per year)  | 13,370| 3,542 | 16,912|

*) Deviations of ±1 are caused by rounded figures

Valuation of noise-induced health problems
The costs of these health problems are then calculated. Health costs include the following components:
• Medical treatment costs: these include the costs of hospital treatment on an inpatient and part-inpatient basis (infrastructure, doctor, medication, etc.), as well as outpatient treatment (doctor's appointments, medication, etc.).
• Output loss: the health problem caused by noise means that people are prevented temporarily or permanently from participating in the workforce.
• Intangible costs: intangible costs include the loss of well-being, pain and suffering sustained by the person concerned. In particular in cases of death or chronic illness intangible costs may be significantly larger than material costs (treatment costs and loss of output). The table given below sets out the cost rates used per health outcome. To derive these cost rates some difficult valuation issues had to be solved. Particularly important to the overall result is the valuation of intangible costs in the case of years of life lost. To address this, the study applies the willingness to pay approach, which is used to express a reduction in the risk of death in monetary units. Based on international studies, the rate for each year of life lost is 85,000 CHF. Willingness to pay rates from the international literature have also been used to place a value on the intangible costs of illness. Swiss data exclusively have been used to
determine medical treatment costs and the net loss of output (gross loss of output less own consumption). The results are given in terms of factor costs, i.e. indirect taxes (VAT etc.) of 7.7% are not included in the cost rates. This improves international comparability.

| Table 4: Overview of the cost rates applied (in CHF at factor costs in the year 2000) |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Ischaemic heart diseases         | Hypertension related diseases   |
|                                 | WTP | TC   | NLO  | Total | WTP   | TC   | NLO  | Total |
| Years of life lost              | 85,473 | -    | -    | 85,473 | 85,473 | -    | -    | 85,473 |
| Working years lost              | -    | -    | 35,434 | 35,434 | -    | -    | 35,434 | 35,434 |
| Hospital admissions (inpatient) | 14,191 | -    | -    | 14,191 | 1,309 | -    | -    | 1,309 |
| Hospital admissions (part-inpatient) | 1,546 | 502  | 74   | 2,522  | 1,309 | 731  | 41   | 2,081 |
| Number of days in hospital (inpatient) | -    | 902  | -    | 902    | -    | 731  | -    | 731    |
| Working days lost               | -    | -    | 291  | 291    | -    | -    | 291  | 291    |
| Outpatient treatments           | -    | -    | 12   | 12     | 1,309 | -    | 7    | 1,316  |

WTP = willingness to pay, TC = treatment costs, NLO = net loss of output.

COMMENT - again the key point is that the valuation of health effects in the Swiss method is based on Ischaemic Heart Disease and on Hypertension, with dose-response functions being derived from Babisch, van Kempen et al.

3.6.3 Methodologies in other countries - Summary and Conclusions

The email survey produced only a few responses. However, through other means, a number of relevant publications from the past 5 or 6 years have been identified and reviewed. Secondary references arising from these have also been assessed.

Five examples of the use of dose-effect relationships for cardiovascular effects of noise have been noted, in valuation methods and in assessment of noise policy issues. In some cases these are "national" methods, in others the methods have been developed in the context of EU research projects, such as the UNITE project and then applied in comparisons across several countries.

In the case of Denmark and Switzerland, "official" valuation methods applied to road / rail transport are based on such dose-effect relationships.

The information gathered also includes details of how the dose-effect relationships are used within the overall valuation methodologies in these other countries.

Valuable contacts have been established with experts in these other countries, which will enable further exchange of information within this project.
This recent information on methods used in other countries provides strong confirmation of the emphasis on Cardiovascular effects proposed in the Interim Report on the NEE 01012 project, produced for the October 28 2008 meeting and also confirms that the 2006 review report by Babisch and the 2002 meta-analysis by RIVM provide a good basis for any new UK methodology.

3.7 Economist input
We consulted a senior economist to review the overarching approach identified by the IGCB (N). In particular he was asked to consider the means of valuing health effects, asking whether dose-response functions were a suitable approach or if other approaches might also be relevant.

Professor Graham Loomes of UEA provided detailed input, in the form of a discussion paper. The text of this is provided as Annex 3. A summary is provided here.

**Economic Analysis of (Reductions in) the Harm to Human Health Resulting from Exposure to Noise**

Summary

This paper raises the question – do the benefits of noise reductions justify whatever costs may be incurred in achieving them? Or, put slightly differently: if certain scarce resources are devoted to the reduction of noise, does this produce more benefit for the population than could be achieved by allocating those resources to some other use? It is noted that during the past quarter of a century, UK government departments/agencies have explored and developed various methods of trying to incorporate people’s preferences for health and safety improvements into policy appraisal. The paper then provides a detailed comparison of different ways of valuing health/life, including Quality Adjusted Life Years (QALYs), Value of Statistical Life” (VoSL), and Value of a Life Year (VoLY)

It is shown that although there may be ways of making links between different approaches to cost-benefit, cost-effectiveness and cost-utility analysis, there is as yet no simple, robust and comprehensive alignment between them. However, it is also suggested that there is a way of proceeding that is broadly in line with practice in other parts of the UK public sector and that may be able to yield some useful results, albeit subject to certain caveats.

A general procedure is outlined for valuing the damage associated with the two health impacts identified as being of particular interest, namely cardiovascular disease and sleep disturbance. In the case of cardiovascular disease, this would involve estimating numbers of years of life lost. Depending on the strength of the evidence about the average remaining life expectancy of those whose death would be prevented by reducing exposure to noise, and the quality of life that would be expected during those years, it would in principle be possible to assign a value of a full health year and then adjust that for quality, using either the tariff employed by NICE or DALY. It is noted that there is room here for examining the sensitivity of the estimates to various different measures and to different assumptions about the appropriate VoLY figure.)

It is concluded that, although there is no robust simple formula that can generate values across all policy contexts and all levels of health impairment, and although we must be cautious about the extent to which any existing value is the ‘correct’ value, there appears to be scope for putting the valuation of the health impacts of noise exposure on a broadly similar footing to valuations used elsewhere in the UK public sector. Needless to say, there is room for further development of such techniques and for greater co-ordination and
systematization across sectors. However, given the current state of knowledge, an economic evaluation along the lines indicated above, and with appropriate checks for sensitivity to different assumptions, would appear to be entirely feasible and, arguably, highly desirable.

4. GENERAL DISCUSSION OF CRITERIA AND IMPLICATIONS FOR METHODOLOGY

4.1 General criteria for scientific robustness and policy relevance
As in most areas of research, the scientific robustness and policy relevance of the results depends to a considerable extent on the detailed design and execution of the study in relation to the original objectives of that study. Assuming finite resources, the original objectives may often have to be limited or constrained in order to achieve scientific robustness, and there is often a temptation for administrators and regulators to use the results of studies for applications which are outside the range of input variables which were included in the study design.

The main criteria which determine the scientific robustness of any dose-response relationships observed in any study of noise and adverse health effects are;

a) the relevance, statistical representativeness, and measurement accuracy of the dose, or input variables, measured in the research study,

b) the relevance, statistical representativeness and measurement accuracy of the response, or outcome, variables measured in the research study,

c) the range of applicability to other types of noise exposure and/or environment not included in the research study,

d) the range of applicability to other types of adverse health effects not included in the research study,

e) the statistical strength of the observed dose-response relationship in relation to known and/or estimated statistical uncertainty and in relation to the statistical power of the research study as designed,

f) the relative absence of potential confounding variables that could have been equally or more responsible for the observed dose-response relationships,

g) the scientific plausibility of the observed dose-response relationship considered in terms of known or theoretical biological mechanisms.

It should be noted that compliance with the above criteria does not, of itself, prove causality. It is possible, particularly in cross-sectional studies, for two variables to show a strong statistical association without the relationship necessarily being causal. In other words, statistical association does not prove, by itself, that variation in the input variable causes associated variation in the outcome variable. Additional evidence may be required before this point can be accepted or confirmed. The policy relevance of this point is that while statistical association may be enough in many people’s opinion to justify some kind of action, without causality there is no guarantee that management action directed at reduction in the level of an input variable, in this case sound level, would actually have the expected effect on the associated outcome variable.

In addition, the policy relevance of any observed dose-response relationships also depends on the relative applicability of the dose and response variables measured in the research study to specific input and outcome variables that are of interest for noise assessment or noise management policy.

a) The dose or input variables
The two terms noise dose and noise exposure are often used to mean approximately the same thing, although it can be helpful to define precisely different meanings for them. In this report we have used the terms noise dose to describe the amount of noise energy as actually absorbed by a person’s body, and noise exposure to describe the amount of noise measured...
outdoors at a defined position that would be available to be absorbed by a person if a person was there to absorb it and was not protected by being inside a house or by not being there at all. The noise dose could be thought of as being analogous to the amount of chemical absorbed by the human body in studies of chemical toxicity. By convention, and unless otherwise specified, the noise exposure is generally understood to be an indicator of sound levels measured outside a person's house, although this is not always clear. It should be noted that in some studies of noise and sleep, the primary indicators of sound levels are measured inside the bedroom (or sleep laboratory) while in other studies the primary indicators of sound levels are measured outside.

The two words noise and sound also have precisely different meanings, although this is not always apparent in published documents and reports. Noise can be most easily defined as unwanted sound. Most sound is not harmful and if there is nobody present there are no human effects at all, either positive or negative, unless it is the knowledge that the sound exists which deters people from visiting the location. In this case the sound could be categorised as a noise in the sense that it deters people from visiting the location, but at the location itself it would be just a sound because there is nobody present to be adversely affected by it. Sound either means the physical phenomenon of acoustic waves travelling through the air, or it could mean the subjective sensation of hearing (a sound). Tinnitus is a special case where a person experiences the subjective sensation of hearing a sound which is not physically present in the environment outside that person's head. Tinnitus can occur in association with hearing loss after prolonged exposure at very high sound levels, but is not normally associated with typical sound levels of environmental noise. Tinnitus can be categorised as an adverse health effect and can have distressing psychological consequences for some sufferers.

Sound only becomes noise when it interferes with or disturbs some desired activity or is otherwise deemed to be inappropriate. Natural sounds, musical sounds, speech sounds, etc. can all be wanted, neutral, or harmful depending the context in which they occur. Because of this dependence on context and on the attitudes and sensitivities of the listener, it is not possible to discriminate between sound and noise simply from the objectively measurable acoustic characteristics of the sound. In practice, this means that in many published documents the use of the words noise and noise level can be sometimes be ambiguous and may even be misleading. Strictly speaking, in most research studies what is actually measured as the key dose or input variable is the physical or objective sound level. Use of the term noise level can imply negativity that might not be actually present. For example, it is often assumed that all outdoor city sounds (such as local road traffic) are generally negative, and that harmful effects increase in some proportion to the measured sound level. However, there is good anecdotal evidence that there are many people who are not particularly sensitive to outdoor city sounds and some of these people do not like things to be 'too quiet'. For example, many old people who live alone like to be able to see and hear evidence of 'life' going on outside. It is not scientifically rigorous to ignore the possibility that some outdoor sounds may be preferred by at least some of the people who are exposed to them. Unfortunately however, because of the widespread ambiguity between the two words sound and noise as used in the existing research literature and in existing standards and regulations, it has not been possible to make a clear distinction between the two words in this report, and we have therefore in this report been obliged to use the words noise and noise level even in places where sound and sound level would have been technically more appropriate.

Where and what to measure
Starting from the widely held assumption that with all other things being equal most noise effects would be expected to be proportional to the amount of noise dose as actually received by the person, many research studies into the adverse health effects of environmental noise use measurements of outdoor noise exposure as a proxy for the actual
noise dose received by the people included in the study. In any particular situation described only by the sound level (noise exposure) as measured outside a person's house, the actual noise dose received depends on the amount of time that the person spends at home and either outdoors or indoors with the windows open or closed. Any aetiologically relevant psychological components of the noise dose may also depend (to some extent) on the amount of conscious attention being paid to the noise when present. A person who spends very little time at home and when they are at home, keeps the windows tightly shut, is likely to receive a much smaller physically measurable noise dose from the sources present outside the house than a person who spends a lot of time at home, either outdoors, or indoors with the windows open. On the other hand, a person who spends a lot of time away from home could receive a significant noise dose from other noise sources not included in any measurement of noise exposure made outside their house.

