**World Health Organization Regional Office for Europe
European Centre for Environment and Health
Bonn Office**

**Technical meeting on exposure-response relationships of noise on health
19-21 September 2002 Bonn, Germany
Meeting report**

Abstract
This document summarises the discussions and results of the meeting on exposure – response relationships on noise and annoyance, sleep disturbance, hearing impairment, loss of productivity in children (learning difficulties, loss of concentration) and loss of productivity in adults. The metrics, sources, human perception, and the existing clear scientific evidence, were reviewed in order to establish exposure-response relationships that can support the member states in developing policies in the field of noise abatement and control of noise problems.

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Introduction

Background

The WHO European Centre for Environment and Health in Bonn, Germany, organized an international meeting of experts in the field of community noise from the 19th to the 21st September 2002. The main objective was to review existing exposure-response relationships between noise exposure and annoyance, sleep disturbance, hearing impairment, loss of productivity in children (learning difficulties, loss of concentration) and loss of productivity in adults.

The WHO Guidelines for Community Noise were published in April 1999. The experts derived guideline values for various adverse health impacts by consensus. These guidelines values were based on expert judgment of the existing exposure-response findings. At the time when the expert meeting took place, there was, apparently, not enough information available on the exposure-response relationships to consider developing curves, which would allow prediction of the effects of exposure to different noise doses.

This meeting reviewed the existing knowledge and gaps in knowledge, using new scientific and medical studies, about exposure to noise and different human responses, in order to clarify exposure-response relationships, and identify areas of uncertainty.

Summary of the meeting

The meeting focused on noise and its effects on health. The metrics, sources, human perception, and the existing clear scientific evidence, were reviewed in order to establish exposure-response relationships that can support the member states in developing policies in the field of noise abatement and control of noise problems.

Objectives of the meeting:

1. Establish noise exposure-response relationships for:
     Annoyance in adults
     Sleep disturbance in children and adults
     Hearing impairments in children and adults
     Productivity reduction in adults
     Cognitive effects in children

2. Develop the necessary elements to calculate the environmental noise related burden of disease (EBD) for:
     Annoyance;
     Sleep disturbance (pattern, awakenings, stages, subjective quality);
     Disturbance of daily activities (conversation, listening to music etc;
     Disturbance of concentration, performance etc.

3. Find the most effective instrument to advise and support member states in developing policies for noise abatement and public health.

4. Work closely with the experts from all WHO regions where noise is not a priority, to provide them with results that can be useful in describing a calculation of EBD and consequently help them to show the actual magnitude of the problem.

5. To improve health and reduce the risks of the population exposed to different noise sources

19 experts and WHO staff attended the meeting, from different European countries and from the different WHO regions (see participants list in Annex 3).

Summary of the meeting discussion

Dr G. Klein welcomed the participants on behalf of Dr.M. Danzon, the Regional Director, and introduced the WHO regional office for Europe and the work on noise and health. Similarly to air quality and water, noise is a risk factor for environmental health and the assessment, understanding and knowledge of exposure-response relationships is fundamental for member states in order to establish policies to protect population's health.

Dr Schwela and Mr Bonnefoy explained the work of WHO in more detail. The problem of noise is a global concern and not only a regional problem and the future work undertaken in Bonn shall be as global as possible to be applied in the developed and in the developing world. In fact, the noise and health program of the WHO will be run from European center for environment and Health in Bonn.

Then Mrs C. Rodrigues presented the meeting objectives and provided work guidance in order to optimise the work during the meeting.

Seven papers were presented by the invited experts, each of them followed with a short discussion within the whole group. More detailed analysis took place during working groups.

A representative of each of the six regions of the WHO made a presentation. Studies and some available information on the existing exposure data of the population to noise in each region were introduced during these presentations.

The meeting discussion, concentrated mainly on the following issues:

a) Terminology: until the present moment different terminologies have been used to designate the relationships between noise and health - dose-response relationships; dose-effect relationships or exposure-effect relationships. WHO and the participants agreed that *"exposure – response"* relationship is the best terminology.

b) Noise sources and their characteristics: One of the most complex issues is how can experts take into consideration the differences between the noise sources? Can they rely

only on noise level measures? What is the respective role of each type of source on different health effects?

c) Target groups: What are the main differences in vulnerability between specific age groups? How important are noise sources, periods of exposure, perception, meaning of noise, complaints, activities interfered with and coping strategies?

d) The choice of noise metric is also controversial: Can L_{den} be the only metric used for quantifying all the health effects? Or are other noise metrics that consider the peak sound level and the number of events necessary to quantify certain effects?

e) Health effects: Noise annoyance is well documented and people complain they are often disturbed by noise, even during their sleep time. What are the extra physiological effects of noise exposure? For example does sleep disturbance increase accidents? To what extent? Does annoyance provokes aggressiveness or unusual behavior? Is it possible to establish a relationship? In fact often "after-exposure to noise" health effects are more important than the effects during noise exposure.

Presentation of papers and discussion:

Seven papers were presented:

1) Relationships between exposure to single or multiple transportation noise sources and noise annoyance (Mr H.M.E. Miedema)

2) Sleep disturbance dose-effect relationships on adults (Prof Alain Muzet)

3) Sleep disturbance dose-effect relationships on children (Prof André Kahn);

4) Estimation of hearing damage from noise exposure (Prof Deepak Prasher);

5) Noise Exposure from various sources: Effects on Children's Hearing (Prof Deepak Prasher).

6) Noise exposure - Productivity, learning and concentration on adults (Dr Staffan Hygge);

7) Noise exposure from various sources - cognitive effects on children (Prof Stephen Stansfeld).

The full papers of the experts are attached as an annex to this report. The papers were reviewed, after the meeting, by the authors, in order to take into consideration the discussion.

Working groups

After having heard the presentations on the possibility of deriving exposure-response relationships in some specific areas of noise exposure and having discussed the presentations, three Working Groups were created.

The terms of reference of each group were discussed before the formation of the groups. The participants agreed that the most efficient way of analysing the problem of noise and health was to work on the proposals put forward by the speakers and try to reach a consensus on the final « shape » of the curves and the exposure-response relationships that can be established at present, and those which need further research. Each group dealt with a specific health problem, rather than separating children and adults. The work consisted of identifying the existing data and research evidence, the gaps in knowledge, and if the construction of exposure-response curves is possible at present and what further research is needed. The metrics and noise sources were also discussed.

Working Group I: noise and sleep disturbance
Working Group II: hearing impairment
Working Group III: other noise health effects (annoyance, productivity loss and cognitive performance).

A Chairperson / rapporteur was identified for each group:

Group I: Prof Muzet
Group II: Prof Prasher and Dr Smitha
Group III: Mr Miedema and Dr Schwela

All the groups analysed the effects on both children and adults. The conclusions of the three groups can be summarized as follows:

First working group – sleep disturbance

This group analyzed sleep disturbance and the available research evidence to establish exposure – response relationships. A table for the noise sources and the effects on sleep was constructed where the noise sources and their effects on health were rated with a scale of +, - and ? for respectively "enough"data, "few" and "perhaps enough but needs work" to establish exposure-response relationships between noise and sleep disturbance. The concept of sleep disturbance was divided in "night time effects", "next day effects" and "longterm effects" and the consequences of noise on sleep were listed.

The following 3 tables are the results of the group I:

Noise sources	Night time effects (immediate effects)					
	Awakening	Arousal (2)	Sleep stage changes	Motility	Autonomic responses	Hormones
Airplanes	+ (A)	-	+ (A)	+ (A)	**?**	-
Road	+ (A) ? (C)	-	+ (A)	-	**?**	-
Train	?	-	-	-	**-**	-
Impulse	? (1)	-	-	-	-	-
HVAC noise	-	-	-	-	-	-
Domestic noises	-	-	-	-	-	-

Noise sources	Next day effects (secondary effects)			
	Subjective report (3)	Vigilance tests	Performance	Hormones
Airplanes	+ (A)	-	?	-
Road	+ (A)	-	?	-
Train	+ (A)	-	-	-
Impulse	-	-	-	-
HVAC noise	-	-	-	-
Domestic noises	-	-	-	-

Noise sources	Long term effects			
	Fatigue	performance	disease	satisfaction
Airplanes	-	-	-	-
Road	-	-	-	-
Train	-	-	-	-
Impulse	-	-	-	-
HVAC noise	-	-	-	-
Domestic noises	-	-	-	-

Where:

HVAC - heating, ventilation, and air conditioning
(+) *enough data* (?) *perhaps enough but to be reworked* (-) *too few data to determine exposure-response curves*

(1) basic laboratory research results not included (tones, white/pink noises, etc…)
(2) definition of arousal as activation period not leading to awakening
(A) - Adults
(C) - Children

Second working group

The second working group studied the possibility of establishing exposure-response relationships for noise exposure and hearing impairment. This group established a curve based on the following condition: risk increases with exposure (cumulative dose) and the best database available is ISO 99.

This could be used for community noise provided that we consider as correct the following limitations/assumptions:

- Social noise provokes the same impairments as the occupational noise;
- The equal energy principle applies;
- Children react the same way as adults;
- The most sensitive indicator of effect is at 4 kHz

It was felt that there is a need for different exposure/response curves for more sensitive indicators of effect (e.g. otoacoustic emissions, speech discrimination, auditory discrimination).

The group agreed to conclude that in situations where there are either 1) impulsive exposures, or 2) short duration/intermittent noises, or 3) young children (under 6 years), or 4) combined exposures, there is not enough evidence for applying this exposure-response curve.

More data should be collected and studied for children.

Third working group – Other health effects

The third group examined the available noise measurements (existing noise metric) and the possibility of establishing exposure-response curves based on the existing work and evidence for each of range of annoyance, cognitive effects and health effects. The following table summarizes the work.

Exposure indicator 1	Exposure indicator 2	Effects		Exposure-response relationship		
				Database Adults/children	Curve possible? A/C	Curve available A/C
Lden	Ldn	Annoyance		***/-	***/-	yes/no
LAeq,T		Cognitive effects	Attention	*/*	*/*	no/no
LAeq,T			Memory/Recognition	*/***	*/**	no/no
LAeq,T			Memory/Recall	*/***	*/**	no/no
LAeq,T			Reading	*/**	*/*	no/no
LAeq,day	LAmax	Communication	Self-reported speech disturbance	***/-	***/-	no/no
STI			Speech interference	***/*	***/*1	no/no
Sone?			Masking from noise	***/*	***/?	no/no
LAmax/LAeq		Motivation		**/*	?/?	no/no
Laeq		Autonomic		!/!	!/!	no/no
Laeq		Mental health		!/!	!/!	no/no
LAmax		Social behaviour		!/!	!/!	no/no

Database
*** - very good database
** - consistent but small database
* - some data
"-" – no data
! – not sufficient discussed at the meeting

Curve
*** - feasible/small uncertainty
** - fairly sure/large uncertainty
* - not sure/large uncertainty
? –

Countries / regions presentations

The representatives of the regions presented some of the noise related problems in their countries and/or region. The main points that were raised covered: the noise sources, the average levels of the exposure, the people's perception and complaints. For reasons that escape the organizers and the Prof Zaidi and Dr Ming Chen, were not able to attend the meeting, so Dr Schwela presented their articles.

Dr Michionori Kabuto - A dose-response between nighttime indoor sound level due to road traffics and risk for insomnia in Japan (WPRO)

Dr Debrashis Chakrabarty – Noise Pollution—What we have done! - India (SEARO)

Prof Paulo Zannin - Urban Noise Pollution in Residential Areas of the City of Curitiba, Brazil Objective Analysis

Mr Gilles Paque – Summary of the EU environmental noise policy

Prof Shabih Zaidi – Pakistan (EMRO)

Dr Ming Chen – Urban Environmental Noise Pollution And Control Criteria - China

The papers are attached as an annex to this report.

Plenary

A plenary session was organized during which the participants were invited to express their main conclusions, recommendations and future research needs. The following conclusions, recommendations and future research needs have been endorsed by the group:

Conclusions

-   Based on the available evidence, the extra-auditory effects of noise could be pervasive, affecting children's physical and psychological well-being. Changes in sleep quantity together with autonomic reactions are seen when children are exposed to noises during sleep. These changes are related to the intensity and the type of noise.

-   Memory recall and reading seem to be the most noise sensitive functions affected by noise.

-   Taking into account the large amount of data already published, we certainly need to elaborate more comprehensive exposure-response curves and look more precisely to the extremities of these curves to determine protection thresholds and unacceptable limits.

- Noise after effects on motivation and effects of irrelevant speech and sounds are not easily accessible for a conventional dose measurement but have pronounced impact on performance.

- There is insufficient data to derive community/social noise specific exposure/hearing impairment relationships for adults and children but on the basis that social noise is not significantly different from occupational noise and that the equal energy principle is applicable, it is possible to use the ISO 1999 which uses the audiometric threshold shift at 4 kHz as the most sensitive indicator.

- The health effects of noise increase with increases in cumulative exposure and decrease with decreases in cumulative exposure.

- Whenever they can be supported by the available scientific evidence, definitive exposure-response relationships would be extremely helpful for the purposes of informing the public and for cost benefit analysis of alternative noise management strategies.

- The meeting should be considered a starting point for a process of development of noise-exposure response relationships for various policy relevant health endpoints related to annoyance, hearing impairment, cognitive effects and sleep disturbance and their after effects such as reduced performance and productivity.

- There is sufficient and reliable data to derive exposure-response relationships between noise and annoyance. Dose - effect curves exist for road, aircraft, railway noise and multi-exposure.