Existing regulations and standards generally focus on outdoor measurements because this avoids the many administrative and technical problems of having to deal with differences in outdoor to indoor attenuation between different houses and differences in the amount of time spent at home in different activities. Outdoor measurements can be carried out without having to gain access inside people's homes and avoid the confounding effects of indoor noise sources, some of which can be quite significant. When used in regulations and standards, outdoor measurements focus noise management effort onto practical measures which reduce sound levels generated at source or on measures which increase the attenuation from the source to the outside of the house while ignoring variations due to differences in outdoor to indoor attenuation or the amount of time spent at home. This is often perceived as a useful distinction because, in the UK, most of the policy levers available to administrators and regulators are intended for acting on sound levels at source or on attenuation along the propagation path whilst having no control over individual dose received within that context. On the other hand, where some possibility exists for taking outdoor to indoor attenuation into account, for example, by specifying the required attenuation for noise insulating windows, then the exposure inside the house also becomes relevant as an input variable, even if there is still no control over the amount of time that a person spends in each room, awake or asleep, with the windows open or closed, or quietly reading a book or operating a noisy vacuum cleaner.

If it is assumed that the key input variable determining the adverse health effects of environmental noise is the amount of noise dose as actually received by the person, then it is likely that any lack of correlation between noise exposure measured outside the person's house and noise dose as actually received by the person will significantly reduce any correlation between the noise exposure measured outside the person's house and any resulting adverse health effects. A pilot study carried out as part of the design process for the 2005 Attitudes to Noise from Aviation Sources in England study (ref: DFT website) found that for a limited sample of residents near to Heathrow Airport, there was no correlation at all between personal noise dose as measured using a personal noise dosimeter and outdoor noise measurements outside that person's house, except for limited periods of time when the study participant was sitting down in a conservatory or sun room with limited outdoor to indoor attenuation.

On the other hand, if the main adverse health effects of environmental noise are hypothesised to arise from causes other than, or additional to, the amount of noise energy absorbed by the person, such as from psychological stress caused by unmitigated chronic annoyance, perceived lack of control, or similar phenomena, then the widespread lack of correlation between outdoor measurements of noise exposure and actual personal noise dose could be less important.

Sample measurements of noise dose or noise exposure are not necessarily statistically representative of exposed populations unless the measurements have been applied to the
entire population or the sampling has been designed to ensure that all significant sources of variation have been averaged out. For example, measurements of road traffic noise collected outside specific houses might not be representative of road traffic noise sound levels along the entire street if traffic speeds vary along the length of the street and the topography is not uniform. Road traffic noise sound levels estimated by means of a computer model are only as good as the computer model and the input data to the model will allow. It is unlikely that measurements of road traffic noise collected at the front of a house outside a ground floor window would be representative of road traffic noise sound levels at the back of the house which may be shielded by the structure. Front to back differences are often considered to be less important in the case of single-occupancy houses than in the case of multi-occupancy apartment blocks where individual apartments may only have access to one side of the building. Given that individual or personal noise dose is hardly correlated if at all with outdoor measured noise exposure, it is even less likely that individual or personal noise dose would be correlated at all with outdoor noise exposure measured outside another house some way down the street.

The simple (and possibly naive) solution to this problem would be to measure everywhere and for extended periods of time. However this would be very expensive in both time and resources and might thereby constrain the overall size and scale of the experiment in some other way, which on balance might be considered to be more significant in terms of loss of statistical representativeness. This highlights one of the basic problems of experimental design. For some studies, it may be better to increase the overall sample of respondents and allow a relatively high degree of statistical uncertainty associated with the measurement of each of the key input and outcome variables. For other studies, it may be better to study each individual within the overall sample in greater depth even if it means that the overall sample size would have to be curtailed.

b) The response or outcome variables
There are usually many different ways of measuring the prevalence and/or severity of the response or outcome variables selected for attention in any particular study. Ultimately, most studies of adverse health effects are concerned with diseases leading to, or increasing the risk of, premature death or long-term (i.e. permanent) disability, although according to the current WHO definition, perceived (i.e. reported) quality of life is included along with ‘an absence of disease or infirmity’ within the overall definition of good health. Individual health status can be measured entirely subjectively by using questionnaires or it can be measured objectively by using physiological indicators and medical diagnostic tests. Self-reported health status tends to be less reliable than medical diagnostic tests as a general indicator of adverse health, although on the other hand, self-reported health status is by definition a more reliable indicator of subjectively perceived health status than objective test results. Other indicators are only available on an area basis, for example differences in the supply of different types of medicines as prescribed at different pharmacies for different kinds of disease could vary in different areas with differences in terms of outdoor noise exposure averaged across the entire area. However, unless there is some kind of independent calibration of the extent to which supply might be associated with consumption then drawing any positive conclusions from any observed statistical associations could be problematical. Not all medicines which have been supplied are actually used, and in addition, there is not usually any control over which residents use which pharmacies to obtain their supplies in the first place.

The various indicators available for measuring sleep disturbance associated with, or caused by, night-time noise provide a good example of this general type of problem. Self-reported sleep disturbance can be a good indicator of the extent to which noise-exposed residents feel that the identified noise is having an adverse effect on them, or it might alternatively be reported in support of night noise complaints. However, it is well known that self-reported sleep disturbance is often a very poor indicator of actual sleep disturbance.
Most people are not very much aware of what happens while they are asleep and even if they are wakened by an extraneous noise, during the next day they will not necessarily remember the actual disturbance very clearly, or at all. Where short duration events such as aircraft flyovers cause actual sleep disturbance or even behavioural awakening, there is a high probability that the actual event might have receded and become imperceptible by the time that the affected person has woken up sufficiently to be able to remember the actual cause of the awakening. On the other hand, there is good anecdotal evidence that many people can lie awake trying to get to sleep (late at night or early in the morning having already slept for a few hours) and it is the continued presence of the noise or of a sequence of intermittent noise events that causes the problem rather than the actual magnitude of the sound when present.

Physiological measurements such as EEG (Electro-Encephalo-Gram), heart rate, and blood pressure often show transient disturbances arising at the same time as an intruding noise event. These transient disturbances are not necessarily harmful and might in fact be nothing more than indicators of normal behaviour. However, Babisch, among others (ref: ) considers that transient disturbances which are not harmful when considered individually or separately could accumulate over time to lead to more permanent adverse health effects. Temporarily elevated blood pressure while the body adapts to an external stimulus is a normal response which helps the body to prepare for any action that may become necessary or desirable in response to that stimulus. If, perhaps because the person does not actually wake up, no action follows the preparatory response, then it is possible that an accumulation of so-called stress hormones, or an increased sensitivity to the stress hormones, might occur which could become harmful after repeated exposure over long periods of time. On the other hand, it is equally possible that no long term adverse effects will occur at all, except perhaps in small minority of people who might be peculiarly susceptible to this kind of effect.

These considerations, amongst others, may cause researchers to question the relevance of different identified response outcome variables to the long term adverse health effect of interest. For example, while many studies have shown transient disturbances to noise during sleep, cyclic variation of key physiological indicators during sleep is a well known feature of normal sleep. Transient disturbances should not therefore be considered to be significant adverse health effects on their own unless they also lead onto, or can be shown to lead onto, some more significant chronic or persistent adverse health effect as an intermediate step in a causal chain. In this area, transient disturbances or physiological indicators are of less interest than persistent changes in metabolism or alertness.

The same issues of statistical representativeness and measurement accuracy as previously discussed under sub-section a) the dose or input variables above also apply to the response or outcome variables discussed in this sub-section.

c) The range of applicability to other types of noise

There are many different types of environmental noise and an almost infinite range of different patterns of exposure to those noises. It is effectively impossible for any one study to include comprehensive coverage of all types of noise and all patterns of exposure to those noises. This leaves two main issues which affect the robustness of extrapolations from any single research study to the wider population as a whole; sampling and indicators. It is not (generally) feasible for any one study to include anything more than a very limited range of types of noise and patterns of exposure within the overall sample. In addition to constraints imposed by overall time scale and financial resources, it is not possible (in ecologically valid field studies) to include types of noise and patterns of exposure which cannot be found in that particular region of the country. Including additional noise exposures by artificial means would be ethically doubtful if the intention was to study the possibility of adverse health effects arising as a result of the inclusion.
As an example, when considering *sampling*, a question often arises as to which type of noise is ‘worse’, road traffic noise, railway noise or aircraft noise? It is first necessary to consider the different patterns of exposure arising from typical patterns of road traffic noise as compared to aircraft noise and railway noise. Road traffic noise is typically (although not always) comprised of a more or less continuous sequence of separate road vehicle pass-by events, each of which, on their own, might not be particularly intrusive or disturbing on their own. For road traffic noise it is often the overall sequence of events which continues much the same from one day to the next which is generally believed to be responsible for adverse effects where these exist. The continuity of the sequence varies at different times of the day and night, but the range of variation between one event and another tends to remain more or less constant throughout.

Railway noise and aircraft noise, however, tend to comprise intermittent or irregular sequences of separate events, each of which may be more or less intrusive or disturbing in its own right but which also include significant gaps between the separate events when other sources might be relatively more dominant. Typical patterns of railway noise and aircraft noise (if there are such things), while having instantaneous sound level distributions spread over a wider range than typical patterns of road traffic noise also differ significantly in terms of the range of variability between consecutive events and in terms of variation from one day to the next. All of these variations probably affect reported annoyance and if reported annoyance is different, then the effects of any differences in reported annoyance would also seem likely to affect any adverse health effects arising from any psychological stress caused by the chronic annoyance. It is difficult to imagine any kind of study which could realistically take all these sources of variation into account within the experimental design. Typical patterns of railway noise and aircraft noise, whilst having similarly wider ranges of instantaneous sound level distributions when compared to typical road traffic noise are also different because railway noise events tend to follow a consistent sequence from one day to the next whereas aircraft noise events are much more unpredictable as the pattern of runway use varies depending on wind direction and other factors. Sampling is simple where there is little or no day to day variation in the activity of the source. Close to a main road or busy railway line, a relatively short measurement duration may be sufficient to obtain a representative sample. However, when there is a lot of day to day variation, it becomes increasingly problematical to obtain a representative sample. For aircraft noise, the problem is compounded by the fact that aircraft are usually obliged to use different routes to land and take-off at the airport depending on the wind speed and direction at the time and the relative proximity of any (potentially) conflicting traffic. Measurement durations may need to be considerably extended if representative coverage is required.

The second main issue is that of *indicators*. Mainly for administrative convenience, but probably also because of a not wholly justified belief amongst administrators and regulators in their generalised effectiveness, most research studies use standard indicators based on the long time averaged overall sound level such as LAeq and Lden to describe the amount of noise thought likely to be associated with any adverse effects. Unfortunately, there is a considerable and steadily increasing amount of both anecdotal and experimental evidence which suggests that people tend to perceive environmental noise not as a long time average but instead as a sequence of separate and in some cases intruding or disturbing events. People do not pay attention to everything that is going on around them all the time, but instead can only focus on a limited number of sensory inputs at any one time. Selective attention operates to focus limited cognitive processing power onto the most significant sensory inputs. This often means that steady or continuous sounds such as distant road traffic tend to be ignored unless they directly interfere with some desired task or attention is attracted to them in some other way. Intermittent sounds caused by separate road vehicles,
aircraft or railway trains passing by may attract specific attention, but after an extended period of assumed adaptation and habituation where intermittent noise events are not associated with anything else of interest, many people appear to be able to ignore most external noise events, or at least pay no significant attention to them. The external events which are most likely to be particularly noticed are often the 'noisiest' events (i.e. those with the highest maximum sound levels) or those which are unusual in some other way, for example the character of the sound might be significantly different from the norm. None of this means that the 'ignored' events have no effects on the person, it is possible that the act of ignoring them incurs some psychological or physiological cost, and it is also likely that people still retain some awareness of otherwise ignored events of this type. Many people will notice if external noise caused by road traffic or builders suddenly stops for any reason, even if they had not been paying any conscious attention to the external noise immediately previous to the cessation.

There are no standard sound level indicators which take the possibility of ignorability into account, possibly because the information content of the sounds within the overall context within which they are heard can be of equal or greater importance than the objective or physically measureable sound level. In addition, ignorability cannot be studied by any research method which requires active listening. The technical validity of asking people to report meaningful subjective opinions about sounds which they have not consciously heard is somewhat doubtful. Asking the question will probably encourage respondents to pay attention to sounds which they might otherwise have ignored and thereby give a possibly completely false impression. This issue of possibly focussing attention on sounds which might otherwise be mostly ignored has become an ongoing debate in the context of field study questionnaire design and is difficult to resolve by using questionnaire methods alone.