Recommendations

- It remains to be determined what pervasive effects long-term exposure to ambient noise has on children's development, health and well-being. Evidence should be collected to support an enforcement of strategies for noise reduction at the source as suggested by some studies.

- The evaluation of the long-term effects of poor sleep in children exposed to noisy sleep environments should be conducted. These could include development, learning, behavioural or cardiovascular effects. Subgroups at higher risk should be defined. The potential for the development of adult insomnia in previously poor sleeping children exposed to noise should be evaluated.

- We certainly need also to look more deeply into the specific cases of "sensitive groups" or so called "groups at risk", including better knowledge of children's exposure and its consequences.

- There is a necessity to try to fill the gap between immediate or short term effects (including the discrete autonomic changes provoked by noise which do not habituate in the long term) and the possible long term effects on health. New approaches, such as bio-molecular techniques could bring new insight into this field while large epidemiological studies are still needed as far as they are scientifically designed for this purpose.

-   Additional attention is required regarding the scope of application of exposure-response curves, criteria for inclusion of databases when elaborating such curves, and finally the role of factors other than noise exposure should be extremely clearly evaluated.

-   More recent research into memory recall and reading to establish dose-response relationships are needed.

-   WHO should support all activities aiming at informing the public that noise and its effects on human beings is an important matter of concern for public health.

-   WHO should use all its influence for supporting research activities to clarify the acute, secondary and long-term effects.

-   WHO should provide its Member States with the best guidance on feasible noise reduction measures (technical advances) (sustainable and responsible growth combined with protection of people).

-   WHO should establish a rough timetable to proceed with the work to fix exposure-response relationships.

-   WHO is invited to implement an electronic working space where documents, data, etc. can be down- and uploaded via internet (virtual working groups).

-   WHO should extend the "exposure-response" relationships with a stage that quantifies the damage that the effect does to health in the long time, e.g. the DALY-concept (disability adjusted life years) and develop research from all possible institutions to reach this goal.

-   Consensus on a minimum of standardization concerning the recording of noise stress and effects strain to enable the pooling of data from different studies is needed.

-   Application of comparable methods in the field and in the lab is needed; more field studies are recommended.

-   Exposure-response curves at this stage can only be source-specific. More attention in future should be given to methods of dealing with accumulation/combination of exposures.

-   Exposure – response curves for separate groups (not only children versus adults) are necessary in order to take into account non-acoustical aspects/specific situations, critical life stages/tasks, etc.

-   More attention should be paid to autonomic health effects of noise.

-   An overview has been carried out of effects for which exposure-response relationships would be desirable. In addition to this overview, an evaluation of the relevant available data has been made. It is recommended that relationships are established in the near future for effects for which relationships are desirable and for which sufficient data are already available, but relationships have not yet been established.

- WHO needs to take stock of the knowledge available at the moment in order to be able to introduce exposure effects relations into relevant policies on noise. These relationships would allow us to better assess the potential benefits of noise abatement. This pragmatic approach does not prevent further research being carried out, where groups have been identified.

- Follow-up meetings should be organized by WHO in collaboration with EC, I-INCE and ICBEN to define appropriate noise metrics and, policy relevant health endpoints/after-effects.

- In future meetings, experts should develop sets of exposure – response relationships derived from the existing studies by use of meta-analysis.

- WHO should use the work on exposure-response relationships to estimate the burden of disease due to noise pollution.

- With more sensitive indicators of the effect of noise on hearing such as otoacoustic emissions; different exposure-response relations will need to be derived.

- With respect to the methodologies described in the various papers presented during the meeting (e.g. combining annoyance reaction from different noise sources) international consensus should be achieved on the choice of appropriate methodologies before proposing that they could be applicable on a global scale.

Future research needs

- There is an interest in collecting experimental data in noise-controlled environments to define an exposure-response curve to increasing noise intensities. The curves should be defined according to age groups (premature subjects, newborns, infants, children…).

- When we sleep, our hearing system remains active. This is necessary to adapt to changes in the environment (e.g. danger). This means it is natural that many effects of noise will be seen during sleep. Most of these effects will not be relevant to health. Future research will have to be directed to damaging after effects and only to these effects during sleep, which bear a clear relation to these after effects (such as fatigue, etc.).

- Sleep disturbance: eventually, there will be a preference for developing exposure-response relationships for health end points or other significant effects of sleep disturbance. However, until the data exist to support these relationships, it is recommended that noise exposure policies for sleep disturbance be based on the "percent awakened", using only the data from published field studies. Research needs to be sponsored on the other possible effects.

- Although the non-auditory physiological health effects of noise exposure is an extremely important area of concern, there do not currently exist sufficient data on these effects to develop an exposure response relationship. Additional research in this area is strongly recommended.

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- More research into noise after effects and irrelevant speech and sounds is needed to delineate when a conventional dose-response approach does not apply.

- Further research is necessary to establish:
  i) Whether children are more sensitive/susceptible to hearing damage than adults;

  ii) Normal hearing levels for children across the age range;

  iii) whether single frequency dip in the audiometry can be considered sufficient for noise effect;

  iv) To develop more sensitive and early indicators of damage.

- Research on noise effects in children should be given priority, in particular effects on learning, memory/recall, reading and attention, all highly relevant for the healthy cognitive development of children.

Annex 1 -Technical papers

1) Relationships between exposure to single or multiple transportation noise sources and noise annoyance – Mr H.M.E. Miedema

2) Noise exposure from various sources – Sleep disturbance dose-effect relationships on adults (Prof Alain Muzet)

3) Noise exposure from various sources – Sleep disturbance dose-effect relationships on children (Prof André Kahn);

4) Estimation of hearing damage from noise exposure (Prof Deepak Prasher);

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6) Noise exposure - Productivity, learning and concentration on adults (Dr Staffan Hygge);

7) Noise exposure from various sources - cognitive effects on children (Prof Stephen Stansfeld).

Relationships between exposure to single or multiple transportation noise sources and noise annoyance

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Abstract

First relationships between exposure to noise (metric: *DNL* or *DENL*) from a single source (aircraft, road traffic, or railways) and annoyance are presented. Curves are presented for the percentage 'highly annoyed' (*%HA*, cutoff at 72 on a scale from 0 to 100), the percentage 'annoyed' (*%A*, cutoff at 50 on a scale from 0 to 100), and the percentage (at least) 'a little annoyed' (*%LA*, cutoff at 28 on a scale from 0 to 100). The estimates of the parameters of the relations are based on the data from 19 noise annoyance studies for aircraft (N = 27081), 26 studies for road traffic (N = 19172), and 8 studies for railways (N = 7632). Then the annoyance equivalents model concerning noise from combined sources and the underlying assumptions are presented. The most important assumption, independence of the contributions of the sources, is discussed. It appears that only in rare cases independence will be violated substantially. For use in practice, the application of the model is broken down in five steps. The step by step procedure can be used for the assessment of the total noise level and the associated total annoyance (*%HA*, *%A*, or *%LA*) on the basis of the *DNL* or *DENL* values of the individual sources.

Introduction

Lambert et all.(1994) estimated that in the European Union during daytime approximately 77 million people (i.e. 22 % of the total population of the EU at that time) were exposed to transportation noise levels exceeding 65 dB – which many countries consider to be unacceptable. Almost 170 million Europeans (49 %) lived in, what the authors called, grey zones, i.e. zones which do not ensure acoustic comfort to residents. Depending on the country, road traffic noise annoyed between 20 and 25 % of the population. Even though the uncertainty of these estimates is very large, there is no doubt about the high prevalence of noise annoyance in the EU.

A survey by Al-Harthy and Tamura (1999) in Muscat City, Oman, illustrates that noise and noise annoyance are not confined to the industrialized societies, but grow very fast in cities in the developing countries. The length of the paved roads in Muscat City increased from not more than 50 km in 1975 to 156 km in the old city and 1213 km in the entire city in 1995. This explains the finding that in 1995 (lack of) "quietness" caused the highest dissatisfaction in a sample of 452 inhabitants. It was higher than the dissatisfaction with the 12 other aspects of the surroundings that were rated, such as "public facilities" and "safety". The authors comment that "This rate would be totally non existent in the 1970 because the constructed roads were scarce, cars were very sparsely, …". The above figures illustrate that noise annoyance is widespread in the industrialized countries, as well as in urban areas in the developing countries. The growing transportation network with increasing traffic intensities is an important cause of the high prevalence of noise annoyance. For making policy against environmental noise, it is important to have a set of relationships that show which annoyance level is associated with a given noise exposure level caused by transportation. It is not sufficient to have relationships for individual sources only, because in many cases people are exposed not to either aircraft, road traffic or railway noise, but to a combination of these types of noise. As a consequence, there is also a need for a model that predicts the annoyance caused by combinations of transportation noise. The first part of this article presents relationships that can be used to predict the noise annoyance on the basis of the exposure of a dwelling to noise from one type of transportation. The second part will present a method for quantifying the total annoyance caused by exposure of a dwelling to noise from multiple transportation sources.

PART I: EXPOSURE TO ONE TYPE OF TRANSPORTATION NOISE

State of the art

Many studies have been conducted to establish noise exposure - annoyance relationships for individual sources of transportation noise. Miedema and Vos (1998) presented synthesis curves for aircraft, road traffic, and railway noise. These curves were based on all studies examined by Schultz (1978), and Fidell et al. (1991) for which *DNL* and percentage highly annoyed persons (*%HA*) meeting certain minimal requirements could be derived, augmented with a number of additional studies. Consequently, that synthesis was more comprehensive than the previous ones. Moreover, the kind of errors and inaccuracies Fields (1999) found in the previous syntheses were avoided. Also an attempt was made to find the 95% confidence intervals around the exposure - annoyance curves.

Miedema and Oudshoorn (2001) improved upon the method used to establish the confidence intervals substantially. The same data were analyzed, but the model of the relationship between exposure and annoyance was more sophisticated and better suited for the data. Usage of the more appropriate model gave the relationships and their confidence intervals a firmer basis. The narrow confidence intervals indicate that, even though there is considerable variation between individuals and between studies, the uncertainty regarding the location of the relationships between noise exposure and annoyance is rather limited. In the approach taken, the entire distribution of annoyance reactions is modeled as a function of the noise exposure. Consequently, any annoyance measure that summarizes this distribution, i.e. the percentage highly annoyed (*%HA*) or another measure, can be calculated as a function of the exposure level.

The working group of the European Commission on health effects of environmental noise (EC/DG Env, 2002) recommends in its position paper the relationships presented by Miedema and Oudshoorn (2001) for the estimation of noise annoyance on the basis of the noise exposure of dwellings. The relationships are presented here. The presentation will closely follow the presentation by Miedema and Oudshoorn (2001). For details, e.g. regarding the assessment of exposure measures or the statistical model, we refer to that publication.

Noise metrics and annoyance measures

Previous synthesis studies used the day-night level, DNL, as the descriptor of the noise exposure. This noise descriptor is defined in terms of the LAeq's ("average" levels) during daytime and night-time, and applies a 10 dB penalty to noise in the night:

$$DNL = 10 \lg [(15/24).10LD/10 + (9/24).10(LN+10)/10]$$

Here LD and LN are the LAeq as defined in ISO 1996-2 (1987) for the day (7-22h) and the night (22-7h), respectively.
A noise metric related to DNL is the day-evening-night level, DENL. It is defined in terms of the "average" levels during daytime, evening, and night-time, and applies a 5 dB

penalty to noise in the evening and a 10 dB penalty to noise in the night. The definition is as follows:

$$DENL = 10 \lg [(12/24).10LD/10 + (4/24).10(LE+5)/10 + (8/24).10(LN+10)/10]$$

Here LD, LE, and LN are the A-weighted long term LAeq as defined in ISO 1996-2 (1987) for the day (7-19h), evening (19-23h), and night (23-7h) determined over the year at the most exposed facade. DENL is the new uniform noise metric for the European Union (EC/DG Environment, 2002).

For noise from one type of transportation (aircraft, road traffic, railways), DNL and DENL are highly correlated. The background of choosing DENL as (one of) the descriptor(s) in the European noise policy is described in the Position Paper on EU Noise Indicators (EC/ DG XI, 1999).

Annoyance questions in different studies do not use the same number of response categories. Some questions have only three response categories while others use as many as eleven categories. In order to obtain comparable annoyance measures for different studies, all sets of response categories were translated into a scale from 0 to 100. The translation is based on the assumption that a set of annoyance categories divides the range from 0 to 100 in equally spaced intervals. Then the general rule that gives the position of a category boundary on a scale from 0 to 100 is: scoreboundary i = 100i/m (see table 1). Here i is the rank number of the category boundary, starting with 0 for the lower boundary of the lowest annoyance category, and m is the number of categories.

The distribution of the annoyance scores at a given noise exposure level can be summarized in various ways. Often a cutoff point is chosen on the scale from 0 to 100 and the percentage of the responses exceeding the cutoff is reported. If the cut-off is 72 on a scale from 0 to 100, then the result is called the percentage 'highly annoyed' persons (%HA), with a cutoff at 50 it has been called the percentage 'annoyed' (%A), and with a cutoff at 28 the percentage '(at least) a little annoyed' (%LA). An alternative to the percentage measures is the average annoyance score.

Data

TNO compiles an archive of original datasets from studies on annoyance caused by environmental noise. The collected studies concern different modes of transportation (aircraft, road traffic, and railway) and were carried out in Europe, North America, Australia, and Japan. As far as possible a common set of variables is derived for all studies which includes, among others, noise exposure measures and annoyance measures. Table 2 gives an overview of the studies used in the analyses described here (at present the archive has been further extended). Extreme exposure levels (*DNL* < 45 or > 75 dB) were excluded from the analyses.