Acoustic features which may be relevant to conscious perceptions additional to long term average sound levels include the frequency spectrum (which can be measured in a variety of different ways) and the distribution of instantaneous sound levels over time (which could be summarised by reporting the maximum sound levels reached by separate events and the numbers and temporal distributions of those events), and the steady background noise which is always present and determines the threshold below which the sound levels attributable to the separate events would be masked. Prominent tonal or impulsive features tend to enhance noticeability as does doppler shift associated with movement of the source past the observer. The human auditory system has evolved over millions of years to be able to discriminate particular features within sounds which convey useful information to the organism. Indicators of long term average sound levels are more useful for administrative and regulatory purposes than for any correlation against human perception.

In terms of applicability to other types of noise, simple indicators which do not discriminate between different types of noise in the same way as human listeners cannot represent any resulting differences in perception. This means that extrapolation of research data from the type of noise included in the study to other types of noise might not very robust, particularly if the other types of noise are significantly different in terms of features which are not represented by the type of indicators used in the study. If, for example, the other type of noise has features which make it less ignorable or more intrusive at the same long time average sound level than the type of noise included in the original study then extrapolation using dose-response relationships observed in the original study could provide misleading or erroneous predictions. On the other hand, if there is no other suitable data, then extrapolation based on studies carried out on different types of noise may be the only option available.

d) The range of applicability to other types of adverse health effects

There are many different kinds of adverse health effects which people can be afflicted by. The range of applicability of studies addressed to one particular type of adverse health effect
to other possible effects depends primarily on the underlying causal mechanisms. The range of applicability depends on the relative overlap between the various underlying causal mechanisms.

Apart from adverse health effects caused by direct trauma, most other adverse health effects are complex with multiple causes. This tends to imply that research based on one particular set of environmental noise inputs and adverse health effect outcomes might be generally applicable to other adverse health effects with similar underlying causal mechanisms. This is because the human body is very complex with multiple homeostatic systems working mostly in harmony to maintain an appropriate internal environment for life and bodily functions. Diseases are generally 'caused' by imbalances in the body's internal systems or by infections or by some combination of both. Infections can only take hold when the body's immune systems are unable to defeat the infecting organisms, and imbalances may result from previous infections, so it is often difficult to establish any one single cause. Age and lifestyle also have clear roles in modifying susceptibility to different types of disease.

Noise can potentially affect the human body via one of three main routes. The fluctuating pressures created on the surface of the body by incident sound waves cause vibrational waves to travel through the body tissues until the absorbed acoustic energy is eventually dissipated as heat. For typical sound levels of environmental noise the amounts of acoustical energy absorbed by the body are far too small to cause any measurable heating effect, even after extended exposure. The physical displacements of the body tissues are also far too small to be able to cause any direct physical disruption of the tissues. The internal vibration caused by very high levels of very low frequency sound can sometimes be perceived as internal vibration in muscles or body cavities, but this is not necessarily damaging and the very high sound levels which are required for internal vibration to be perceived do not occur with typical environmental noise.

The remaining two routes for noise to affect the human body are both via the human auditory system which is exquisitely sensitive to nanoscopically small amounts of incident acoustic energy. The auditory nerve transmits coded representations of the incident sound to the brain where it can be perceived as sound. The subjective perception of sound depends on the combined effect of the incident sound as detected by the auditory system together with memory and expectation. By exploiting the high level of information redundancy in normal speech, cognitive processing is capable of filling in gaps in running speech which have not been heard because of transient masking and of separating out the speech of different talkers depending on their direction relative to the listener's head. Acoustic reverberation present in enclosed spaces can be subjectively 'tuned-out' when attending to wanted speech sounds while at the same time helping to create a generic subjective impression or ambience of the space. Listeners are not always consciously aware of all the acoustic features of a space which might nevertheless help to influence subjective mood at a sub-conscious processing level. Conscious perception, some of which may be subliminal, can contribute to psychological stress which could in turn contribute to the aetiology of stress-related diseases. This is the psychological route.

There is also a physiological route by which incident sound can have effects on the human body. Incident sound can directly mediate auditory reflexes which operate at an autonomic level to prepare the body for action. The three main components of the acoustic startle response are, firstly, an immediate, fast acting neural reflex which tends to cause the body to freeze rigid and then possibly, to hunch small. The biological purpose of both actions is to make the human body less visible to potential prey and/or predators. Neural reflexes are fast acting and do not persist. The second and third components are both endocrine. The body secretes fast acting (adrenaline) and slow acting (cortisol) hormones which serve to prepare the muscles for action over longer time periods than could be maintained by neural reflexes alone. Each component of the acoustic startle response has a normal biological
function and there is no direct evidence that any component is or should be considered as being maladaptive. However, because of the complex links which exist between all internal body systems, it is not possible to disprove any hypothesis that the various components of the acoustic startle response might aggregate together to cause physiological stress over longer term exposure.

A wide range of possible adverse health effects of noise has been proposed in the literature over the past 20 years and more. Most of these should be capable of being categorised as either physical, psychological, or physiological in nature. As discussed above, it is unlikely that typical environmental noise would have any direct physical effects on the body. This leaves only the possible psychological and physiological effects, also as discussed above. Any stress-related illness could in theory be 'caused' by either psychological and/or physiological stress, or by a combination of both. Therefore, in theory at least, any research which shows a statistical association or a causal link based on the stress hypothesis between an environmental noise variable and a particular adverse health effect should be applicable to other adverse health effects caused by or associated with excessive stress. This is notwithstanding the widely hypothesised notion that different individuals vary in their response to psychological and/or physiological stress. Some people appear to need a certain minimum level of stress to even function at all, while others cannot function if the level of stress is too high. If stress sensitivity levels in relation to one adverse health outcome were correlated with stress sensitivity levels in relation to different adverse health outcomes, then this would increase the relative correlation between the different adverse health outcomes.

e) Statistical strength
The statistical significance of any research finding is only an estimate of the underlying strength of the relationship. If the study does not have sufficient statistical power, then weak but nevertheless causal relationships where the actual prevalence rate of the adverse health outcome is quite small might not be detected. Statistical power arises from the size of the sample compared to the underlying variability not associated with any of the key variables in the study. Increasing the sample size reduces the confidence intervals within which the mean or average values of each variable for the entire population have been estimated by the sample means. Small differences between the mean values of the main outcome variables between noise exposed and non-noise exposed subjects might not be statistically significant if there is insufficient statistical power. On the other hand, a study with very large sample sizes might be capable of detecting very small effects which might turn out to be statistically significant when applying standard statistical tests but which might nevertheless be too small to be of any practical or policy relevant significance.

The levels of statistical significance achieved in any study must be interpreted against the possibility that the study design might not have provided enough statistical power to detect small effects which were not too small to be of no importance if they had been discovered, or against the possibility that very small effects were discovered which were of no practical significance because the statistical power was too high.

It should also be noted that statistical significance is not the only criterion for action. If it is important to avoid even a small risk then a small increase in relative risk associated with higher noise levels may be considered to be sufficient motivation to justify noise management action even if the standard tests of statistical significance are not met. On the other hand, if the anticipated costs of noise management exceed the supposed benefits of the small difference in relative risk then this might be a good reason to accept the finding of no statistical significance as a justification for taking no action. The standard statistical tests generally take a middle ground between avoiding the two types of interpretative error a) that there is a real effect which was not detected by the experiment or b) that the experiment detected an apparent effect which was not real.
f) Confounding variables
Probably one of the biggest problems facing the designers of research studies in this general area is the large number of possible causal factors which could contribute to the aetiology of the adverse health effects under study. If the noise exposed and non-noise exposed populations are not closely matched across all potential confounding variables, such as age, sex, socio-economic status, type of employment, diet, smoker or not, etc. etc. then any observed differences in the mean prevalence rates of the adverse health effects under study could be equally attributable to variation in the unmatched variable. If the potential confounding variables cannot be matched, then more complex statistical models can be applied to estimate their separate contributions to the observed differences in prevalence, but only if there is independent means to allow those effects to be estimated. Particular difficulties arise where there are two or more possible confounding variables which are statistically correlated with the differences in noise level. For example, to date, it has not been possible to devise any study which has successfully separated out the potentially different effects of road traffic noise and road traffic air pollution. Problems arise because locations subject to higher levels of road traffic noise are inevitably subject to higher levels of road traffic air pollution and vice versa. Observed high prevalence rates for adverse health effects in areas exposed to higher levels of road traffic noise might not have been caused by the higher levels of road traffic noise if the higher levels of road traffic air pollution were actually to blame. Or they could have been ‘caused by’ other unobserved differences in the population resident in the high and low road traffic noise areas. It is possible that people who live alongside main roads may be different, on average, in socioeconomic status, family lifestyle stage or simply environmental preference from people who live in quieter back streets. While many of these variables can be allowed for in the experimental design, there is always a possibility that the real ‘cause’ of the observed effect is some other variable which has not been measured and therefore cannot be controlled or otherwise allowed for in the statistical analysis.

g) Scientific plausibility
The scientific plausibility of any observed and statistically significant dose-response relationship also depends on being able to devise a plausible explanation for how the stressor (environmental noise) increases the prevalence rate of the adverse health effect under study. Scientific plausibility is not a pre-condition for policy relevance, but if scientific plausibility cannot be shown, then this is an indication that alternative explanations of the study findings might be available. The scientific plausibility of many of the dose-response relationships observed in recent studies depends on unproven assumptions about the way that normal physiological stress responses, if repeated hundreds or thousands of times over long periods of exposure to noise, might accumulate or aggregate to lead to chronically elevated levels of the same physiological indicators with known associations with other adverse health effects. The possible mechanism for accumulating repeated physiological stress is not understood and hence might not even exist. On the other hand, if statistically significant dose-response relationships have been found (as they have) then the present absence of plausible and fully defensible scientific explanations of the aetiology of these effects is not necessarily a sufficient reason for rejecting the observed relationships which have been shown to exist even though they cannot yet be fully explained.

h) Causality
The final scientific issue which should be taken into account is causality. The statistical analysis of the data obtained in any study does not of itself discover which of the two variables is the cause and which is the effect. Additional information is required to identify which variable is the input variable to the relationship and which is the outcome variable from the relationship. In the case of cross-sectional ecological field studies of noise and adverse health effects, statistical associations between the two variables might be interpreted either way round. Such studies are usually designed to test the hypothesis that higher prevalence
rates for the adverse health effects under study will be found in the higher noise level areas thereby implying (disregarding other confounding variables) that the higher noise levels cause the higher prevalence rates of the adverse health effects. However, it might be difficult to reject the alternate hypothesis that people who are caused by genetic or lifestyle factors to have increased probability of developing the adverse health effects under study are also more likely to find themselves living in higher noise areas. If the alternate hypothesis were true, then management action addressed to reducing noise would have no effect on the prevalence rates of the adverse health effects under study.

Assumptions about causality can be strengthened by the scientific plausibility of assumed causal relationships. For example, if the assumed causal hypothesis, that the noise causes stress which causes increased prevalence of the adverse health effects under study is considered to be biologically plausible and the alternative hypothesis, that people with higher probabilities of developing the adverse health effects under study (caused by other factors) also have a higher probability of finding themselves living in higher noise areas, is considered to be less plausible, then the balance of the evidence would favour (but not prove) the first hypothesis.

Longitudinal or prospective studies where the development of adverse health effects in exposed and non-exposed populations is studied over time go some way towards solving the problem that simple cross-sectional studies do not by themselves provide strong evidence of which variable is the cause and which is the effect. This is because longitudinal studies allow for much improved control of variables associated with each individual who is 'measured' several times during the course of the study. However, convincing interpretation still depends on the biological plausibility of the underlying causal relationship invoked as a way of explaining the results.

i) Policy relevance
The policy relevance of observed results really depends on the potential usefulness of the results for predicting the likely effects of any changes in policy. Therefore, to be relevant for policy, the study has to have included variables as inputs which can be or are available for modification by existing or proposed policy levers. If there are no policy levers available which could have an effect on any of the input variables included in the study, then the study is not relevant to current policy. To apply this test a wide ranging view could be taken as to which policy levers might be made available. For example, it is administratively simpler to manage noise at night against whole night long term average sound level targets notwithstanding the fact that most night time noise problems are caused by separate noise events distributed through the night, not by the whole night long term average sound level. Studies of night time noise effects which address disturbance caused by separate events would therefore be less relevant for policy than studies which use whole night long term average sound levels as the key input variables, even though they might appear to be more relevant in scientific terms.