Exposure - response model

The noise annoyance of an individual on a scale from 0 to 100 is denoted by A^*. Instead of observing the noise annoyance A^* precisely, it is only known for an individual in which interval on the scale from 0 to 100 A^* comes. The locations of the boundaries of the intervals depend on the annoyance response categories used in a study (see table 1). A^* has values only in the range [0, 100] so that its distribution has bounded support. It is assumed to have a censored normal distribution[1] on [0, 100], with the mean increasing as a function of *DNL*. Instead of considering the annoyance variable A^*, it is more convenient to model the corresponding[2] normally distributed variable *A*. The mean of *A* is assumed to be a linear function of *DNL* (or *DENL*). Then, including a random study effect on the intercept and an individual error term, the exposure-response model is (using individual index *i* and study index *j*):

$$A_{ij} = \beta_0 + \beta_1 DNL_{ij} + u_{0j} + \varepsilon_{ij},$$

Here β_0 is the intercept, β_1 is the slope coefficient of *DNL*, u_{0j} is the normally distributed random study effect (zero mean and variance σ_0^2), and ε is the normally distributed individual error (zero mean and constant variance σ^2). According to this model the relation between *DNL* and annoyance can have a different intercept in each study. The average intercept is equal to β_0. The total random component is equal to $u_{0j} + \varepsilon_{ij}$.

The probability that a randomly selected person from a randomly selected study, with exposure level *DNL*, has an annoyance level that exceeds *C*, i.e. $p_C(DNL)$, is:

$$p_C(DNL) \quad = Prob(\beta_0 + \beta_1 DNL + u_{0j} + \varepsilon \geq C)$$

$$= 1 - \Phi((C - \beta_0 - \beta_1 DNL)/\sqrt{(\sigma^2 + \sigma_0^2)}),$$

where Φ is the cumulative standard normal distribution. The expected percentage of persons with noise exposure *DNL* whose annoyance exceeds C, is 100 times this probability:

$$Percentage_C(DNL) \quad = 100 * [1 - \Phi((C - \beta_0 - \beta_1 DNL)/\sqrt{(\sigma^2 + \sigma_0^2)})].$$

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[1] A random variable *X* with bounded support $[\tau_L, \tau_R]$ has a censored normal distribution with parameters μ, σ, τ_L and τ_R (the left and right censoring points) if its density equals $\phi((x - \mu)/\sigma)$ for $x \in]\tau_L \ \tau_U[$ and if at the censoring points $P(X = \tau_L) = \Phi((\tau_L - \mu)/\sigma)$ and $P(X = \tau_R) = 1 - \Phi((\tau_R - \mu)/\sigma)$. $\Phi(x)$ represents the cumulative standard normal distribution and $\phi(x)$ the standard normal density.

[2] For censored normal distribution with parameters μ, σ, τ_L and τ_R (see note 1), the corresponding normal distribution is the normal distribution with parameters μ and σ.

Relationships for the prediction of annoyance

In order to find the actual percentages with the above equation, the four parameters β_0, β_1, σ_0^2, and σ^2 must be estimated. We used SAS PROC NLMIXED (SAS version 8) to obtain the estimates, because with this procedure the study effect could be properly taken into account (see SAS/STAT Online User's Guide V8, the NLMIXED Procedure, Example 46.3: Probit-Normal Model with ordinal data). The model was fitted separately for aircraft, road traffic, and railways. Figure 1 (for *DNL*) and figure 2 (for *DENL*) show the percentage of persons who are (at least) a little annoyed (annoyance $\geq$ 28), annoyed (annoyance $\geq$ 50), and highly annoyed (annoyance $\geq$ 72). In addition to the curves, the corresponding confidence intervals are also shown in figures 1 and 2 (dotted lines). The estimates of the coefficients β_0, β_1, σ_0^2, and σ^2 for aircraft, road traffic, and railways are presented in table 3 (for *DNL*) and table 4 (for *DENL*) with their estimated standard errors and significance levels. Comparing the estimates of σ_0^2 and σ^2, shows that there is for aircraft and road traffic a significant between study variation, but the within study variation is much larger. The order of magnitude of the within study variation, and hence of the total variation, is equal for aircraft, road traffic, and railways. Curves for other annoyance cutoff points *C* can be obtained by substituting the chosen *C* and the estimates of the coefficients (tables 3 and 4) in the equation for percentage$_C$(DNL) given in the previous section.

The obtained curves can be approximated accurately with third order polynomials. Approximations for *DNL* are (*%LA* is the percentage 'little annoyed'; *%A* is the percentage 'annoyed', and *%HA* is the percentage 'highly annoyed'):

Aircraft: $\%LA = -5.741*10^{-4} (DNL\text{-}32)^3 + 2.863*10^{-2} (DNL\text{-}32)^2 + 1.912 (DNL\text{-}32);$

Road traffic: $\%LA = -6.188*10^{-4} (DNL\text{-}32)^3 + 5.379*10^{-2} (DNL\text{-}32)^2 + 0.723 (DNL\text{-}32);$

Railways: $\%LA = -3.343*10^{-4} (DNL\text{-}32)^3 + 4.918*10^{-2} (DNL\text{-}32)^2 + 0.175 (DNL\text{-}32);$

Aircraft: $\%A = 1.460*10^{-5} (DNL\text{-}37)^3 + 1.511*10^{-2} (DNL\text{-}37)^2 + 1.346 (DNL\text{-}37);$

Road traffic: $\%A = 1.732*10^{-4} (DNL\text{-}37)^3 + 2.079*10^{-2} (DNL\text{-}37)^2 + 0.566 (DNL\text{-}37);$

Railways: $\%A = 4.552*10^{-4} (DNL\text{-}37)^3 + 9.400*10^{-3} (DNL\text{-}37)^2 + 0.212 (DNL\text{-}37);$

Aircraft: $\%HA = -1.395*10^{-4} (DNL\text{-}42)^3 + 4.081*10^{-2} (DNL\text{-}42)^2 + 0.342 (DNL\text{-}42);$

Road traffic: $\%HA = 9.994*10^{-4} (DNL\text{-}42)^3 - 1.523*10^{-2} (DNL\text{-}42)^2 + 0.538 (DNL\text{-}42);$

Railways: $\%HA = 7.158*10^{-4} (DNL\text{-}42)^3 - 7.774*10^{-3} (DNL\text{-}42)^2 + 0.163 (DNL\text{-}42);$

and for *DENL*:

Aircraft: $\%LA = -6.158*10^{-4} (DENL\text{-}32)^3 + 3.410*10^{-2} (DENL\text{-}32)^2 + 1.738 (DENL\text{-}32);$

Road traffic: $\%LA = -6.235*10^{-4} (DENL-32)^3 + 5.509*10^{-2} (DENL-32)^2 + 0.6693 (DENL-32)$;

Railways: $\%LA = -3.229*10^{-4} (DENL-32)^3 + 4.871*10^{-2}(DENL-32)^2 + 0.1673 (DENL-32)$;

Aircraft: $\%A = 8.588*10^{-6} (DENL-37)^3 + 1.777*10^{-2} (DENL-37)^2 + 1.221 (DENL-37)$;

Road traffic: $\%A = 1.795*10^{-4} (DENL-37)^3 + 2.110*10^{-2} (DENL-37)^2 + 0.5353 (DENL-37)$;

Railways: $\%A = 4.538*10^{-4} (DENL-37)^3 + 9.482*10^{-3} (DENL-37)^2 + 0.2129 (DENL-37)$;

Aircraft: $\%HA = -9.199*10^{-5} (DENL-42)^3 + 3.932*10^{-2} (DENL-42)^2 + 0.2939 (DENL-42)$;

Road traffic: $\%HA = 9.868*10^{-4} (DENL-42)^3 - 1.436*10^{-2} (DENL-42)^2 + 0.5118 (DENL-42)$;

Railways $\%HA = 7.239*10^{-4} (DENL-42)^3 - 7.851*10^{-3} (DENL-42)^2 + 0.1695 (DENL-42)$.

Figures 3 (*DNL*) and 4 (*DENL*) show that the approximations (dashed lines) are almost equal to the estimated curves (solid lines).

An alternative to measures such as *%LA*, *%A* and *%HA* is the mean annoyance. For establishing the mean annoyance as a function of *DNL* or *DENL*, it is important to note that the estimated annoyance distribution is non-zero outside the interval [0,100], while the actual annoyance scores are restricted to that interval. Consequently, not the mean of the estimated normal annoyance distribution, but the mean of the corresponding censored normal distribution is an estimate of the mean annoyance observed with a scale from 0 to 100.

Conclusion and discussion regarding relationships for single sources

A model of the distribution of noise annoyance with the mean varying as a function of the noise exposure has been presented. *DNL* as well as *DENL* were used as noise descriptor. Because the entire annoyance distribution has been modelled, any annoyance measure that summarizes this distribution can be calculated from the model. The model has been fitted to data from noise annoyance studies for aircraft, road traffic, and railways separately. Polynomial approximations of relationships implied by the model for the combinations of the following exposure and annoyance measures are presented: on the one hand, *DNL* or *DENL*, and, on the other hand percentage 'highly annoyed' (*%HA*, cutoff at 72 on a scale from 0 to 100), the percentage 'annoyed' (*%A*, cutoff at 50 on a scale from 0 to 100), and the percentage (at least) 'a little annoyed' (*%LA*, cutoff at 28 on a scale from 0 to 100). These approximations are very good, and they are easier to use for practical calculations than the model itself, because the model involves a normal distribution.

The noise annoyance curves have rather narrow confidence intervals. This means that the location of these curves in the population is known rather accurately. Nevertheless, substantial deviations from the predicted distribution of annoyance responses for limited

groups at individual sites must be expected because random factors, individual and local circumstances and study characteristics affect the noise annoyance. However, in many cases the prediction on the basis of a 'norm' curve that is valid for the entire population is a more suitable basis for policy than the actual annoyance of a particular individual or group. For example, a 'norm' curve is useful when exposure limits for dwellings and noise abatement measures are discussed. Equity and consistency require that limits and abatement measures do not depend on the particuliarities of the persons and their actual circumstances. For similar reasons, a 'norm' curve also can be used to estimate the number of highly annoyed persons in the vicinity of an airport, road, or railway when different scenarios concerning e.g. extension of these activities or emission reductions are to be compared. That the norm curve does not take local circumstances or reactions to a change in exposure itself into account, is considered to be an advantage for many purposes. Equity and consistency of policy would not be served if in each case the actual annoyance is taken as the (only) basis for these evaluations.

Most studies on annoyance that were analysed to obtain the relationships have been carried out in moderate climates. In principle, climate could have an effect on noise annoyance in various ways. For example, in cold climates with severe winters, people spend more time indoors with the windows closed in insulated houses. On the one hand, this causes the personal exposure to be lower and therefore could lower noise annoyance. On the other, it makes the limited time that can be spent with windows open or outdoors more highly valued, and may increase the dissatisfaction with noise disturbing those moments. Moreover, in the warmest climates people also may stay indoors in the warmest periods, and especially if they have air conditioning and can shut the windows, this will reduce their exposure to environmental noise. Additional information is needed for deciding whether climate (or other factors that differ geographically) need to be taken into account in exposure - annoyance relationships.

An important elaboration of the present model would be the inclusion of more (exposure) variables as predictors of annoyance, in addition to *DNL* or *DENL* (at the most exposed side of a dwelling). In the presented relationships, factors that influence noise annoyance in addition to *DNL* or *DENL* and the type of source, are treated as random factors that contribute to the unexplained variance of the noise annoyance response. It is possible to elaborate the exposure – response model and incorporate e.g. additional factors that defined vulnerable groups, such as age (see Miedema and Vos, 1999), as predictors. Most interesting are factors that can be influenced by policy. Examples of such factors are the sound insulation of the dwelling and the presence of a relatively quiet side of the dwelling. The latter factor depends on the configuration and orientation of the building relative to the noise source. The purpose then would be to establish a model of the annoyance reactions in the population as a function of *DNL* or *DENL*, the sound insulation of the dwelling, and the level at the most quiet side of the dwelling.

PART II: EXPOSURE TO MULTIPLE TRANSPORTATION NOISE SOURCES

State of the art

An overview of procedures that have been proposed for rating the total annoyance caused by multiple noise sources can be found in Schulte-Fortkamp et al. (1996). We first discuss the simplest approach (energy summation model), and the model that often has been found to give a better description of empirical data than other models (dominance model). Two elements can be distinguished in models for combined exposures: the definition of a noise metric for the combined exposure (*L*), which is often but not always defined in terms of the noise metrics for the individual sources (*L$_i$*), and the relationship between *L* and the total noise annoyance (*A*). The following discussions of the energy summation model and the dominance model consist of the presentation of these two elements, and an evaluation of the model.