4.2 Implications for valuation methodology

**Cardiovascular effects**
It is interesting at this stage to consider the dose-response for acute myocardial infarction developed by Babisch in 2006 and which has been the subject of the evaluation by our Statistical Adviser as outlined above. Considering the first 5 of the above criteria, we could say there were “minor concerns” with the Babisch function. Thus the noise exposure measures in each of the different studies which made up the meta-analysis were all harmonised to a measure of a 16-hour \( L_{\text{day}} \) indicator. The primary research only dealt with road traffic noise and such limitations need to be kept in mind when considering the use of the function for other noise sources. Similarly the more general use of the curve for all
Ischemic Heart Disease needs to be treated with caution. There is a large uncertainty in the function, bearing in mind the range of Odds Ratios at each noise exposure category, and in some cases the 95% confidence intervals include the value 1.0.

It would also be true to say there were more substantial concerns over the last two criteria. Thus although many of the potential confounding factors are now well understood, there remain doubts about some of these, for example the role of air pollution. In addition the whole issue of causality and the various possible biological mechanisms is one where residual uncertainties remain. To some extent causality can never be fully proven because of the complexity of the underlying mechanisms and the interactions between factors, and the direct relationship between noise exposure and cardiovascular health outcomes is becomes a “matter of faith”, based on the summation of the various strands of statistical evidence, together with the issue of “biological plausibility”.

However, having noted these concerns, if the limitations are borne in mind, the relationship can still form the basis of a valuation methodology, and indeed has been used as such in a number of countries for policy appraisals. In Section 5 which follows the way the relationship can be used is outlined with an example.

Sleep disturbance
In section 3.4 the sleep disturbance dose-response relationships were already assessed against a number of criteria for robustness. These criteria have been developed further and added to in this section. Next we briefly restate how the sleep disturbance relationships meet the now 7 criteria set out above, using the previous analysis as a base.

The relevance, statistical representativeness, and measurement accuracy of the dose, or input variables, measured in the research study - The reviews have shown that there appears to be no single noise exposure metric or general measurement approach that is generally agreed upon for noise-induced sleep disturbance.

The relevance, statistical representativeness and measurement accuracy of the response, or outcome, variables measured in the research study - There are many different measures of response dependent on the type of response as well as the equipment used. The choice of measurement methods and sleep disturbance indicators is still controversial. The reviews have shown that the diversity of end point analysis (choice of that based on EEG, motility or BCAs) can detract from the clarity of any results. For the purposes of this work it can concluded at present that although there are a number of successful measures of awakenings and of sleep structure changes, it is not clear how these in turn relate to overall impacts on health. This means that we can either adopt a relationship based on awakening and recognize that it is unclear how these lead to overall health effects, or recognize that our current level of understanding of the overall causality chain to health effects is not known, so using awakening as an indicator for overall health effects for policy purposes is not reliable at this time.

The range of applicability to other types of noise exposure and/or environment not included in the research study - It was concluded that the existing exposure-response relationships are not fully representativeness for all types of noise and cannot necessarily be applied outside the narrow context for which they were derived.

The range of applicability to other types of adverse health effects not included in the research study - Many of the relationships have focused on awakening from sleep once asleep but there are uncertainties over shoulder hours, noise can delay sleep onset, and/or hasten final awakening. The relationships derived therefore also fair on a minor level on its point.
The statistical strength of the observed dose-response relationship in relation to known and/or estimated statistical uncertainty and in relation to the statistical power of the research study as designed - Unfortunately, it is only really possible to conclude here that none of the relationships that have been scientifically derived to date, account for a high level of variance and therefore cannot be reliably used for policy purposes.

The relative absence of potential confounding variables that could have been equally or more responsible for the observed dose-response relationships - The reviews of the research have identified a number of factors that limit the applicability of the dose-response relationships to the general population. These factors can be what are termed modifying factors which include perceived predictability, perceived control, trust and recognition, general attitudes, personal benefits, sensitivity to noise, habituation. Vulnerable groups may have a requirement for increased protection and a general population based dose-response relationship may not be applicable for policy purposes. Children have a higher awakening threshold than adults and therefore are often seen to be less sensitive at night but they are in bed longer (including the shoulder hours) so may be seen as an at risk group. With age, sleep structure becomes more fragmented; so elderly people are more vulnerable to disturbance. This is also applicable to pregnant women and people with ill health. Shift workers are also at risk as their sleep structure is under stress. Therefore, in considering using any exposure-response relationship for policy purposes, all these factors have to be taken into account, or caveats clearly set out ring fencing its use.

The scientific plausibility of the observed dose-response relationship considered in terms of known or theoretical biological mechanisms – Our work here has focused on the direct link between noise and awakenings as this has been the most research and sufficient evidence has been found to link the two. However, this is only a small part in the chain as in practice it is very difficult to identify all the cause effect links, let alone disentangle them. The reviews generally concur that there is very little known about the long-term cumulative effects of intermittent sleep disturbance from community noise exposure. It is not known the mechanisms though which noise effects sleep and the interrelations between self-reported sleep disturbances sleep disturbance, extra motility, cardiovascular response, EEG arousals and changes in EEG pattern. In addition it is unclear how these relate to actual longer-term clinical health consequences. We find a general overview that there is a need for more insight into the mechanisms causing the effects and the interrelations between effects.

Policy Relevance - The reviews have shown that there appears to be no exposure-response relationship that sufficiently meets all above criteria for a robust dose-response relationship for noise induced sleep disturbance applicable for policy application in relation to monetary valuation of adverse health effects. Whilst SEL and awakenings seem to give the most reliable relationships, and may be useable for strategic applications other than cumulative health effects, SEL is not a aggregated measure and it is unclear the precise links between awakenings and longer term clinical health effects. Unfortunately, it is only really possible to conclude here that none of the relationships that have been scientifically derived to date, account for a high level of variance and therefore cannot be reliably used for policy purposes. Any tools used in policy application should be applicable to the general population unless it is stated that the policy is to protect a specific subset of the population. The reviews of the research have identified a number of factors that limit the applicability of the dose-response relationships to the general population and therefore limit their use for general policy purposes. To conclude, there does not exist at present any reliable dose-response relationship for noise and sleep disturbed related health effects that could be used for policy purposes in relation to monetary valuation of adverse health effects.
5. OUTLINE OF POSSIBLE VALUATION METHODOLOGY

5.1 General
This section sets out the steps which would be followed in using the Babisch dose-response relationship for cardiovascular effects in an overall methodology for valuation. The outline is given in the form of an example of comparing two scenarios for road traffic noise, where in one case an Action Plan requires that an upper limit is imposed on noise exposure.

5.2 Outline of methodology
The example which follows is based on the work done by BEL for the Greater London Authority in which estimates were made of the numbers of people potentially affected by cardiovascular disease arising from exposure to road traffic noise across the whole of the GLA area.4

The calculation relies on having the following information:
1. An exposure-response relationship between the health effect [expressed as Relative Risk RR or Odds Ratio OR] and the noise exposure, and,
2. Two sets of input data for a given population, for the same given year under consideration - data on the occurrence of cardiovascular disease, and data on the noise exposure of the population to the noise source in question.

Data on the occurrence of Cardiovascular disease
Our particular interest is in the total number of cases of Acute Myocardial Infarction within the population considered.

Data on Noise Exposure
This takes the form of a “distribution” of the percentage of the population exposed to different noise levels, normally in 5dB steps or categories.

Following the conventional terminology in this topic [Reference 3], the number of people affected, either within a given Noise Exposure category, or in total, is known as the Population Attributable Risk PAR.

PAR is itself calculated by multiplying the Population Attributable Risk percentage PAR% by Nc, the total number of cases of AMI – as follows;

\[ PAR = \frac{PAR\%}{100} \times Nc \]

PAR% is calculated from the Relative Risk RR at a given Noise level - which is itself derived from the Exposure-response relationship - together with the Percentage of the population exposed at that noise level Pe, from the following equation;

\[ PAR\% = \frac{Pe/100 \times (RR-1)}{(Pe/100 \times (RR-1) + 1)} \times 100 \]

The calculation of PAR can be done using a MSExcel spreadsheet to implement the above formulae.

This is designed to generate a series of Tables of the generic kind shown below (following the format used in the 2006 Babisch Report);

<table>
<thead>
<tr>
<th>NOISE SOURCE</th>
<th>Relative risk OR</th>
<th>Percentage Exposed %</th>
<th>PAR%</th>
<th>PAR = number affected per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOISE LEVEL dB</td>
<td>55-59</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Once we are able to estimate the actual numbers of people affected at different levels of noise exposure we can proceed to put economic valuations on the effects using Disability Adjusted Life Years DALYs. Thus, for various scenarios, we can calculate the number of cases attributable to noise exposure \( N_c \) and, from mortality rates, the number of deaths \( N_d \).

We then use the standard formula:

\[ \text{DALY} = \text{YLL} + \text{YLD} \]

Where \( \text{YLD} = \text{Incidence} \times \text{Disability Weight} \times \text{Length of time} \)

Then assuming 1 year, \( \text{YLL} = \text{number of deaths} \) \( N_d \) and \( \text{YLD} = N_c \times \text{DW} \times 1 \)

The final step is to assign a monetary value to the number of DALYs.

### 5.3 Example calculation

#### 5.3.1 Input data on occurrence of cardiovascular disease

For the work for the GLA the assistance of the London Health Observatory (LHO) was obtained, and data was extracted and provided on the number of people admitted to hospital\(^5\) under the following International Classification of Diseases ICD codes:

- **Cardiovascular Disease (ICD10: I00 - I99)**
- **Ischaemic Heart Disease (ICD10: I20 - I25)**
- **Acute Myocardial Infarction (ICD10: I21 - I22)**
- **Acute Myocardial Infarction (ICD10: I21)**

**NOTE:** ICD Codes I21-I22 includes I21 which is acute myocardial infarction AMI, and I22 which is subsequent (recurrent) myocardial infarction.

Such data was obtained for the year 2001/2 and for 2005/6.

It was felt that Codes I21-I22 represented the closest “equivalent”, which could be readily obtained, to the data used by Babisch on “occurrence”, or numbers of “cases” of AMI. It was also considered that this would provide a “worst-case” estimate of the potential number of cases in the study.

The full data set is given in Table 8 below.

### Table 8. Occurrence of Cardiovascular diseases in London, 2001 and 2006

<table>
<thead>
<tr>
<th>Disease</th>
<th>Persons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiovascular Disease (ICD10: I00 - I99)</td>
<td>77,489</td>
</tr>
<tr>
<td>Ischaemic Heart Disease (ICD10: I20 - I25)</td>
<td>27,550</td>
</tr>
<tr>
<td>Acute Myocardial Infarction (ICD10: I21 - I22)</td>
<td>5,991</td>
</tr>
<tr>
<td>Acute Myocardial Infarction (ICD10: I21)</td>
<td>5,482</td>
</tr>
</tbody>
</table>

\(^5\) i.e. persons admitted more than once for the same health problem only count as one.

NOTE: this information was provided by the LHO solely for the purposes of the Report for the GLA from Hospital Episode Statistics (Department of Health) for 2001/02 and 2005/06, and must not be used without permission of the LHO.

Mortality
Information on numbers of deaths from AMI (ICD10: I21 - I22), and from Ischaemic Heart Disease (ICD10: I20 - I25), in London, was obtained from the website of the National Centre for Health Outcomes Development (NCHOD) www.nchod.nhs.uk.

The information on numbers of deaths is shown below in Table 9.

Table 9. Numbers of deaths from AMI and IHD.

<table>
<thead>
<tr>
<th>Year</th>
<th>Male deaths from AMI</th>
<th>Female deaths from AMI</th>
<th>Total AMI deaths [persons]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>2451</td>
<td>1886</td>
<td>4337</td>
</tr>
<tr>
<td>2006</td>
<td>1636</td>
<td>1290</td>
<td>2926</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Male deaths from IHD</th>
<th>Female deaths from IHD</th>
<th>Total IHD deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>4482</td>
<td>3347</td>
<td>7828</td>
</tr>
</tbody>
</table>

5.3.2 Input data on the “population noise exposure” to road traffic noise.

Information on the Percentage of the GLA population exposed to different levels of noise from Road Traffic was taken from the “population exposure analysis” in the report on the Defra London Noise Mapping project.

This provides information for Major Roads, defined as “roads within the Transport for London Road Network (TLRN) and motorways”, as well as for “all modelled roads”, designated as All Roads. It should be noted that “all modelled roads” in the Defra London Road Traffic Noise Map means only those roads for which traffic data are available and excludes many small ‘local’ roads, such as within housing estates. However, in most cases, the noise levels from these roads will be much lower and are likely to be below the level (i.e. the 60-65 dB contour band) at which the cardiovascular risk factors are greater than 1.

This data, which makes use of 2001 Traffic flow and Census data etc, is given in Table 10 below, for L\textsubscript{day}, L\textsubscript{12h}, and L\textsubscript{den}.