Energy summation model
The energy summation model (see e.g. Taylor, 1982) simply applies the same metric (e.g. *DNL* or *DENL*) used for individual sources to the total noise exposure. According to the energy summation model, the *DNL* or *DENL* of the total exposure gives a consistent indication of the annoyance caused by this exposure. It can be calculated from the exposures to the individual sources by 'energetic summation':

$$ L \quad = \quad 10 \lg \sum\nolimits_i 10^{\,0.1 \times L_i} \ . $$

The noise annoyance A then is given by an exposure - annoyance relationship (not specified by the energy summation model):

$$ A \quad = \quad h(L) $$

In a single source situation the above total noise metric *L* is equal to the noise level *L$_i$* of the single source. Since the model assumes that there is one single relation *h* between *L* and annoyance, this means that the energy summation model predicts that exposures to aircraft noise, to road traffic noise, and to railway noise, cause equal annoyance if their *DNL*'s or *DENL*'s are equal. This, however, is not consistent with empirical findings presented in Part I, which show that the *DNL*'s or *DENL*'s of two transportation sources that cause equal annoyance can differ 10 dB. Thus, the energy summation model does not describe empirical findings with sufficient accuracy because it does not take into account the differences among transportation noise sources in their potency to cause annoyance.

Dominance model
According to the dominance model (see e.g. Rice, 1986), the total annoyance is equal to the maximum of the single source annoyances.

$$ A \quad = \quad \max\nolimits_i [h_i(L_i)] $$

Here *h$_i$* is the exposure – annoyance function for source *i*. The source causing the highest annoyance is called the dominant source. A total noise metric can be defined by

translating the annoyance of the dominant source into the equally annoying exposure level of an arbitrary reference source:

$$L \quad = \quad h^{-1} \mathrm{o} \max{}_i [h_i(L_i)]$$

Here h^{-1} is the inverse of an exposure – annoyance function (not specified by the model). It has been frequently observed that the total annoyance rating is equal or *lower* than the highest single source annoyance (Rice, 1986). The dominance model implies that the total annoyance is always *equal* to the highest single source annoyance while alternative models, such as the above energy summation model, imply that the total annoyance is (equal or) *higher* than the highest single source annoyance. Consequently, the dominance model fits the data on total annoyance ratings better than the alternative models. Therefore it has been regarded as the proper model for the prediction of annoyance caused by combined sources. However, there is a systematic discrepancy between the annoyance model and the data showing lower total annoyance, which may be related with difficulties people have with evaluating the total annoyance from various sources at once in a single judgment.

Empirical findings contradict the following implication of the dominance model. According to the dominance model, the total annoyance A is constant when the level of a non-dominant source changes, as long as it does not become the dominant source. This means that such situations with different levels of the non-dominant source are predicted to cause equal annoyance. However, it has been found (see Miedema, 1987) that the total annoyance increases if the annoyance level from the non-dominant source approaches the annoyance level of the dominant source. Thus, the dominance model does not describe the empirical data correctly for the important cases where the difference in annoyance between dominant and non-dominant sources is limited.

Annoyance equivalents model

The annoyance equivalents model (cf. Vos, 1992; Miedema, 1996) resembles the toxic equivalents models used in toxicology to describe the toxicity of certain mixtures, e.g. mixtures of dioxins. Using so-called toxic equivalence factors, the concentrations of compounds are translated into the equally toxic concentrations of a reference compound which then are summed. The annoyance equivalents model can be seen as an elaboration of the energy summation model. Instead of summing the sound energy from the individual sources directly, it first translates the noise from the individual sources into the equally annoying sound energy levels of a reference source and then sums these levels. Figure 5 illustrates this for two different noise sources A and B. The noise levels from these sources are L_A and L_B, respectively. Source A is selected as the reference. In order to calculated the total noise annoyance, L_B is transformed into an equally annoying level of A, L'_B, as shown in the figure. Then L_A and L'_B are added on an energy basis, giving L. The corresponding annoyance from the two combined sources is found by using the exposure – annoyance relationship of A, with exposure L.

Total Annoyance Theorem

The above description of the annoyance equivalents model means that the total noise level L is defined as follows:

$$L \quad = \quad 10.\lg \sum_i 10^{\,0.1 \times h_{ref}^{-1} \circ h_i\,(L_i)}$$

Here h_i is the exposure – annoyance function for source i, and h_{ref}^{-1} is the inverse of that function for the reference source. Thus, the composite function $h_{ref}^{-1} \circ h_i$ transforms the noise level of source i into the equally annoying level of the reference source, as illustrated in figure 5. Furthermore, the total annoyance score is the value of the exposure – annoyance function of the reference source at L:

$$A \quad = \quad h_{ref}\,(L)$$

There is a theorem (see: Krantz et al., 1971; Miedema, 1996: theorem 6.1) which implies that the annoyance equivalents model is correct for combinations of aircraft, road traffic and railway noise, provided that the following four conditions hold, and it is assumed that for one type of source i the annoyance is a strictly increasing function of the noise level of that source, L_i. In the description of the conditions, x,y, and z are each a combination of three noise levels from the three types of sources (levels may be nihil so that the variables may also represent a quiet situation or an exposure to only a single source):
Transitivity: If x is at least as annoying as y, and y is at least as annoying as z, then x is at least as annoying as z.
Restricted solvability: If x is at least as annoying as y, then the exposure of any source in the combination y can be changed so that the combination becomes equally annoying as x.
Independence: If x and y both are combinations of exposures such that
- source i (say, aircraft) has in combination x a noise level that is at least equal as its noise level in combination y,
- the exposure levels of the other sources (of road traffic and of railways) are equal in x and y, then x is at least as annoying as y.

Connected: either x is at least as annoying as y or y is at least as annoying as x , or both, i.e., the annoyance level of a combination relative to another combination always is defined.

Empirical basis and limitations

The above mentioned theorem is *not* an empirical theory, but a theorem that has been mathematically proven to be correct (see : Krantz et al., 1971; Miedema, 1996). The theorem means that the annoyance equivalents model is correct, if the four specified properties of annoyance hold. In principle, verification of the properties of noise annoyance requires empirical testing. The properties also may be accepted without testing if they are considered to be very plausible, or acceptable simplifications or useful idealizations. An important aspect of the properties is that only comparisons of the annoyance caused by (combined) exposures are needed for their testing, and not total

annoyance rating of which the validity is questionable (see the above discussion of the dominance model).

The critical property is independence. The following example illustrates the probably most important violation of independence. The ordering of (combined) exposures with respect to the noise annoyance they cause is called the annoyance ordering. Consider:

- the annoyance ordering of all situations with only road traffic noise;
- the annoyance ordering of the situations obtained from the 'only road traffic noise' situations by adding to each the same tonal sound (e.g., squeeling railway noise).

Then independence is violated if a tonal sound with little or no road traffic noise is more annoying than the same tonal sound with a higher level of road traffic noise. This may actually occur if the tonal sound is masked in the latter case. A similar phenomenon may be found with very low frequency noise, or impulsive noise instead of tonal noise. In these cases the annoyance reduction caused by the masking of the very irritating sound may outweigh the annoyance increase caused by the higher road traffic noise.

Although such situations do exist, they will be rather scarce because of the following reasons:

- The above-mentioned types of very irritating sounds, for which the described effect may be important, are rather scarce compared to the widespread prevalence of noise from various types of transportation without these specific aspects.
- In general, if the above-mentioned types of very irritating sounds occur, it is unlikely that masking will occur to an extent that affects the reaction to this sound. The reason for this is that important binaural masking requires, in addition to a sufficiently high level of the masker, overlap in time, overlap in frequency spectrum, and spatial proximity of the source of the irritating sound and the masking noise.

Findings of Fields (1998) demonstrate that the influence of a second noise source on the evaluation of another source in general is not important. This supports that the above discussed violations of independence are not important. He found that "residents' reactions to an audible environmental noise (…) are only slightly or not at all reduced by the presence of another noise source (…) in residential environments."

Procedure for the assessment of annoyance based on the annoyance equivalents model

For use of the annoyance equivalents model, the individual exposure - annoyance relationships h_i need to be known, and a reference source must be chosen (see the above equations for the model). The information needed regarding the relationships is specified in Part I, tables 3 and 4. In principle, the choice of the reference source is not arbitrary, but actually it is not so important as it could be because the relationships given in Part I are linear and have nearly equal slopes. With linear relationships having equal slopes, the annoyance predicted by the annoyance equivalents model is independent of the choice of the reference source. Road traffic is chosen as the reference source, as has been done previously.

Using the information regarding individual exposure – annoyance relationships from Part I, the assessment of the total noise level and the corresponding percentage annoyed can be broken down in the following steps when using DNL:

1.   Assess *DNL* for aircraft, road traffic, and railways (L_{air}, L_{road}, and L_{rail});

2.   Calculate the annoyance level for aircraft and for railways[3]:

- ▪ $A_{air} = 2.16\ L_{air}\ -\ 89.7$

- ▪ $A_{rail} = 2.06\ L_{rail}\ -\ 107.5$;

3.   Calculate the equally annoying road traffic levels for aircraft and for railways:

- ▪ $L_{air}' = (A_{air} + 105.7)\ /\ 2.21$

- ▪ $L_{rail}' = (A_{rail} + 105.7)\ /\ 2.21$;

4.   Calculate the total noise level:

$$L\ =\ 10.\lg\ (10^{\,0.1\times L_{air}'} + 10^{\,0.1\times L_{road}} + 10^{\,0.1\times L_{rail}'})\ ;$$

5.   Calculate the percentage a little annoyed, annoyed, or highly annoyed for the combined, multiple sources[4]:

$\%LA = -6.188*10^{-4}\ (L\text{-}32)^3 + 5.379*10^{-2}\ (L\text{-}32)^2 + 0.723\ (L\text{-}32)$;

$\%A = 1.732*10^{-4}\ (L\text{-}37)^3 + 2.079*10^{-2}\ (L\text{-}37)^2 + 0.566\ (L\text{-}37)$;

$\%HA = 9.994*10^{-4}\ (L\text{-}42)^3 - 1.523*10^{-2}\ (L\text{-}42)^2 + 0.538\ (L\text{-}42)$.

The steps when using *DENL* are:

1.   Assess *DENL* for aircraft, road traffic, and railways (L_{air}, L_{road}, and L_{rail});

2.   Calculate the annoyance level for aircraft and for railways[5]:

- ▪ $A_{air} = 2.17\ L_{air}\ -\ 91.4$

- ▪ $A_{rail} = 2.10\ L_{rail}\ -\ 110.1$;

3.   Calculate the equally annoying road traffic levels for aircraft and for railways:

- ▪ $L_{air}' = (A_{air} + 107.0)\ /\ 2.22$

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[3] Note that the linear relationships do not have the observed annoyance score as the dependent variable, but the corresponding variable with a normal distribution. While the range of the observed annoyance score is 0 – 100 so that negative values do not occur, the corresponding normally distributed variable may be negative.

[4] A percentage obtained for a single source situation with aircraft or railway noise only may differ a little from the percentage obtained by estimating the percentage directly with the proper exposure – annoyance curve for that source, because the estimates of σ_0^2, and σ^2 depend on the type of source. This may be remedied in the future by making common estimates of these parameters for all three types of sources.

[5] See note 2.

- $L_{rail}' = (A_{rail} + 107.0) / 2.22;$

4.   Calculate the total noise level:

$$L = 10 . \lg (10^{0.1 \times L_{air}'} + 10^{0.1 \times L_{road}} + 10^{0.1 \times L_{rail}'}) ;$$

4. Calculate the percentage a little annoyed, annoyed, or highly annoyed for the combined, multiple sources[6]:

$\%LA = -6.235*10^{-4} (L-32)^3 + 5.509*10^{-2} (L-32)^2 + 0.6693 (L-32);$

$\%A = 1.795*10^{-4} (L-37)^3 + 2.110*10^{-2} (L-37)^2 + 0.5353 (L-37);$

$\%HA = 9.868*10^{-4} (L-42)^3 - 1.436*10^{-2} (L-42)^2 + 0.5118 (L-42);$

Conclusion and discussion regarding the model for multiple sources

The annoyance equivalents model has been presented. It describes the annoyance caused by aircraft, road traffic, and railway noise. This model has not been tested directly, but follows from four assumptions regarding noise annoyance, using a (mathematical) theorem. The theorem means that the annoyance equivalents model is correct, if the four specified properties hold. The properties may be accepted without testing if they are considered to be very plausible, or acceptable simplifications or useful idealizations. The critical property is independence. The violation of independence is discussed, and it is concluded that important violations are expected only in a limited number of practical situations. The exposure – annoyance relationships for individual sources from Part I are used to further specify the annoyance equivalents model. For use in practice, the application of the model is broken down in five steps. This step by step procedure can be used for the assessment of the total noise level and the associated total annoyance.

An annoyance percentage for a single source situation obtained with the procedure for the assessment of the total annoyance may differ a little from the percentage obtained by estimating the percentage directly with the proper exposure – annoyance curve for that source. This may be remedied in the future by making common estimates of the variances of the annoyance distributions for all three types of sources (aircraft, road traffic, and railways).
The most important elaboration of the above approach concerns the spatial distribution of the noise exposure of a dwelling. It is likely that there is a difference in total annoyance between the situation with two sources affecting the same side of a dwelling, and the situation with the same two sources affecting different sides of the dwelling. Taking this into account would require further elaboration of the exposure – annoyance relationships by including more (exposure) variables as predictors of annoyance, in addition to *DNL* or *DENL* (at the most exposed side of a dwelling), especially the presence of a relatively quiet side of the dwelling.

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[6] See note 3.

Acknowledgement

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Table 1   Boundary quantifications for different annoyance scales.

number of effective categories	boundary quantifications
3	0-33-67-100
4	0-25-50-75-100
5	0-20-40-60-80-100
6	0-17-33-50-67-83-100
7	0-14-28-43-57-72-86-100
10	0-10-20-..-80-90-100
11	0-9-18-..-82-91-100

Table 2   Datasets used to establish the relationships between noise exposure and annoyance.

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

Road Traffic

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

Railway		
Fields= code	Name of the survey	
FRA-063	Paris Area Railway Noise Survey (1972)	
GER-192	German Road/Railway Noise Comparison Study (1978/1981)	
NET-153	Netherlands Railway Noise Survey (1977)	
NET-276	Netherlands Tram and Road Traffic Noise Survey (1983)	
SWE-165	Gothenburg Tramway Noise Survey (1976)	
SWE-228	Swedish Railway Study (1978-1980)	
SWE-365	Swedish 15-site Railway Study (1992-1993)	
UKD-116	British National Railway Noise Survey (1975/1976)	

Table 3: The estimated coefficients of model of annoyance percentages with DNL as the noise exposure metric for aircraft, road traffic and railways separately, and the standard errors and p-values.

Aircraft (total number of observations = 27081, number of studies = 19)			
Parameter	Estimate	Standard Error	p-value
β_0	-89.67	3.30	<.0001
β_1	2.16	0.0406	< .0001
σ_0^2	81.05	26.93	0.0075
σ^2	1185.90	20.11	< .0001
Road traffic (total number of observations = 19172, number of studies = 26)			
Parameter	Estimate	Standard Error	p-value
β_0	-105.72	3.89	< .0001
β_1	2.21	0.0473	< .0001
σ_0^2	150.32	42.93	0.0018
σ^2	1150.08	18.65	< .0001
Railways (total number of observations = 7632, number of studies = 8)			
Parameter	Estimate	Standard Error	p-value
β_0	-107.45	6.16	< .0001
β_1	2.06	0.0819	< .0001
σ_0^2	51.01	26.90	0.0998
σ^2	1043.43	44.32	< .0001

Table 4: The estimated coefficients of model of annoyance percentages with DENL as the noise exposure metric, separately for aircraft, road traffic and railways, and the standard errors and p-values.

Aircraft (total number of observations = 27081, number of studies = 19)			
Parameter	Estimate	Standard Error	p-value
β_0	-91.42	3.30	<.0001
β_1	2.17	0.0407	<.0001
σ_0^2	77.64	25.83	0.0076
σ^2	1187.11	20.13	<.0001
Road traffic (total number of observations = 19 172, number of studies = 26)			
Parameter	Estimate	Standard Error	p-value
β_0	-106.97	3.91	<.0001
β_1	2.22	0.0476	<.0001
σ_0^2	150.54	42.99	0.0018
σ^2	1150.71	18.66	<.0001
Railways (total number of observations = 7 632, number of studies = 8)			
Parameter	Estimate	Standard Error	p-value
β_0	-110.09	6.33	<.0001
β_1	2.10	0.0840	<.0001
σ_0^2	53.86	28.55	0.1013
σ^2	1078.73	47.21	<.0001

Figure 1   For aircraft, road traffic and railways *%LA* (upper row), *%A* (middle row) and *%HA* (lower row) as a function of *DNL*, together with the 95% confidence intervals. The curves were found by fitting the model of the annoyance percentages to the data from field surveys (see table 2). The estimates of the parameters are given in table 3.

Figure 2 For aircraft, road traffic and railways *%LA* (upper row), *%A* (middle row) and *%HA* (lower row) as a function of *DENL*, together with the 95% confidence intervals. The curves were found by fitting the model of annoyance percentages to the data from field surveys (see table 2). The estimates of the parameters are given in table 4.
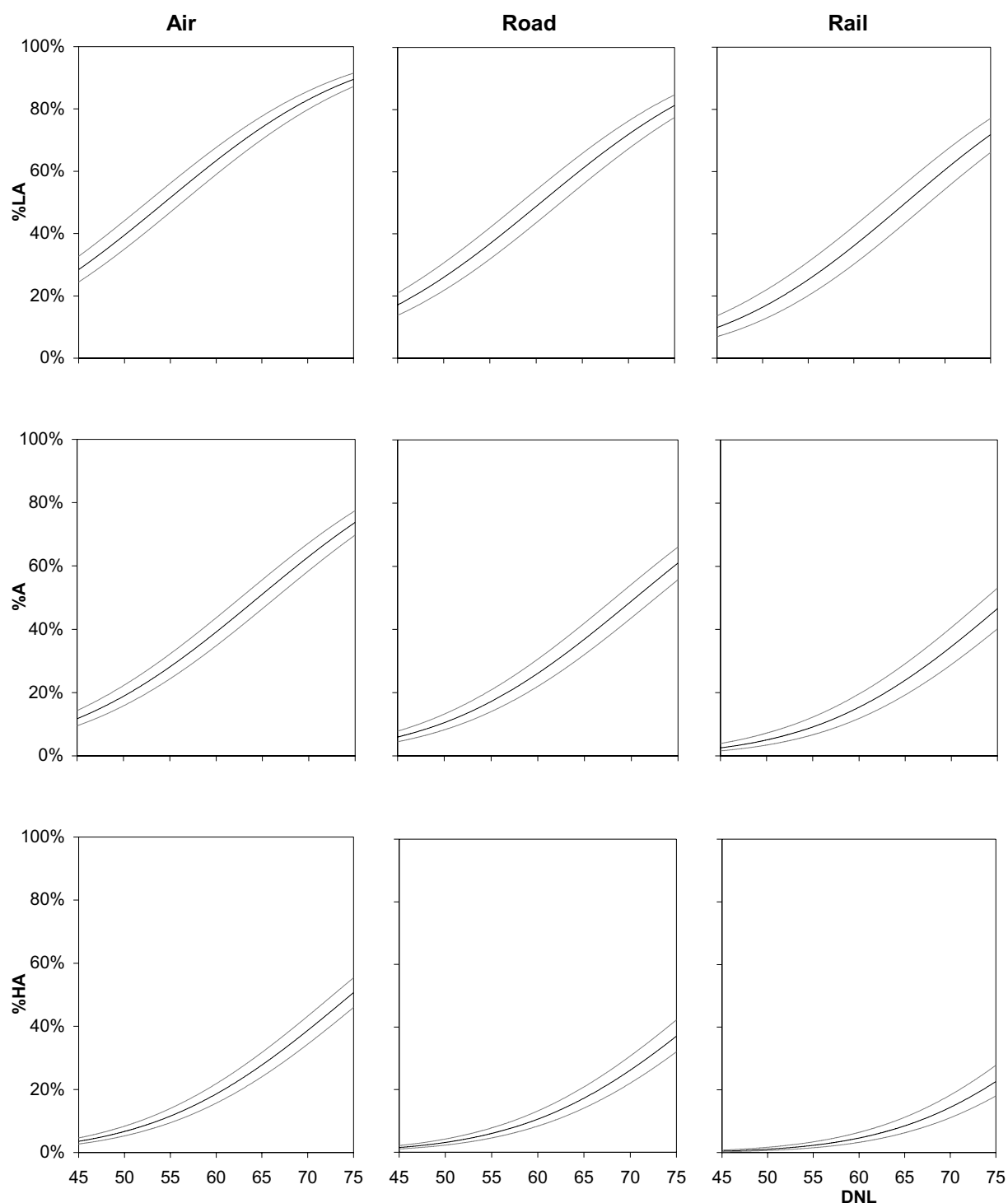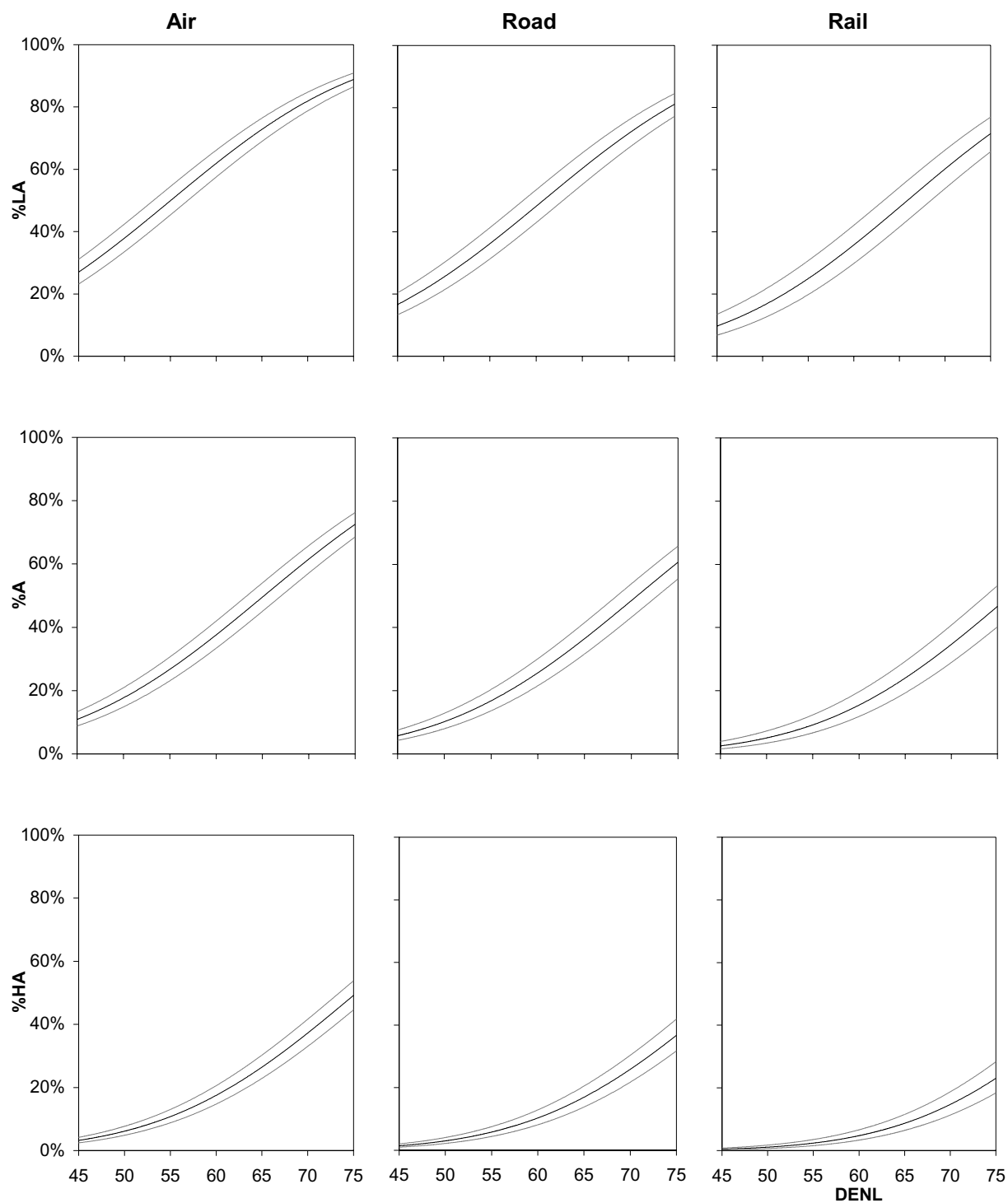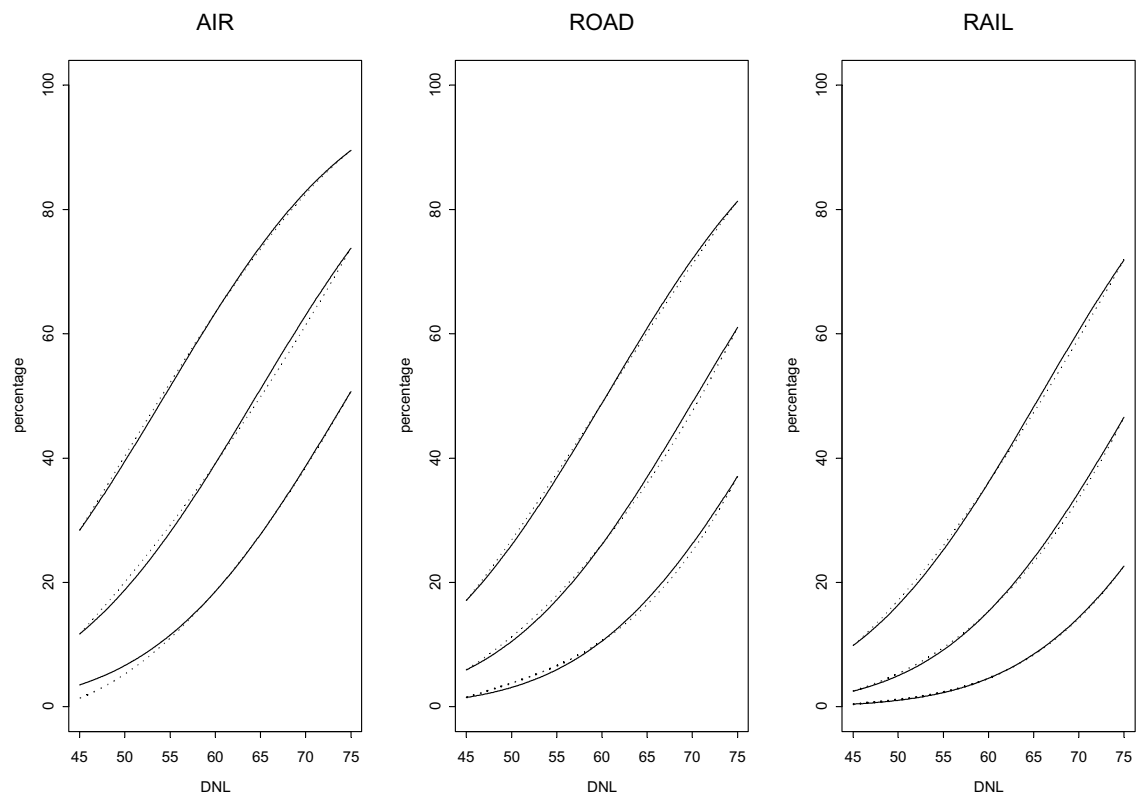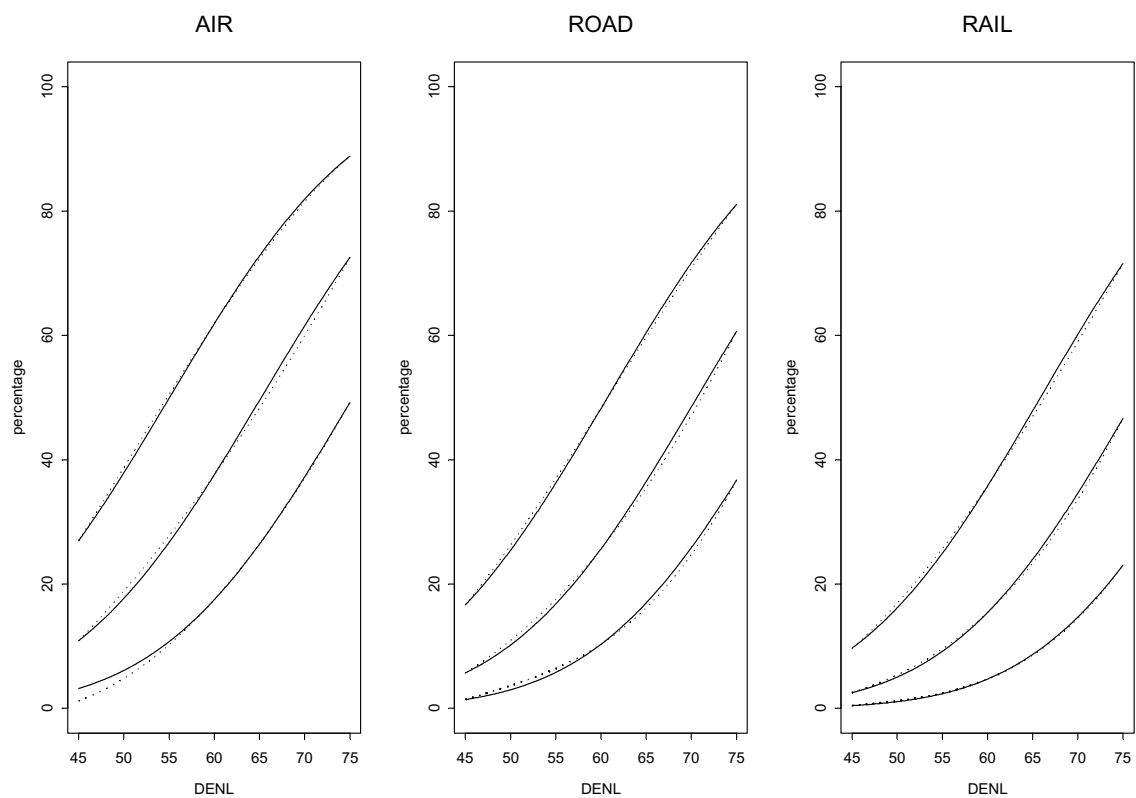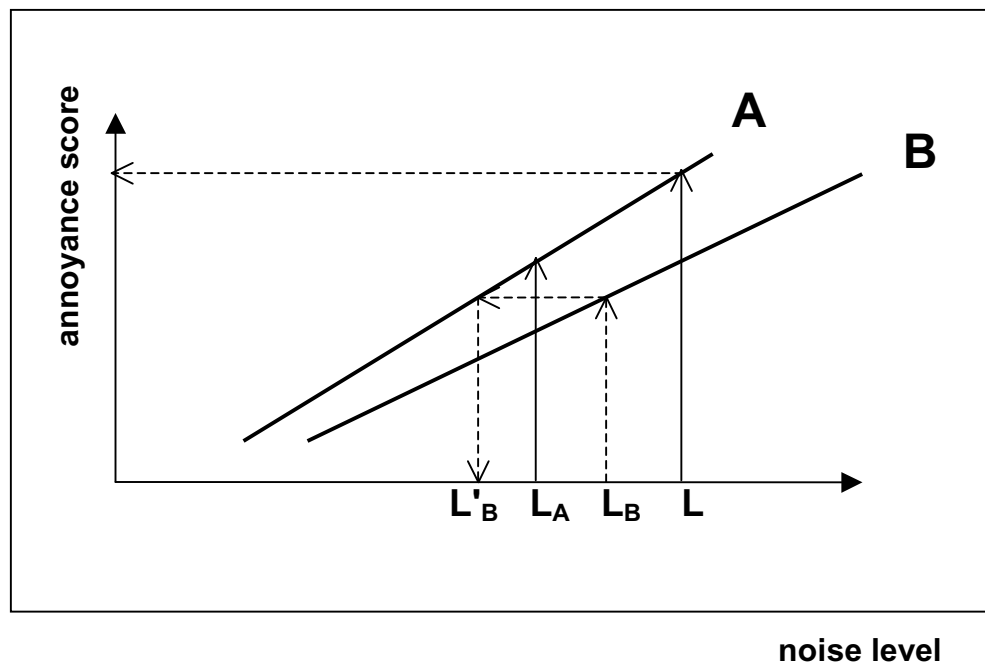
Figure 4: The estimated curves (solid lines) and their polynomial approximations (dashed lines) for *DENL*.