Because this was derived from Noise Mapping under the Environmental Noise Directive, the noise data relate to annual averages.

Table 10. Percentage of population exposed to different levels of Road Traffic Noise.

<table>
<thead>
<tr>
<th>Noise level</th>
<th>Noise Exposure Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L\textsubscript{day, 12h}</td>
</tr>
<tr>
<td>&lt; 50 dB</td>
<td>72.76 %</td>
</tr>
<tr>
<td>50 -55</td>
<td>7.19%</td>
</tr>
<tr>
<td>60 -65</td>
<td>7.82 %</td>
</tr>
<tr>
<td>65 -70</td>
<td>9.23 %</td>
</tr>
<tr>
<td>70 -75</td>
<td>2.91 %</td>
</tr>
</tbody>
</table>
5.3.3 Calculation of numbers of people at risk
Using the above data and the dose-response relationship of Babisch for Acute Myocardial Infarction AMI, and making the assumption that $L_{\text{day}, 16h}$ and $L_{\text{day}, 12h}$ are numerically equivalent, the application of the formulae for PAR% etc results in the following table.

Table 11

<table>
<thead>
<tr>
<th>NOISE SOURCE ROAD TRAFFIC NOISE</th>
<th>Relative Risk OR</th>
<th>Percent Risk Exposed</th>
<th>PAR%</th>
<th>PAR number affected per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL ROADS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOISE LEVEL $L_{\text{day}, 12h}$ dB</td>
<td>From $L_{\text{day}}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 55</td>
<td>1</td>
<td>72.76</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>55-60</td>
<td>1</td>
<td>7.19</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>60-65</td>
<td>1.05</td>
<td>7.82</td>
<td>0.39</td>
<td>23</td>
</tr>
<tr>
<td>65-70</td>
<td>1.09</td>
<td>9.23</td>
<td>0.82</td>
<td>49</td>
</tr>
<tr>
<td>70-75</td>
<td>1.19</td>
<td>2.91</td>
<td>0.55</td>
<td>33</td>
</tr>
<tr>
<td>&gt; 75 dB</td>
<td>1.47</td>
<td>0.1</td>
<td>0.05</td>
<td>3</td>
</tr>
<tr>
<td>SUM</td>
<td></td>
<td></td>
<td>1.81</td>
<td>108</td>
</tr>
</tbody>
</table>

Thus, of the 5991 cases of AMI, 1.81% or 108 cases are potentially related to noise exposure. Using the above 2001 mortality data the number of deaths would be 78, and the number of non-fatal cases would be 30.

Thus to calculate DALYS;
- YLL = 78
- YLD = 30 X 0.405 [using WHO figure for Disability weight]

\[ \text{DALY} = 78 + 12 = 90 \]

This represents the “status quo”. If for example an Action plan was considered in which the population exposed above 70 dB was zero, we can see from the above that the number of cases would be reduced by 36 to 72. The associated number of deaths would be 52, with 20 non-fatal cases.

The DALY calculation would then be;
- \[ \text{DALY} = 52 + [20 \times 0.405] = 60. \]

Thus the Action Plan results in a reduction of 30 DALYs.

If we took the value of a life year as 78,500 Euros as, used in the MSR report outlined elsewhere in this Report then the noise reduction above would be equivalent to 30 X 78,500 = 2.355 million euro.

It should be noted that this simplified example of the methodology does not take into account the factor of time. There are two aspects to this. It is known that “time of residence” has a bearing on the risk of developing cardiovascular disease. Also the above calculation applies to only one year. The costs would need to be multiplied by the number of years.
It should also be noted that the Babisch curve on which this method is based was derived from a meta-analysis of studies which only involved road traffic noise. To make use of the curve for other noise sources, e.g. aircraft noise, one would have to assume that the same dose-response relationship applied. See page 28 of this report.
6. OVERALL CONCLUSIONS

There is increasing demand for reliable information on adverse health effects of noise to inform noise assessment and policy appraisal.

The main aims of this project were:
- to identify the potential adverse health impacts and review the current state of evidence for each of the impacts; and
- where a robust evidence base exists, to develop robust dose-response functions for the impacts of noise and health which could be applied to policy appraisal in the UK.

These aims have been met in a programme of work in 2 phases reported here.

In Phase 1 of the project the quality and depth of current evidence on the various health effects was reviewed. The effects considered were:
- Annoyance;
- Mental Health effects;
- Cardiovascular and physiological effects;
- Night time effects, sleep disturbance;
- Cognitive effects of noise on children;
- Hearing impairment

This initial review was based mainly on previous published and unpublished reviews. Existing dose-response functions were also reviewed.

Current evidence and dose-response relationships were also reviewed in the light of “additional criteria” which are relevant to the kinds of application which IGCB (N) have in mind.

These criteria are:
- Direct effects, as opposed to indirect effects?
- Nature of the effect/endpoint
- Relevance at typical environmental noise levels?
- How “generally applicable” is the Dose-effect relationship?
- Use of noise-exposure metrics in the dose-response relationships, which relate to EU policy / END etc.

Summary matrices were produced as part of these reviews. Interim conclusions were derived from Phase 1 and recommendations made for Phase 2.

Thus it was found that while evidence exists on the link between noise and all the considered health impacts the primary focus of further work should be on Cardiovascular effects, but that Sleep disturbance [awakenings] should also be considered in more detail.

Phase 2 presents a review of the 2006 review by Babisch and of more recent studies on cardiovascular effects. It also summarises a comparison of studies on hypertension and aircraft noise and deals with input from a Statistical Adviser who was asked to evaluate the approach used by Babisch in the 2006 meta-analysis.

Cardiovascular effects were also the main topic of face-to-face discussions with international experts at RIVM in the Netherlands and in Berlin.

It is concluded that the dose-response relationship proposed by Babisch in 2006 between Lday and Myocardial infarction provides an adequate basis for a methodology to value health effects.
This conclusion is confirmed by a review of methodologies in use in other countries, where a number of countries already have well developed methodologies based on cardiovascular effects.

The views of an expert economist have been obtained on the overall approach to using dose-response functions as the basis of a valuation methodology and his report has been supportive.

The visits to other experts also provided some ideas on “structural challenges” and “institutional reasons” possibly underlying the fact that there has not already broader agreement on dose-response relationships. Thus the following aspects were noted.

- Differences in basic methodology, including regression analyses
- Basic differences in “belief”, about causality
- Institutional inertia where methods already exist
- A bias towards methods based only on national research in a particular country
- Conflicting views of stakeholders.

Phase 2 of the project also included a detailed review of Dose Response Relationships for Noise induced Sleep Disturbance.

There appears to be no dose-response relationship that sufficiently meets all the criteria for a robust dose-response relationship for noise induced sleep disturbance applicable for a methodology to value health effects.

Phase 2 also reviewed other Health effects, and dose-response functions, where available. Indicative dose-response functions were given. These include the dose-response function for self-reported sleep disturbance which, whilst not meeting the strict criteria applied in this project, could be used for assessing Quality of Life or amenity issues and in sensitivity analyses.

A detailed survey/review of Methodologies on other countries has been provided. A number of relevant publications from the past 5 or 6 years have been identified and reviewed. Five examples of the use of dose-effect relationships for cardiovascular effects of noise have been noted, in valuation methods and in assessment of noise policy issues. In some cases these are “national” methods, in others the methods have been developed in the context of EU research projects, such as the UNITE project and then applied in comparisons across several countries.

In the case of Denmark and Switzerland, “official” valuation methods applied to road / rail transport are based on such dose-effect relationships.

The information gathered also includes details of how the dose-effect relationships are used within the overall valuation methodologies in these other countries.

This information on methods used in other countries provides strong confirmation of the emphasis on Cardiovascular effects and also confirms that the 2006 review report by Babisch and the 2002 meta-analysis by RIVM provide a good basis for any new UK methodology.

A general discussion is given of the main criteria which determine the scientific robustness of any so-called 'dose-response' relationships observed in any study of noise and adverse health effects. These are;

h) the relevance, statistical representativeness, and measurement accuracy of the dose, or input variables, measured in the research study,

i) the relevance, statistical representativeness and measurement accuracy of the response, or outcome, variables measured in the research study,
j) the range of applicability to other types of noise exposure and/or environment not included in the research study,
k) the range of applicability to other types of adverse health effects not included in the research study,
l) the statistical strength of the observed dose-response relationship in relation to known and/or estimated statistical uncertainty and in relation to the statistical power of the research study as designed,
m) the relative absence of potential confounding variables that could have been equally or more responsible for the observed dose-response relationships,
n) the scientific plausibility of the observed dose-response relationship considered in terms of known or theoretical biological mechanisms.

The issue of “policy relevance” of the results of studies on health effects is also discussed.

Despite certain concerns about the dose-response relationship for myocardial infarction in relation to the above criteria, if the limitations are borne in mind, the relationship can still form the basis of a valuation methodology, and indeed has been used as such in a number of countries for policy appraisals.

However, in the case of Sleep disturbance, there does not exist at present any reliable dose-response relationship for noise and sleep disturbed related health effects that could be used for policy purposes in relation to monetary valuation of adverse health effects.

We have set out the steps which would be followed in using the Babisch dose-response relationship for cardiovascular effects in an overall methodology for valuation. The outline is given in the form of an example of comparing two scenarios for road traffic noise, where in one case an Action Plan requires that an upper limit is imposed on noise exposure.

During the course of this project we have identified a number of areas where additional research would be very valuable, or where information provided during the course of the project could usefully be followed up. These are briefly outlined here.

1. Sleep disturbance
   One of the factors behind the conclusion noted above, that no single dose-response relationship could be recommended for sleep disturbance as part of a valuation methodology, is the lack of linkage between the transient effects of noise on sleep and possible longer-term chronic health effects. It is recommended that a more thorough review be undertaken to assess if more recent publications are available in this area. Structured discussions with experts in this topic would also be very valuable.

2. Cognitive effects on children
   Only a limited number of high quality studies have been published, such as the RANCH project and although the numbers of children affected is likely to be small as compared to the numbers of people exposed to high levels of road traffic noise, the fact that children are involved gives the issue higher prominence. This is an emerging area of research which should be evaluated further. For example a “follow-up study” of the UK RANCH sample of children has been completed but not fully assessed.
3. **Air Pollution**

   There is a need for more work on the role of air pollution in cardiovascular effects. To date, studies have been limited, and attempts to avoid the normal inter-correlation of high noise levels with high levels of air pollution have not always been successful. Some of this work could involve re-analysis of data from previous studies, such as HYENA.

4. **Other noise sources**

   There are major gaps in knowledge about the health effects of railway noise, and of industrial noise. A limited number of studies have looked at sleep disturbance from railway noise but none have looked at cardiovascular effects. Such studies might have the advantage of having low air pollution levels and thus help to resolve some of the problems of inter-correlation noted above.

5. **Hypertension**

   It was noted during the course of the review of more recent studies that new information on hypertension, and possible dose response relationships is emerging, and this issue should be monitored closely.

6. **Other work in progress**

   During the course of the project, we became aware of a number of ongoing projects, and draft publications, the outcome of which might eventually provide valuable new information. These include for example, the joint paper being prepared by Babisch and van Kempen. We suggest that some mechanism be put in place to update the reviews given in this report in order to assess the implications for a possible Defra appraisal methodology.

7. **Further development of methodology**

   Section 5 above presents an outline of a possible methodology for economic valuation based on cardiovascular effects, and gives a simplified example of its application. There is clearly scope for developing the method and testing it out on a wide range of scenarios.
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Aircraft noise is one of the most noticeable environmental factors of airport operations and is specific to the system. Although there are other noise sources in the system, noise from aircraft taking off and landing, from aircraft braking and taxiing at the airport and from aircraft engine testing are dominant ones. At the airport, noise from ground traffic can be considerable and will in particular affect airport workers. In the vicinity of an airport one will usually find residential locations where air traffic noise is a dominant source of environmental noise exposure. Aircraft noise levels are determined by the position of the runways and the flight patterns. Outdoor aircraft noise exposure in residential areas around large airports may exceed 60 and occasionally 70 dB(A) (day-night or day-evening-night exposure level).

Hearing impairment is a well-documented effect of noise exposure. In an airport operations system it is of concern at operations at the airport, especially in ground handling and in engine testing. Only in very exceptional cases will environmental noise exposure induce hearing loss. The other effects for which there is sufficient evidence for a causal relationship with noise exposure are listed in the table below. Effects are only observed in exposed populations at noise levels above the observation threshold. ‘Sleep disturbance’ in the table denotes a conglomerate of effects, including awakening, sleep stage and sleep pattern changes, heart rate changes, and effects on mood the next day. Limited evidence exists for the effects of night-time noise exposure on performance the next day and changes in hormone levels.