Figure 5   Illustration of the annoyance equivalents model (see text)

NOISE EXPOSURE FROM VARIOUS SOURCES
SLEEP DISTURBANCE, DOSE-EFFECT RELATIONSHIPS ON ADULTS

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Executive summary*: Sleep disturbance is among the most frequent incriminated effects of noise exposure. Numerous studies have been performed during the last 30 years, in both laboratory environment and home settings. Controversial results have sometime been published and large discrepancies have been noticed. Therefore, there is a need for a better understanding of why such different results have been obtained. Are the main reasons more related to the complexity of noise exposure or to basic methodological differences? An attempt to review the existing literature and to explain some of the differences has been made and further research in this area appears to be necessary.*

1. Introduction

During the last 30 years, noise has been considered by the general public as the most disturbing environmental factor in the everyday life. This appreciation was confirmed through a large body of works which have been performed to evaluate the adverse effects of noise exposure. These effects can be separated into both specific (hearing impairment) and non specific effects (extra-auditory effects), and the latter can be subdivided into subjective (annoyance) and more objective effects (communication interference, sleep disturbance,….).

Among the extra-auditory effects, sleep disturbance is a common effect described by most of the noise-exposed populations, and their complaints are often very impressive. We know that protection of this particular rest period is necessary for a good quality of life, as daytime well being often depends on sleep quality and efficiency. However, the survey of the literature shows large differences between results obtained in numerous laboratory studies and those issued from epidemiological or experimental studies made in real situations. The comparison of these results shows that the differences appear, to a large extend, to be related to the rate of nocturnal awakenings which is much smaller in field studies than in the laboratories. It seems obvious that a certain degree of habituation occurs in the field for the number of provoked awakenings, while some subjective adaptation is building up progressively. In the other hand, modifications in sleep stage architecture (number of sleep stage changes) seem to less habituate with time, while autonomic responses do not habituate over extended periods of time. Effects on endocrine and immune systems are more difficult to establish through both laboratory and field studies, and further research is clearly needed in these areas. These latter effects integrate many more factors over time, and it is therefore more difficult to extract the exact part due to the noise exposure.

Nevertheless, it seems obvious that public complaints are supported by objective facts as the exposed populations have no direct interest in complaining except protecting their living environments. It is therefore important to try to establish dose-effect relationships for different types of noise exposure. Thus, the objective of the present work is to look through

the available literature in order to examine if it is possible to extract dose-effect relationships from the published experimental data and what are the limits of such an approach.

2. Noise exposure

2.1. Different types of noise exposure

Noise is produced by a large variety of sources in various environments, and as most of the people complaining from noise are exposed to different noise sources, this is defined as multi exposure. Noise is present everywhere in our everyday life and effects of excessive noise have even be studied in the hospital environment in one of the most advanced care unit: the intensive care unit (Aaron et al., 1996). The effects of transportation noises have been most studied, but outside specific areas they are less prevalent than noises coming from the neighbourhood such as domestic, lawnmower, dog or leisure noises.

2.2. Different noise characteristics and measurements

Different indices have been used to describe noise-exposure and there is no general agreement on which should be preferred among integrated energy indices (L_{Aeq}, L_{DEN}, L_{night},…), statistical indices (L_{10}, L_{50},…) or event indices (L_{Amax}, Sound Exposure Level: SEL, Number of Noise Events: NNE,…). As we shall see later, it is difficult to correlate night time noise exposure defined by integrated indices with actual sleep disturbance. These indices, giving a good overall description of global noise exposure, are much better for daytime or 24-hour exposure, while event indices would be more practical to predict sleep disturbance. A large review of the literature shows that it is generally acknowledged that measures of peak sound level are better predictors of disturbances in sleep that measures of average sound level (Berglund et al., 1990 ; Hofman, 1994).

In addition, it is better to choose indices which can be measured easily and, in view of their impact to the public, to be more easily understood by the noise-exposed populations. This is why the French Airport Noise Control Authority has proposed to defined a threshold of $L_{Aeq(1sec)} = 85$ dB(A) as the maximum noise level measured on the ground from aircrafts flying over residential area at night. According to the average sound attenuation value of 35 dB(A) applicable in these well-defined areas by adapted techniques, the residual value of individual peak levels should not be exceeding 50 dB(A) inside the bedrooms.

3. Sleep disturbance

The effects of noise on sleep can be measured immediately or be evaluated afterwards, at the end of the night or in the following day. Thus, immediate effects are mainly measured by objective data recorded during sleep and they show how the sleeper is reacting to noise. After effects are measured at the end of the night by subjective evaluations or by some specific biological data (such as levels of stress hormones) or by performance level during the following day.

3.1. Immediate effect

To some degree, sleep disturbance may be quantified by number and duration of nocturnal awakenings, number of sleep stage changes, number of electroencephalographic (EEG) arousals, and global modifications in total amount of sleep stages or in their time organisation (sleep architecture). In complement, concomitant modifications in the autonomic functions (heart rate, blood pressure, vasoconstriction and respiratory rate) could be indicative of the reactivity of the sleeper.

3.1.1. Arousal responses

The earliest response to noise during sleep is the arousal reaction. It can be obtained with very low noise intensity and its consequences can be very limited in terms of impact on sleep. However, arousals do occur spontaneously in non-disturbed sleep, and depending on the sleeper their number varies between a few to several tens per night. In its simple expression, the arousal is affecting the EEG recordings for a few seconds (disappearance of slow waves or sleep spindles, occurrence of alpha and/or fast EEG waves) together with autonomic signs of activation (increased heart rate for a few seconds, peripheral vasoconstriction). At a higher level, the arousal reaction is accompanied by body movements of the sleeper and possible sleep stage changes. With its maximum magnitude, arousal leads to a sudden transition from the existing sleep stage to awakening.

3.1.2. Sleep stage changes

As indicated above, transitions from deep stages of sleep to shallower sleep stages can be direct consequences of the arousals provoked by occurring nocturnal noises. These unwanted transitions are not perceived by the sleeper, but they modify the sleep architecture and total amount of slow wave sleep (SWS) and of Rapid Eye Movement (REM) sleep can be significantly reduced. Carter indicated that the amount of SWS can be significantly reduced by noise exposure during the night (Carter, 1996). It has been shown also that REM sleep rhythmicity can be deteriorated by exposure to noise (Naitoh et al., 1975; Thiessen, 1988). Therefore, these sleep stage changes are detrimental to deep stages of sleep, to the benefit of light sleep stages.

3.1.3. Nocturnal awakenings

It is obvious that noise occurring during sleep can provoke awakenings. Thus, some of the arousals provoked by the noises are so intense that they induce transitions to awakenings and this leads to sleep disruption or fragmentation and global sleep disturbance. The noise threshold for such a major disturbance depends on several factors. It is the case for the sleeper's current stage of sleep: the threshold is particularly high in deep slow wave sleep (stages 3 and 4) while it is much lower in shallower sleep stages (stages 1 and 2). In REM sleep the awakening threshold is variable and mainly depending on the stimulus signification. The awakening threshold also depends on physical characteristics of the noisy environment (intermittent and sharp rising noise occurring above a low background noise, will be particularly disturbing) as well as noise signification. Thus, it has been demonstrated long before, that whispering the

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sleeper's name while he or she is in REM sleep can induce a larger behavioural response than pronouncing somebody else name or producing a much louder but neutral acoustic stimulus (Oswald et al., 1960). Similarly, and with a same intensity, an alarm noise can awake the sleeper more easily than a noise without any particular signification. Therefore, these results suggest that sleeper's reaction to noise is not always function of the intensity of the stimulus and that its signification may sometime be more important than its physical characteristics.

3.1.4. Total waking time

Total sleep time can be reduced by both longer time to fall asleep and premature final awakening. It has been reported that intermittent noises with peak noise levels of 45 dB(A) and above, can increase the time to fall asleep by a few minutes to 20 minutes (Öhrström, 1993). In another hand, sleep pressure is significantly reduced after the first 5 to 6 hours of sleep. Therefore, in the morning hours, noise events can more easily awake and prevent the sleeper to go back to sleep. The main problem, therefore, is to determine whether a significant part of sleep can be chronically reduced with no detrimental effect on the long term.