<table>
<thead>
<tr>
<th>response</th>
<th>severity</th>
<th>number affected</th>
<th>observation threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>hypertension</td>
<td>**</td>
<td>**</td>
<td>eq. outdoors sound level (06-22 h) of 70 dB(A)</td>
</tr>
<tr>
<td>ischemic heart disease</td>
<td>***</td>
<td></td>
<td>eq. outdoors sound level (06-22 h) of 70 dB(A)</td>
</tr>
<tr>
<td>annoyance</td>
<td>*</td>
<td>***</td>
<td>outdoors day-night level of 42 dB(A)</td>
</tr>
<tr>
<td>sleep disturbance</td>
<td>**</td>
<td>***</td>
<td>depending on effect, indoors SEL of 35-50 dB(A)</td>
</tr>
<tr>
<td>performance at school</td>
<td>**</td>
<td>**</td>
<td>eq. outdoors sound level (school hours) of 70 dB(A)</td>
</tr>
</tbody>
</table>

1 * = slight, ** = moderate, *** = severe
2 * = susceptible individuals, ** = specific subgroups, *** = substantial part of exposed population
3 threshold for ‘high annoyance’: the day-night level is the equivalent sound level over 24 hours, with the sound levels during the night (period of 23-07 h) increased by 10 dB(A).
4 SEL is the equivalent sound level during the noise event normalised to a period of one second.

A variety of other effects has been linked to noise exposure, such as decreased general performance, biochemical effects, deterioration of the immune system,
decrease in birth weight, psychiatric disorders and negative effects on psycho-social well-being. The committee considers the evidence for the causal relationship of these phenomena with noise exposure to be limited. With the exception of psychiatric disorders (severe), and effects on birth weight and psycho-social well-being (moderate), the committee rates the other effects as slight. There is evidence that congenital effects do not result from the exposure of pregnant women to environmental noise. The understanding of the committee is that, hearing impairment excepted, the public health effects of noise depend on both the (psychological) appraisal of the noise exposure by the organism and the vegetative reactions induced. Some of the somatic and psychosomatic effects, such as hypertension and cardiovascular disease may be a direct consequence of this processing of noise exposure by the organism, others are possibly a consequence of noise-related annoyance. Annoyance is defined here as a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when an environmental factor interferes with a person’s thoughts, feelings or activities. Noise exposure is only one of the determinants of annoyance. Studies have shown that aircraft noise is more annoying than road and rail traffic noise at the same day-night exposure levels. Aircraft noise-induced annoyance is influenced by the degree of anxiety associated with the possibility of aeroplane crashes. Other so-called non-acoustical factors that modify annoyance are the degree of openness on the part of the airport authorities or the government concerning the developments at the airport and the way in which the authorities enforce environmental standards. These latter factors can work both ways, i.e. they can be instrumental in reducing (more openness, strict enforcement) or increasing annoyance. Recent studies appear to confirm older work on the negative impact of aircraft noise on the cognitive abilities of children. The committee deems this to be a subject that warrants further study to elucidate exposure-response relationships and to assess the possible long term impacts.

**HEALTH CANADA 2001**

**Noise From Civilian Aircraft in the Vicinity of Airports - Implications for Human Health - Noise, Stress and Cardiovascular Disease**

2001
ISBN: 0-662-30975-8
Cat. No.: H46-2/01-256E

3.3.1.1 Hypertension - Conclusions

The review of studies that investigated the potential link between hypertension and either aircraft or traffic noise exposure, indicated that the available evidence does not appear to convincingly demonstrate an association between aircraft noise and hypertension.

3.3.2.1 Ischemic Heart Disease - Conclusions

There is no convincing evidence for a causal relationship between environmental noise and ischemic heart disease. At traditional 95% confidence levels used to assess statistical significance, dose response relationships have not been demonstrated. Also, potential trends with improved exposure assessment procedures and increasing years in residence may have been due to chance. Furthermore, the strength of the associations is typically relatively weak, with observed relative risk ratios or odds ratios ranging from 1.3 to 1.6, at most in the Berlin and the Caerphilly and Speedwell studies. In these studies, important confounding factors were taken into account and efforts had been made to reduce bias, including the effort of determining exposures by measurement.
However, the available studies provide some evidence to suggest that there may be a slight increase in the risk of ischemic heart disease in people residing in areas with daily averaged traffic noise levels greater than 65 dBA. This indicates that more research on this subject is needed. Also, there needs to be continued assessment of future research on the potential for cardiovascular risks from aircraft noise. This follows from the relative consistency of elevated risk among the exposure groups with daily averaged sound levels greater than 65 dBA. It also follows from the temporal effect suggested by the increasing odds ratios with years of residence in the Caerphilly and Speedwell study. The need for more research in this area is also consistent with the suggested trend of increasing odds ratios with improved exposure assessment.

The available research does not support the contention that there is a significant risk of chronic stress and/or cardiovascular disease arising from long term exposure to outdoor daily aircraft noise levels above 65 dBA. This corresponds to Noise Exposure Forecast levels of about NEF = 33. (The NEF is used in Canada to characterize aircraft noise in an area.) However, the available studies indicate that more research is needed. Also, there needs to be continued assessment of future research on the potential for chronic stress and cardiovascular risks from aircraft noise. This will ensure that timely and accurate advice can be presented to the public and regulatory authorities to enable them to exercise their responsibility of managing the health risks of environmental aircraft noise.

RIVM 2005

Conclusions and recommendations
This report is a background document that can be used to assess the health impact attributable to noise in the Netherlands. To this end the available exposure-effect-relationships in the field of noise and health were evaluated. This evaluation reveals that the following relationships are suitable for health impact assessment purposes at this stage. These are:
● the relationships for the association between noise from road, rail and air traffic and annoyance derived by Miedema and Oudshoorn (2001);
● the relationships for the association between noise from road, rail and air traffic and sleep disturbance derived by Miedema (2003 and 2004); and
● the relationships describing the effects of noise on the cardiovascular system derived by Van Kempen (2002).
With regard to the effects on sleep, also relationships for awakenings and motility have been proposed. However, the applicability of these curves is rather limited. An important reason is that the effects were only studied at individual level. In order to assess the impact of noise on children’s reading ability, the results of the RANCH-study can be used. Although the results of this study are robust, the interpretation at population level is difficult.
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 climate and 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. For aircraft noise exposure there are indications that the annoyance and sleep disturbance response increased during the last years. Therefore we recommend the use of national reference data if available. If this is not possible, the generalised relations published by Miedema (2001) (2003) (2004) could be used to estimate annoyance and sleep disturbance levels.
Despite the fact that the underlying mechanisms are plausible and the large amount of
available data, the epidemiological evidence for an association between noise and cardiovascular disease is limited. At the moment, some risk estimates for road traffic and aircraft noise are available for adults which can be used. The thresholds of no-effect to be used and the shape of the curve are still debatable. In order to get a feeling how these uncertainties might affect the estimates, we recommend that they are accompanied with a sensitivity analysis. As an alternative for the meta-analysis, one could also decide to use the results of a more recent and better study, when estimating the noise impact on cardiovascular disease. When doing this, one should check whether the study has sufficient power and whether the investigated sample is comparable with the Dutch population.

H Miedema.2007
*Exposure-response relationships for environmental noise*
*Proc Internoise 2007 Paper 07-179 CDROM*
This paper presents an overview of exposure-response relationships that can be used for assessing the impact of environmental noise. It covers - Annoyance [transportation noise, stationary industrial noise and combined sources], Sleep disturbance, and myocardial infarction MI.
Miedema used the data in the above Babisch review of 2006 to arrive at the relationship for MI. See Figure 6 below

![Figure 6 from Miedema 2007](image)

**Figure 6 - from Miedema 2007.** [The points that indicate the relative risk (RR) of myocardial infarction for different noise exposure classes, and a line fitted through these points - based on Babisch - assuming that in this case odds ratios can be equated to relative risks and that for road traffic $L_{den} = L_{06} - 22 + 2$.]

CLARK AND STANSFELD 2007


This narrative review evaluates recent studies of transport noise that have advanced or synthesized the knowledge about several non-auditory effects: namely,
hypertension and coronary heart disease, stress hormones, sleep disturbance, mental health, and cognitive development: effects for children and adults are discussed.

Note- ANNOYANCE NOT REVIEWED – SEE BELOW

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It is beyond the limits of this paper to include a review of the effect of noise exposure on annoyance responses. Annoyance is a multifaceted psychological concept including both evaluative and behavioral components (Guski, Schuemer, & Felscher-Shur, 1999), used to describe negative reactions to noise. Annoyance is an important health effect of noise (WHO, 2000). Annoyance is the most reported problem caused by transport noise exposure and is often the primary outcome used to evaluate the effect of noise on communities. Acoustic factors such as noise source, exposure level and time of day of exposure only partly determine an individual’s annoyance response: many non-acoustical factors such as the extent of interference experienced, ability to cope, expectations, fear associated with the noise source, noise sensitivity, anger, and beliefs about whether noise could be reduced by those responsible influence annoyance responses (WHO, 2000). Studies have derived exposure-effect associations for the effects of different noise sources on annoyance responses (Miedema & Vos, 1998; Miedema & Oudshoorn, 2001), finding that aircraft noise produces greater annoyance responses than road traffic noise at the same level of exposure.

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In summary, there is convincing evidence for non-auditory effects of noise on health and cognition for some outcomes. Evidence for the effect of aircraft noise on children’s cognitive performance is strong. Evidence for health outcomes is increasing and there is consistent evidence for a small but significant effect of transport noise on hypertension and coronary heart disease. Furthermore, there is sufficient evidence for an effect of noise on sleep disturbance. Evidence for an effect of noise on endocrine markers is weak and inconclusive, especially for adults. Health effects of noise on the endocrine system cannot yet be ruled out and further, large scale studies are required focusing on adults. Evidence for an effect of noise on psychological health suggests that for both adults and children noise is probably not associated with serious psychological ill-health but may affect quality of life and well-being. As yet, there are no prospective studies published on the effects of noise exposure on psychological health and few studies examine psychiatric diagnoses. The conclusions from cross-sectional evidence should be treated cautiously, as individuals who are experiencing poor mental health are more likely to also evaluate the environment negatively, bringing into question the direction of causality between noise exposure and mental health.

In conclusion, noise is a main cause of environmental annoyance and it negatively affects the quality of life of a large proportion of the population. In addition, health and cognitive effects, although modest, may be of importance given the number of people increasingly exposed to environmental noise and the chronic nature of exposure. Future research needs to further develop understanding not only of the magnitude of effects and exposure-effect relationships, which can inform interventions and policy, but also needs to further consider mechanisms for the effects such as the role of annoyance, adaptation, habituation, acclimation, and coping strategies and the role these may play in non-auditory effects of noise.
Annex 2. Other projects in Progress [see also report of visit to Babisch]

Vancouver study
From the Proceedings of the ICBEN 2008 conference, we have noted the following;

Joint effects of noise and air pollution: A progress report on the Vancouver retrospective cohort study.

Hugh W. Davies, P.A. Demers, M. Buzzelli, M. Brauer
University of British Columbia, Vancouver BC, Canada

Abstract
To investigate the joint effects of noise and air pollution on CVD, we are following an adult population of all those 45-85 years old in 1999 who have lived in the Greater Vancouver Regional District (GVRD) for 5 years (approximate N=800,000), including a sub-cohort who had a significant co-morbidity in the preceding 5 years (the 'susceptible cohort'). Residential histories and health outcomes (deaths, hospital admissions, and potentially all physician visits, pharmacy records) were linked through administrative health records. Exposure assessment for noise and air pollution were obtained by computer modeling using Cadna/A mapping software for the former, and land-use regression modeling for the latter. Disease rates in various exposure groups will be examined by tradition epidemiologic strategies. To date, the cohort has been created and air pollution level surfaces prepared. We are currently producing a noise 'map' for the metropolitan Vancouver area, the first of its scale in North America. We will present the project methodology in detail, project findings to date, as well as discuss the challenges faced and the expected outcomes of the study, as well as future opportunities for research with this new tool.

EU ESCAPE project
Also, through our discussions with RIVM, we have also been made aware of the ESCAPE project - ESCAPE: European Study of Cohorts for Air Pollution Effects.
http://www8.umu.se/phmed/envmed/aktuellt/dokument/text%20folder%20ESCAPE.pdf

The ESCAPE project is a study on the health effects of outdoor air pollution financed by the European Union. It is conducted by 24 universities and research institutes spread over Europe. The project is coordinated by Utrecht University in the Netherlands.