3.1.5. Autonomic responses

The occurrence of intermittent noises during sleep has been found to induce a biphasic cardiac response and a transient constriction of peripheral vessels together with a short phasic activation in the EEG, while no other behavioural effect can be seen (Muzet and Ehrhart, 1978).

This biphasic cardiac response is constituted by an initial increase in heart rate, probably due to a phasic inhibition of the parasympathetic cardio-inhibitory centre, followed by a compensatory decrease due to a phasic decrease in orthosympathetic activity (Keefe et al., 1971; Muzet and Ehrhart, 1980). The vasoconstrictive response was reported to be due to the sympathetic peripheral stimulation provoked by the auditory reflex (Kryter and Poza, 1980).

The most striking is that none of these cardiovascular responses show habituation to noise after a prolonged exposure, while subjective habituation occurs within a few days (Muzet and Ehrhart, 1980). More recently, it has been shown that beat by beat blood pressure changes can be induced by suddenly occurring noises (Carter et al., 2002).

3.2. After effects

The after effects are measurable within a few hours or a few days after the end of the disturbed nights. The most studied are the subjective complaints of the populations exposed to various types of noise. Subjective evaluations can be completed by other measures such as daytime performance or some endocrine responses to stress induced by nocturnal noises.

3.2.1. Subjective evaluation of sleep disturbance

Subjective evaluation of reduced sleep quality is often the only way used to size the impact of noise at night. Sleep recordings are too costly and difficult to run on large samples of the population, while sleep questionnaires remain an easier way of collecting data in this case. Sleep disturbance can be assessed from complaints about bad sleep quality, nocturnal awakenings, often accompanied by impaired quality of subsequent daytime period with increased tiredness, daytime sleepiness and need for compensatory resting periods.

However, subjective complaints are not at all parallel to objective (instrumental) measures. If the number of the noise events increases, the number of sleep modifications or awakenings also increases, although not proportionally. As indicated by Porter et al. (Porter et al., 2000), noise heard at night will be more intrusive and noticeable than during the day. This is due to the reduced outside and inside background noises at night. Night time period may also be a time of higher noise sensitivity, especially in the case of awakenings related to the aircrafts flying over.

However, if the number of noise events is important and that noise level is high, a single nocturnal awakening (spontaneous or provoked) can be excessively prolonged and may even constitute a premature final awakening of the night. Sleep disturbance occurring during the early part of the night and during the time just preceding usual awakening appear to be most annoying (Fields, 1986; Öhrström, 1993). In this case, sleep disturbances can lead to excessive daytime fatigue, often accompanied by daytime sleepiness with its specific consequences in terms of low vigilance, low work capacity and increased accident rate.

In complement, it is also obvious, that fear to be living under aircraft routes is often a major reason for people to protest against aircraft noise, even if the measured noise levels are relatively low. This example explains for a large part the difficulty of finding a clear relationship between subjective complaints and actual noise exposure levels.

3.2.2. Other measures

Other measures made after noise-exposure, include daytime performance and cognitive function deterioration analyses. The excretion of stress hormones in the morning urine flow can be measured to evaluate the impact of global noise-exposure at night (Maschke et al., 1993). However, these types of measures are quite difficult to perform in field situations and only a few studies have included them in the recent years.

4. Important questions related to sleep disturbance due to noise

4.1. The habituation phenomenon

A certain degree of habituation to noise does exist. If the noise load is not in excess, subjective habituation can occur in a few days or weeks. However, this habituation is not complete and the measured modifications of the cardiovascular functions still remain unchanged over long periods of exposure time (Muzet and Ehrhart, 1980;

Vallet et al., 1983). It is not excluded that this long term effect could perhaps lead to permanent cardiovascular system impairment (Carter, 1996; Carter, 1998). However, to date, there is no evidence for conclusive effect of chronic exposure to noise during sleep on cardiovascular diseases, but no evidence does not mean that the study has been done! Again, this could be due to the difficulty to separate cumulative effects of night time exposure to noise from the global exposure to other environmental factors (including noise) over the 24-hour period. To our knowledge, no epidemiological study has tried to specifically answer the question of the effects of noise exposure during the night compared to the more global daily exposure.

4.2. Individual sensitivity

Sensitivity to noise may vary greatly from one individual to another. Primary self-evaluation of sensitivity to noise has been used as a factor to evaluate highly sensitive and non sensitive groups and to compare their reactions to noise exposure during daytime and night time (Di Nisi et al., 1990). In this study, self-declared highly sensitive individuals had higher cardiovascular response rate to noise than non sensitive people during their waking exposure, while there was no difference in sensitivity to noise between these two groups during their night time exposure while they were asleep.

The physiological sensitivity to noise depends also on the age of the sleeper. Thus, while EEG modifications and awakening thresholds are, on the average, 10 dB(A) higher in children than in adults, their cardiovascular sensitivity to noise is similar, if not higher, than the older group ([Muzet et al., 1981). Elderly people complain much more than younger adults about environmental noise. However, their spontaneous awakenings occurring during the night sleep are also much more numerous. Therefore, it is difficult to conclude if elderly people are more sensitive to noise or if they hear noise because they are often awake during the night. This natural fragmentation of their night sleep tends also to lengthen their return to the sleeping state and this account for a significant part in their subjective complaints.

Differences in sensitivity to noise have been found between both sexes. Thus, young men seem to complain more about noise-disturbed sleep than young females (Muzet et al., 1973). However, this difference seems to reverse for populations over 30 years of age and then females (often mothers) appear to be more sensitive to noise than males (Lukas, 1972).

4.3. Specific subgroups

The main question about possible sensitive groups remains almost entirely unanswered. Most of the studies (in laboratories as well as in the homes) have been done on groups of "healthy" people, and where some specific pathologies have been systematically excluded.

The sleep of shift workers is often disturbed by combined influences of ambient factors (noise is one of them) and chronobiological factor (sleeping at unusual time of the day). Thus, noise was considered as the first cause of sleep interruptions in a shift

worker female group (Lee, 1992). It is also considered as a major cause of sleep shortening during daytime (Knauth and Rutenfranz, 1975).

To our knowledge, only two experimental studies have been looking into the specific situation of shift workers (Nicolas et al. 1993; Carter et al., 2002) (see table I).

Authors	Site	Type of noise	Number of subjects (mean age ± SD)	Effects studied	Background noise	Max peak level	Min peak level	Overall Leq
Nicolas et al., 1993	lab	traffic	14 males (37years ± 5)	Sleep EEG & cardiovasc. resp.	35 dB(A)	71 dB(A)	64 dB(A)	49 dB(A)
Carter et al., 2002	lab	Tones and aircrafts	9 females (27.5 years)	Sleep EEG, HR, Blood Press.	30 dB(A)	75 dB(A)	55 dB(A)	

Table I: Characteristics of the studies made on the effects of noise on shift-workers

Comparing daytime to night time sleep disturbance due to noise in shift workers, Nicolas et al. found that the percentage of noise-induced EEG effects was significantly higher during daytime than during night time REM sleep (Nicolas et al., 1993). These authors also stated that the inversion of the sleep-wake cycle did not markedly influence the average cardiovascular reactivity to noise and they concluded that daytime sleep disturbance by noise was as important and harmful as night time disturbance. Carter and his colleagues underlined the effects of noise on the cardiovascular side and particularly the modifications in blood pressure due to suddenly occurring noises (Carter et al., 2002).

5. Looking for dose-effect relationships: Are we able to establish them today?

A large review of the literature shows that a fully credible dose-effect relationship for assessing sleep disturbance by night time noise exposure is a highly difficult and perhaps impossible goal to reach. Large differences exist between laboratory and field studies, but inside both categories there are large discrepancies which account for a very large variability of the results. Of course, there are numerous types of noise exposure, not only by the existing noise sources and their combinations, but also by the timing of the noise occurrences and their physical characteristics and subjective significations.

All kinds of measures have been used for both the noise-exposure specifications and the effects of sleep disturbance. Especially for night time exposure, the choice of taking integrated measures over several hours instead of event-by-event noise measurement is not innocent. Behind any L_{Aeq} value there are numerous possibilities of noise-exposure, from a few but noisy events to a large number of noise events with individually reduced L_{Amax}. Therefore, it is hard to believe that a given L_{Aeq} value will correspond to specific and recurrent patterns of sleep disturbance. It is also not without any consequence to use different ways of evaluating the disturbance of the sleeper. Even if the sleep alphabet seems to be the same for all investigators, the choice of the elementary sleep scoring period (from 10 sec to

one minute) or the length of the recording period to be analysed after the onset of a noise event, can change dramatically the final results published.

The populations themselves are quite different in terms of age, social profile, life style and experience with noise-exposure. As a matter of facts, most of the studies report results on young and healthy subjects, and subjects suffering from illnesses are generally excluded from the analyses.

Therefore, looking for dose-effects relationships appears to be controversial as these relationships might be reductive or, at least, be considered as average concepts containing a large variability; and this statement must be kept in mind.

5.1. Existing dose-effect curves

Finding dose-effect relationships for noise disturbed sleep is an ambitious goal but several attempts have been made already. The complexity of establishing such relationships is due to the number of factors which have to be taken into account. Noise itself cannot be simply described by its rise time, maximum level, duration, and spectral composition. These characteristics are insufficient to predict possible sleep disturbance and, as said before, number and signification of each individualized noise are important additional factors (Langford et al., 1974). As noted by Stansfeld (Stansfeld, 2002), "*there is a low association between outdoor noise levels and sleep disturbance*". Number of occurring noise events during the night, whatever their peak level, is often presented as a key factor. However, the way these noises are distributed along the night or the period where they are concentrated must also be considered. The shoulder periods of the night (time to fall asleep in the first part of the night and early morning hours) are important to protect, but in depressed patients the awakening in the middle of the night is the worst as it is often followed by a long insomnia episode.

According to WHO, during sleep equivalent sound level ($L_{Aeq, 8h}$) should not be higher than 30 dB(A) and single noise events (L_{Amax}) should not exceed 45 dB(A) (WHO, 2000). However, these values can be considered as the most preservative and, at the same time, still difficult to be achieved. In many cases it is clear that such levels will not be obtained at night without clearing large areas around the noise sources and moving out thousands of exposed people.

Several attempts have been made to summarize results issued from different published studies in order to draw dose-effect curves. Table II presents the most prominent of these reviews.

Authors	Year	Number of studies	Site	Type of noise	Noise exposure measures *	Effects considered (curves)
Lukas	1975	13	Lab.	Aircraft, sonic boom & road traffic	L_{Amax}, EPNL & SENEL	Awakening, arousal & no sleep disruption
Griefahn	1980	10	Lab.	Aircraft, train, white noise, tones & road traffic	L_{Amax}	Awakening & 0-reaction
Pearsons	1989	21	Lab. & field	Aircraft, train, white noise, tones & road traffic	L_{Amax} & SEL	Awakening or aroused & sleep disruption
Hofman	1994	53	Lab & field	Aircraft, road traffic, train, industry, mixed	L_{Amax}	Awakenings & sleep stage changes

* L_{Amax}: maximum A-level; PNL: perceived noise level; EPNL: effective perceived noise level; SEL: sound exposure level; SENEL: single event noise exposure level.

Table II: Main characteristics of the reviews made on dose-response curves.

It appears clearly in table I, that different noise sources have been mixed together in all these reviews. It is obvious that the first step of the performed analyses could be the rough evaluation of a possible relationship between a single dose measurement and the expected provoked effects. However, it is not certain that each type of noise can be sorted from its own context and just be represented by a few of its physical characteristics.

The last of these reviews has been prepared by Hofman and presented in her thesis document (Hofman, 1994). In this elaborated work, she has been using a large meta-analytical approach. Looking into the literature between 1961 and 1991, she has found 112 articles (45 reviews and 67 experimental reports) and her final analysis was made on 53 of the reported studies. Two thirds of these studies were made in the laboratory and one third in the field. Traffic noise was the most frequent noise source (64 %) while aircraft noise was the second (23 %). In 82 % of the experiments adults were studied while, in the remaining, children and old subjects were used. The most commonly exploited variables were: awakenings, sleep stage changes, sleep architecture, sleep latency and subjective sleep quality. Figure 1 presents the relationships between the L_{Amax} values used and the probability of awakenings. From this figure it can be seen that the variance explained by the regression line of the traffic noise data was high (R^2 = .753), while the regression line concerning the aircraft noise data explained only a reduced part of the total variance (R^2 = 0.074). The data points corresponding to the traffic noise exposure in elderly subjects were quite close from those of the young subjects traffic noises data points.
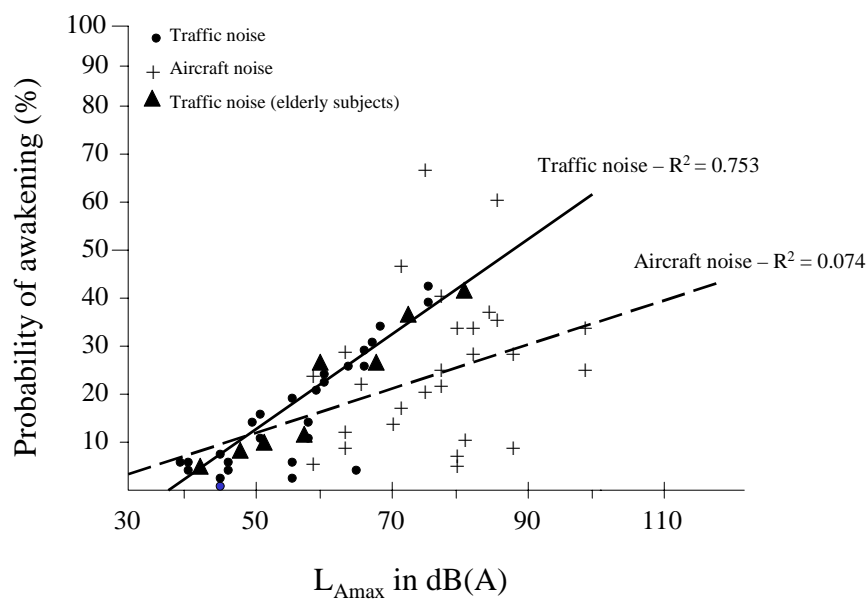
Figure 1: Relationship between L_{Amax} values of road traffic and aircraft noises and the probability of awakening (from Hofman, 1994).