In some selected cohorts (on cardiovascular endpoints and mortality), RIVM intend to assess the road traffic noise exposure to look into the combined effects of air pollution and noise. Results to be expected in 2012-2013.

TNO project – Eindhoven
Through RIVM we are also now aware that TNO in the Netherlands are currently working on cardiovascular health effects of combined exposures (noise and air pollution) in another large cohort study in the Eindhoven area. This is similar to the previous Groningen study reviewed in Annex 2 of this Report. The results of the Eindhoven study are not yet published. Preliminary results were published at ICBEN and the ISEE/ISEA conference (USA) this year.

1. Introduction

There now appears to be some strong evidence that exposure to noise – at least, above certain levels – can have adverse effects on human health and life expectancy. On this basis, it might be supposed that measures which reduce some kinds/levels of noise exposure will reduce the prevalence and/or severity of certain adverse effects on human health. The question is then: do the benefits of such reductions justify whatever costs may be incurred in achieving them? Put slightly differently: if certain scarce resources are devoted to the reduction of noise, does this produce more benefit for the population than could be achieved by allocating those resources to some other use?

The latter, somewhat broader, question raises two issues. First, it allows for the possibility that a reduction in noise may generate other benefits in addition to health benefits – for example, there may be a reduction in the (possibly considerable) annoyance people feel about the disturbance of their work or leisure activities (including sleep), with possible implications for productivity. Second, it puts noise policy in a broader public policy context: even if the benefits from some set of noise reduction measures are greater than their estimated costs, there might be even greater public benefits that could be produced by using the resources in some other way – improving road safety, for example, or reducing the risks of being a victim of crime, or a host of other potential benefits.

In order to allow diverse benefits to be compared with one another and with the costs of producing them, it is desirable to measure them all in the same currency – i.e. place a monetary value on them all. While the relationship between the standardised monetary value of all benefits of a project and the standardised monetary value of all costs is not the only factor that policymakers may wish to consider⁶, it is potentially a valuable piece of information.

Cost-benefit analysis (CBA) is generally regarded as preferable to Cost-Effectiveness Analysis (CEA) in all circumstances where there are different forms of effect/outcome that cannot easily be weighed or traded off against each other. However, CBA poses the problem of how to assign appropriate money values to diverse non-monetary benefits. This will be addressed in the next section of this paper.

However, another crucial component of any policy appraisal involves establishing just what a particular intervention may be expected to achieve. Ideally, this will involve the use of impact pathway analysis (IPA). In the case of noise, this involves trying to establish the connection between the level/pattern of exposure to noise emissions and the effects of such exposure (estimated subject to confidence intervals) on whatever outcomes are deemed relevant (e.g. morbidity, mortality, annoyance, productivity). In principle, such analysis allows the likely effect of any intervention to be judged in terms of those outcomes, to which monetary values may then be assigned and compared with the costs of implementing the intervention.

⁶. Policymakers may also be concerned about distributional issues – for example, even when the aggregate money sums are the same, greater weight may be given to reducing the noise nuisance suffered by a small number of people exposed to very high ‘doses’ than to a larger number of people whose baseline exposure is much lower. For a general discussion of the history of the deployment of CBA and some of the limitations or caveats involved, see Turner (2006).
In practice, the informational demands necessary for a comprehensive IPA may be substantial, and even then there may be many remaining sources of variability and uncertainty. These may be such that some judgment needs to be made about the balance between the costs of collecting more data and/or undertaking more research or modelling and the likely benefits of doing so. Such issues are discussed elsewhere in this report. However, once those outcomes deemed relevant have been identified, and once there is some prospect of estimating the effect of interventions upon those outcomes, we then must address the issue of how to assign money values to them. The remainder of this chapter discusses this issue with particular reference to health outcomes in the form of both morbidity and mortality.

2. Background

During the past quarter of a century, UK government departments/agencies have explored and developed various methods of trying to incorporate people’s preferences for health and safety improvements into policy appraisal.

In the 1980’s, the then Department of Transport moved away from the old system of valuing the economic loss associated with a transport accident fatality in terms of the estimated damage to Gross Domestic Product and began to use a ‘value of statistical life’ (VoSL) measure which included a substantial element representing people’s stated personal values for reducing the risks of premature death. Because the terminology of a ‘value of statistical life’ has been regarded by some as giving a potentially misleading impression, the same concept is also referred to as the ‘value of preventing a (statistical) fatality’ (VPF). Later work (in the 1990s) extended this approach to include values for preventing non-fatal injuries (VPFs) of various severities. Such monetary values can be (and are) used directly as inputs into cost-benefit analyses of schemes which have substantial safety implications.

Meanwhile, the then Department for Health and Social Security became increasingly interested in using cost-effectiveness – or perhaps more accurately, cost-utility – techniques revolving around the Quality Adjusted Life Year (QALY) as a measure of the benefit generated by health care interventions. The attractiveness of each health care intervention might then be reflected by the ‘cost-per-QALY’ involved, with those delivering QALYs for a lower cost-per-QALY being regarded as better value for money, all other things being equal.

Those two approaches still co-exist in the UK, supplemented by other variants/hybrids. In the next section, more will be said about each of these measures, their underpinnings and the relationships between them. The fourth and final section will then draw out from that discussion the possible implications for the economic analysis of the health impacts of exposure to noise.

3. Different Ways of Valuing Health/Life

3.1 QALYs

The key idea underpinning the QALY is that people are not exclusively focused on the extension of remaining life expectancy as the sole measure of the value of a health care intervention but are also concerned with the quality of their health during their lives; and indeed, may be willing to ‘trade’ between the two. For example, people may be willing to undergo unpleasant treatments and endure periods of reduced quality in order to increase their life expectancy; but they may also prefer to forego some debilitating or disfiguring intervention in order to have a higher quality of life, albeit for a shorter period of time.
Indeed, the current quality of life ‘tariff’ endorsed by the Department of Health and by the National Institute for Health and Clinical Excellence (NICE) is derived from ‘time trade-off’ questions of the following form. In any particular question, a ‘health state’ was described in terms of various levels on a standard set of health dimensions, and a representative sample of members of the public was asked to contemplate spending the next 10 years in that state of health, followed by death. They were then asked how many years (up to 10) in full health they would regard as being just as good as 10 years in the impaired health state they had been considering. If an individual judges that 10 years in health state H is equivalent to, say, 7 years in full health, the inference drawn is that the individual is effectively assigning a quality of life index number of 0.7 to that impaired health state H (so that the number of years spent in that state multiplied by its quality of life index number converts it to 7 QALYs).

Put another way, going from 10 years in full health to 10 years in the impaired health state entails a loss of 3 QALYs. So an intervention which prevents such a loss (or alternatively, a treatment which cures the impairment and restores the individual to full health for those 10 years) generates a benefit of 3 QALYs. If such an intervention costs, say, £120k (once any other costs and benefits have been factored out), the cost-per-QALY is £40k.

In principle, all interventions could be ranked according to cost-per-QALY, with those that deliver QALYs for the lowest cost being given highest priority. But where should the cut-off point be? At what cost-per-QALY would an intervention be deemed to give too little value for money to be worth allocating scarce resources to it? Broadly speaking, when NICE is asked to judge a new medicine, it will rarely hesitate to approve it if it has been shown to produce QALYs for £20k or less; whereas if the costs work out at more than about £50k per QALY, there will generally need to be some compelling ‘other considerations’ before NICE will approve its use in the NHS. As an approximate guide, the ‘threshold’ for NICE approval and hence the allocation of public money to provide this treatment in the NHS has in recent years been in the region of £30k per QALY (see, for example, Devlin and Parkin, 2004).

However, the origins of, and justification for, the £30k threshold are uncertain and contested, and the issue of whether this is the appropriate figure is currently subject to debate and review. By contrast, the origins of, and justification for, the figures used in transport safety policy are much clearer and seemingly well-established.

3.2 VoSLs / VPFs / VPIs

Many typical road safety measures entail reductions in the risks of death and injury which are really quite small as far as any individual road user is concerned but which, when delivered to thousands or tens of thousands of road users, may be expected to prevent a number of deaths or injuries that would otherwise have occurred.

The principle underlying what has come to be known as the ‘willingness-to-pay’ (WTP) based approach is that the value of the risk reduction afforded to each individual is reflected by the money they would be prepared to divert from other sources of gratification/utility/wellbeing in order to achieve that reduction. Their collective WTP is therefore a measure of the overall

7 Another measure, known as a Disability Adjusted Life Year (DALY), has also been developed. In principle, it can be operated in much the same way, although it is based on a different system of health loss descriptors and the values assigned to such losses are based on ‘expert/clinical judgment’ rather than samples of the population at large. And there are other systems that might be used for indexing the quality of life in diverse health states. The details of each system and the differences between them need not detain us here, since the underlying principle of converting different health state profiles over various periods of time to some single comparable quantitative scale is the essence of the approach.
value to be assigned to the numbers of deaths/injuries thereby expected to be prevented. For example, if a million road users would each have their risk of being killed on the roads reduced by 0.00001 during the lifetime of a particular road safety intervention, that intervention would, overall, be expected to prevent 10 fatalities. And if each of those million road users (or their households) thought that the reduction in the risk to them was worth, say, £15 on average, then they would between them value the benefit at £15m. If (once all other costs and benefits have been netted out) it costs less than £15m to implement this particular road safety measure, it passes the basic cost-benefit test. Moreover, if this case is typical and any large sample of the population would state values that average out at about £1.5m for each fatality expected to be prevented, road safety cost-benefit analysis more generally can use a VPF of £1.5m to represent the value placed by the public on potential life-saving interventions of this kind. The corresponding values of preventing injuries of various degrees of severity can be derived according to the same principles.

Of course, the VPF terminology must not be interpreted TOO literally. The safety measure is not, strictly speaking, preventing the death of some individuals: they will in due course die of other causes. What it is really doing is preventing some people dying earlier than they would otherwise have done, and it is thereby giving some people more years of life than they would otherwise have had. In fact, given the age-distribution of road accident fatalities, the average prevented fatality entails something like 40 extra years of life expectancy, much of it likely to be in good health. So it is not obvious that a VPF of £1.5m (which is, in round terms, more or less the current figure used in transport safety appraisal) would be the appropriate figure to use for other kinds of interventions in other parts of the public sector. For example, consider an intervention that prevents, say, some strokes among people predominantly in their 70s and 80s with, on average, perhaps 10 years of remaining life expectancy, some of which might anyway be spent in quite poor health. To assign the prevention of fatalities of this kind the same £1.5m value that is used in transport safety could be seen as being equivalent to giving a zero value to the 30 years of life (between 40 and 70) in typically good health that the beneficiary of the road safety measure could be expected to enjoy. And this would seem to many people to be a puzzling, or even absurd, thing to do.

One possible way of dealing with this, in principle at least, would be to mount a separate survey to elicit a value for preventing a late-life fatality of the kind envisaged in the stroke scenario above. But then where would this stop? How many other premature death / injury / illness scenarios would require their own tailor-made surveys?

An alternative would be to use a value for a specified unit of time, such as the ‘value of a life year’ (VoLY), or its close relative, the ‘value of remaining life expectancy’ (VoRLE).

3.3 VoLYs and VoRLEs

In many studies designed to estimate a VPF, there has been some interest in trying to identify the characteristics of respondents that systematically influence the VPF. Regression analysis has identified two that frequently show up as significant influences: the incomes of respondents, and their ages.

In the case of income, the relationship seems fairly straightforward: the more people earn, the more they say they are willing to pay for a given reduction in risk. (Note, however, that UK policy does not use different values for different income groups: the same value is applied irrespective of the income of potential beneficiaries.)

In the case of age, things are less straightforward. There seems to be some consensus that the empirical relationship follows an ‘inverted-U’ shape: all other things being held constant, the VPF tends to rise as the age of respondents increases from around 20 to around 40, peaks/plateaus between 40 and 60, then tends to decline thereafter. What is arguably
somewhat puzzling about such a relationship is the early part of it: since 20-year-olds have quite a few more years to lose than 40-year-olds, one might expect the VPF to be even higher for those in their 20s than those in their 40s. But the usual regression analysis suggests otherwise. Several possible reasons for this have been suggested. One is that young people may simply be unrealistically optimistic about their own chances of survival – the 'recklessness of youth' – while older people, perhaps more conscious of parental responsibilities and more aware of their own mortality, may give greater weight to the same magnitudes of risk. Another more technical argument is that the imperfections of financial markets constrain young people's spending (and therefore WTP) to a greater degree than their lifetime expected wealth would allow, were financial markets to operate more perfectly. A third possibility is that the functional forms used in standard regression analyses may be mis-specified in some way that produces the inverted-U as an artefact.

But whatever the reason, it might be argued that policy should accord at least as much value to preventing the death of a younger person as to preventing the death of an older person, all other things being equal. And arguably, should set aside any recklessness of youth, financial market failures and/or econometric mis-specification and actually place strictly higher values on preventing death among those with greater remaining life expectancies.

One very simple way of doing this is to work on the basis of assigning a standard value to a life year and computing the expected life years gained as a result of an intervention. This approach offers some prospect of 'joining up' the WTP-based VPF approach with the QALY approach: the VoLY for a full-health life year could be seen as the monetary value of a QALY, and the VPF could be seen (in a world free from judgment biases and market imperfections) as the sum of an individual's (possibly time-discounted) values of expected remaining life years. A slightly more sophisticated way of doing this might involve acknowledging that the value of remaining alive is not simply proportional to remaining life expectancy and that as people get older and remaining time gets shorter, they may value each year even more highly (at least, so long as they are in reasonable health). Such a modification is not too difficult to model, can be reconciled with the shape of the latter part of the 'inverted-U' VPF-age relationship and also, arguably, with NICE's inclination to allow higher weights for QALYs that relate to life-extending interventions for people with low remaining life expectancies.

Were one to adopt the VoLY approach, how should the value be determined? One approach would be to start with the VPF that is currently used in transport policy and to derive a VoLY (or a value of a QALY) consistent with that. This seems, in effect, to be what the 2005 Treasury guidance is endorsing in its example in Box 6 on page 29. Using somewhat more sophisticated methods than in that highly simplified example, more recent work has derived (undiscounted) VoLYs in the region of £38k-£40k (and, after adjusting for quality of life reductions especially in later years, values of QALYs in the range £46k-£48k)9. Much the same approach, pegged to a VoLY of roughly £30k for people with 30-40 years of remaining life expectancy, would imply a VoLY of £40k-£50k for those with some 5-10 years of remaining life expectancy.10

Another possibility is to use a value elicited more directly. The 2004 study commissioned by DEFRA to value the health benefits of reducing air pollution asked respondents to state

9 See Mason et al (2008): the figures cited are those from Table II derived using Approach 2b.
10 See Jones-Lee et al (2007), especially Table 3.1 and Figures 3.1-3.3.
their willingness to pay for reductions in air pollution that would generate various specified benefits. One of these was some increase in life expectancy in full health; another involved extending life in poor health; and they were also asked to value the avoidance of an emergency hospital admission with respiratory problems, as well as valuing a reduction of the numbers of days of breathing discomfort suffered by those adversely affected by ‘bad air’ days. On the basis of this study, DEFRA endorsed a value of £27,630 (at 2004 prices) for an extra year in full health; a figure in the range £7,280-£14,280 for an extra year for someone in poor health; a figure in the range £1,310-£7,110 for preventing an emergency hospital admission; and £7-£30 for each averted person-day of breathing discomfort. It should be noted that the figure of £27,630 for a full-health year was one of three estimates generated by the study (the others were substantially lower, at £6,040 and £9,430); nevertheless, that is the one which has been adopted as the basis for economic evaluation.

3.4 VoLYs and (monetary values of) QALYs

As indicated in the previous subsection, one way of trying to reconcile VPFs, VoLYs and QALYs is to derive a VoLY from the relationship between VPF and age, and to adjust for quality of life to map from VoLY to QALY. Two other routes have also been explored.

One, which forms the current basis for Home Office estimates of the ‘intangible costs of crime’ – primarily, the values attached to (prevention of) the physical and psychological injuries sustained by victims of crime – works as follows. The physical and psychological consequences of (typical cases of) different kinds of crime are expressed in QALY (or, as it happened in this context, DALY) form. Some other injury scenario for which an established WTP value exists is also expressed in the same form, and this is used to infer a value for a QALY. Thus Dolan et al (2003) took a road accident scenario known as Injury W, calculated the QALY loss associated with such an injury to be 0.037 of a QALY, linked that to the monetary value for preventing that injury estimated directly from people’s responses to a survey reported by Carthy et al (1999), and inferred a value for a QALY of about £81,000, which was then used as the basis for the values associated with the intangible costs of all of the crime scenarios. It should be noted, however, that this approach – and in particular, the robustness of the figure of £81,000 derived in this way – is currently under review and reconsideration by the Home Office, with a report to be delivered to the Home Office in May 2009.

Other recent studies have investigated the feasibility of eliciting more or less directly some monetary value for a generic QALY – see section 6 of Donaldson et al (2008) and Pinto-Prades et al (2009). Both studies show, in different ways, that the estimates generated may vary a good deal with the scenarios used to elicit them (and, perhaps more worryingly, with the different procedures used, the different ways of analysing the data, and even with the order in which questions are asked). Given that the 2008 UK study is only a feasibility study and very explicitly warns against using figures derived from (relatively small) samples that were NOT randomly selected, it would be wrong to place too much weight on the particular numbers generated. Perhaps the most that should be said is that figures cited above suggesting VoLY/value of QALY figures in the region of £30k-£40k would not be incompatible with at least some of the results of the feasibility study.

4. Possible Implications for the Economic Analysis of the Health Impacts of Exposure to Noise.

The 2005 Treasury guidelines about managing risks to the public suggest (p.24, paragraph 4.15) that “In general, cost benefit analysis is preferred to cost effectiveness analysis as it

12 For details, see http://www.homeoffice.gov.uk/rds/pdfs05/rdsolr3005.pdf.
allows direct comparison between benefits and costs, but there are advantages and disadvantages with both approaches discussed in Annex C which mean that both could be used in the decision making process”.

The previous section of this chapter shows that although there may be ways of making links between different approaches to cost-benefit, cost-effectiveness and cost-utility analysis, there is as yet no simple, robust and comprehensive alignment between them. However, it also suggests that there is a way of proceeding that is broadly in line with practice in other parts of the UK public sector and that may be able to yield some useful results, albeit subject to certain caveats. Moreover, there is some precedent for this way of proceeding, as demonstrated in the study aimed at establishing the external noise costs associated with road and rail traffic in Switzerland in 2000, and the 2008 MSR Theme report on the ‘price of noise’ in the Netherlands.

These, together with the discussion in section 2 above, suggest the following procedure for valuing the damage associated with the two health impacts identified as being of particular interest, namely cardiovascular disease and sleep disturbance.

First, to the extent that the relationship between noise exposure and premature death from heart attack or stroke can be identified, numbers of years of life lost can be estimated. Depending on the strength of the evidence about the average remaining life expectancy of those whose death would be prevented by reducing exposure to noise, and the quality of life that would be expected during those years, it would in principle be possible to assign a value of a full health year and then adjust that for quality, using either the tariff employed by NICE or else the DALY scores used in the Netherlands study and currently by the Home Office. (Clearly, there is room here for examining the sensitivity of the estimates to various different measures and to different assumptions about the appropriate VoLY figure.) This is essentially the approach adopted in the Switzerland study, where years of life lost were assigned a value of 85,473 CHF each at 2000 prices (a spuriously precise figure, perhaps, but one which illustrates the general point).

Other non-fatal impacts upon health, to the extent that they can be attributed to noise exposure, could be put on a comparable QALY/DALY footing and valued on the same basis. The Switzerland study also assigns a value to hospital admissions (presumably derived from some QALY/DALY calculation involving days spent in hospital) and the corresponding estimates based on UK VoLY/value-of-a-QALY figures could perhaps be compared with the more direct values used by DEFRA for emergency respiratory admissions.

Finally, to the extent that sleep disturbance is considered as a separate harm from the other health impairments that may be attributed to it or correlated with it, perhaps some judgment might be made about how such disturbances compare with the days of breathing discomfort for which DEFRA also have a range of monetary values. Clearly, there is also potential here, should there be a desire to do so, to undertake some fieldwork to elicit directly people’s WTP to reduce/prevent these and other non-fatal consequences of exposure to noise.

To conclude: although there is no robust simple formula that can generate values across all policy contexts and all levels of health impairment, and although we must be cautious about the extent to which any existing value is the ‘correct’ value, there appears to be scope for putting the valuation of the health impacts of noise exposure on a broadly similar footing to valuations used elsewhere in the UK public sector. Needless to say, there is room for further development of such techniques and for greater co-ordination and systematization across sectors. However, given the current state of knowledge, an economic evaluation along the lines indicated above, and with appropriate checks for sensitivity to different assumptions, would appear to be entirely feasible and, arguably, highly desirable.
References


Annex 4. Glossary

ACOUSTICAL TERMINOLOGY

**A-weighting.** A frequency weighting that is applied to the electrical signal within a noise-measuring instrument as a way of simulating the way the human ear responds to a range of acoustic frequencies.

**dBA.** Units of sound level on the A-weighted scale.

**L_{A_{eq}}.** Equivalent continuous sound level

**L_{Aeq, 16-hour}** Equivalent sound level of aircraft noise in dBA for the 16 hour annual day [used in UK for aircraft noise]

**L_{day}.** Equivalent sound level of aircraft noise in dBA for the 12-hour annual day (0700-1900).

**L_{night}.** Equivalent sound level of aircraft noise in dBA for the 8-hour annual night (2300-0700).

**L_{den}.** Equivalent sound level of aircraft noise in dBA for the 24-hour annual day, evening, and night where the evening movements are weighted by 5 dB and night movements are weighted by 10 dB.


**NOTE.** The Babisch dose-response curve uses a 16-hour day version of L_{day} [0600-2200h]

**L_{dn}.** 24-hour L_{eq} measure with an un-weighted 11-hour daytime period (0700-2200) and a 10 dB weighting for any noise events occurring during a 9-hour night-time period (2200-0700). This metric is commonly referred to as the Day-Night Level (DNL).

**SEL** The Sound Exposure Level generated by a single aircraft at the measurement point, measured in dBA. This accounts for the duration of the sound as well as its intensity. (SEL is referred to as L_{AE} or L_{E} in some texts

MEDICAL TERMINOLOGY

**Cardiovascular disease**
Disease of the heart and blood vessel system, such as coronary heart disease, heart attack, high blood pressure, stroke, angina and rheumatic heart disease.

**Hypertension**
Chronically elevated blood pressure

**Ischaemic [or Ischemic]**
Refers to the state of not having enough blood flow.

**Ischaemic heart disease**
Includes clinical symptoms of angina pectoris (chest pain), myocardial infarction (heart muscle damage), or electrocardiogram (ECG) abnormalities.

**Angina pectoris**
Chest pain or breathlessness caused by lack of blood flow to the heart.
Myocardial infarction
Heart attack.

STATISTICAL TERMINOLOGY

Exposure-response relationship
Mathematical relationship between the amount or level of a factor, such as noise to which a
group or individual was exposed, and the response. It is a general term, used whether the
"response" is annoyance, sleep disturbance, or other health effect, such as cardiovascular
effects.

Meta-analysis
A statistical technique for combining and integrating the data derived from a number of
experimental studies undertaken on a specific topic.

Odds Ratio [OR]
The ratio of the odds of an event in the experimental (intervention) group to the odds of an
event in the control group. Odds are the ratio of the number of people in a group with an
event to the number without an event. Thus, if a group of 100 people had an event rate of
0.20, the event happened to 20 people and did not happen to 80, and the odds would be
20/80 or 0.25.

Relative risk (RR, or risk ratio)
The ratio of the probability of developing, in a specified period of time, an outcome among
those receiving the treatment of interest or exposed to a risk factor, compared with the
probability of developing the outcome if the risk factor or intervention is not present (i.e. the
ratio of risk in the treated group to the risk in the control group).

Fixed and random weighting
This refers to the use of fixed, or random effects models in multi-level statistical modelling, of
the kind used in epidemiological studies of noise and health, and meta-analyses of such
studies.

Fixed effects model
A statistical model that stipulates that the units under analysis (e.g. people in a trial or study
in a meta-analysis) are the ones of interest, and thus constitute the entire population of units.
Only within-study variation is taken to influence the uncertainty of results (as reflected in the
confidence interval) of a meta-analysis using a fixed-effect model. Variation between the
estimates of effect from each study (heterogeneity) does not affect the confidence interval in
a fixed-effect model.

Random effects model
A statistical model sometimes used in meta-analysis, in which both within-study sampling
error (variance) and between-studies variation are included in the assessment of the
uncertainty (or confidence interval) of the results of a meta-analysis (see Fixed effect model).
If there is significant heterogeneity among the results of the included studies, random-effects
models will give wider confidence intervals than fixed-effects models.