The comparison between the four reviews presented in table II gives an idea of the dispersion between the different studies and also between laboratory and field approaches (figures 2 and 3).

Figure 2: Relationships between sound exposure level (in dB(A)) and probability of arousal or awakening (taken from different reviews of the literature).

Figure 2 shows very large differences between the regression lines which have been proposed in summarizing the results taken from different studies. Although quite parallel, some of the linear regression lines start from very different noise levels. This suggest, as said before, that it is difficult to extract a type of noise from its context and use a single physical value as predictive of its effects. This figure also shows a wide difference between experimental data coming in majority from laboratory studies (lines 1 and 2) and the values issued from pure field studies (line 4).
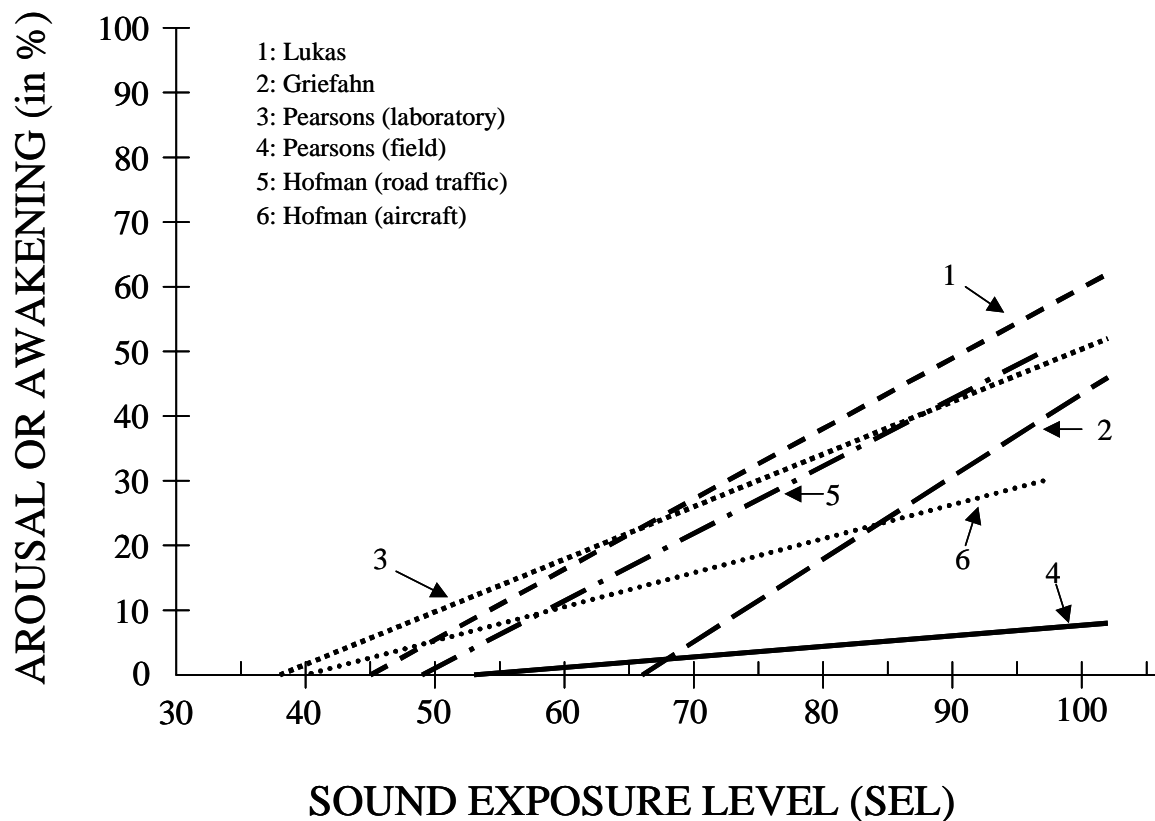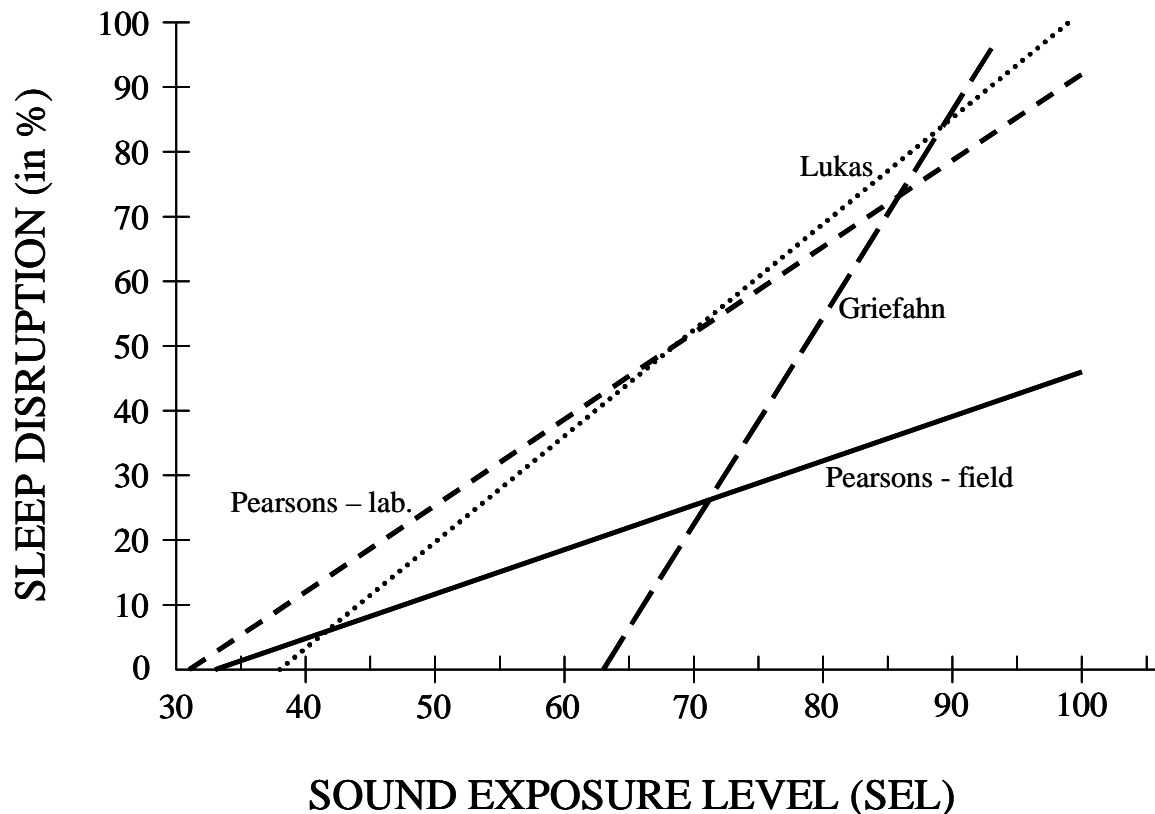
Figure 3: Relationships between sound exposure level (in dB(A)) and probability of sleep disruption (taken from different reviews of the literature).

Figure 3 shows the large variability which exists between the reported data and here again, it appears a clear difference between the results obtained in the laboratory studies and those from the field experiments. Therefore, it can be concluded, at this level, that there are large discrepancies between the experiments and the experimental approaches used. Trying to find answers to these questions appears to be fundamental as these differences should normally have some rational explanations.

5.2. Different dose-effect curves

Why are the reasons for obtaining different dose-effects curves? Of course, it has been listed already some of the possible reasons. Various sources produce noise and each of these types of noise is specific in terms of physical characteristics such as loudness, duration, spectral composition and so on…. Each of these noises may have no or very specific signification for a given person or group of persons, and this will add another dimension to the dose-effect curves (Langford et al., 1974). The large difference between the laboratory and field studies may be in part explained by the fact that people living in noisy area are somewhat accustomed to their living environment. However, this progressive habituation is not complete as most of the exposed populations still complain about their noisy environment at night.

Discussing the determinants factors in the dose-annoyance relationships due to terrestrial transports, Lambert stressed that annoyance is only very partially explained by acoustical factors (Lambert, 2002). Thus, the particular localization of the home, the individual characteristics (including age, sex, income, attitude against noise,…) and social determinants (life style, confidence or defiance towards noise producers and public actions, communication,…) are prominent factors which contribute to the global expression of annoyance. This may explain, for instance, why for similar exposure, train noise is considered as less annoying than traffic noise and that both types are less annoying than air traffic noise (Lambert, 2002). For this author, in case of multi exposure, the dominant noise source is often incriminated by the exposed populations. However, it appears difficult to model the global annoyance by taking into account the different noise sources and the time of day when they are active.

Vallet, evaluating annoyance due to aircraft noises comes to the same conclusion about the partial explanation of annoyance by acoustical factors (Vallet, 2002). He, particularly, underline the fact that, in this area, global noise exposure, measured by integrated indices, is stable or decreasing around major airports while subjective annoyance has been growing during the last years. His opinion is that expressed annoyance not only reflects acoustical levels but also population sensitivity. If annoyance increases these days, it is because exposed-population sensitivity increases! He, also stressed in his report that the most sensitive periods of the day were evening and night.

5.3. Different dose-exposure measurements

Looking into the available literature, it appears that different methodologies have been used for the evaluation of sleep disturbance. As an example, sleep stage changes analyses were sometime made every 10 s, 20 s, 30 s or 60 s. Results coming from these studies, and especially those about number of awakenings, sleep stage changes and sleep architecture, should be totally different!

Some of the most cited field studies present limited sleep disturbance indices and measurements and the choice of indicators made are sometime disputable. This is the case for several studies using either behavioural awakening (push button) and/or body motility as indicators of nocturnal awakening (Horne et al., 1994; Fidell et al., 2000). Pushing a button when being awakened during the night is a rough evaluation of sleep disturbance. Changes in sleep architecture, including sleep stage changes and short-lasting EEG awakenings, can be totally missed by this technique. Body movements during sleep are normal physiological occurring events. Only a small amount of them are concomitant to behavioural awakenings. Therefore, measuring actimetry during sleep is a very poor way of predicting those awakenings. In a recent paper (Fidell et al., 2000), the authors gave individual average values throughout the study about motility and awakenings attributable and non attributable to aircraft noises. What these figures reflect is that there was roughly the same number of awakenings and amount of motility attributable to noise than to other reasons, but this does not indicate that noises had almost no effect on the sleeper!

During sleep, unlike during waking, there is no linear cumulative effect of the number of noises and their intensity. A single noise can be as effective in term of sleep disturbance as tens of them. The same noise repeated several times during the night might have different effects in the same sleeper depending on the time asleep, time of

the night, current sleep stage. In same instances, noise can have strictly no effect while, later on, it will provoke a sudden awakening followed by a long insomnia episode. Therefore, integrated noise level such as LAeq or Lnight will often have no meaning while LAmax and number of events will be necessary indices in appreciating sleep disturbance. In their review paper on noise and health, Mouret and Vallet concluded that increasing number of noises at night would increase the probability to be awakened and that if this number is increasing, it is necessary to reduce the individual noise levels (Mouret and Vallet, 1999). Analysing the effects of nocturnal aircraft noises around Paris-Charles-de-Gaulle airport, they reported that in order to avoid 90 % of the awakenings there should be no more than 15 to 20 noises per night, with a maximum level of 48 dB(A) (Lmax).

6. Do we need further research? Some of the possible trails

Objective compared to subjective measures
One important objective is to better establish if there exist a clear relationship between objective and subjective sleep disturbance and the noise exposure. Scientific literature indicates a rather weak overall agreement about dose-response relationships and objective measures of sleep disturbance, in terms of awakening or in probability of inducing a sleep stage change. Such agreement is also very difficult to reach when comparing subjective annoyance and noise exposure levels. In addition, there are clear evidence of cases where no objective noise effect is accompanied by loud complaints, and cases where people do not complain about the noisy environment and still exhibit clear sleep and/or cardiovascular modifications on the long term. Therefore, one explanation could be that objective and subjective measures are weakly correlated and this is why there is no strong relationship between them. If this is true, objective and subjective effects should be considered separately, although being both related to health and well being.

Identification of noise sensitive groups
As stated before, most of what we know refers to well delimited groups and populations. It seems important to focus future research into the definition of highly noise-sensitive groups and evaluate the amplitude of noise impact on these groups. The existence of sensitive groups may be hypothesized: old people, ill people, people with chronic insomnia, shift workers and people resting during daytime, people with tendency to neurosis, light sleepers, people with high anxiety and high stress levels. These groups should preferably be observed in their normal living quarters as additional stress related to laboratory situation would be a highly interactive factor. We still need large epidemiological studies able to take into account the specific impact of nocturnal noise exposure compared to the global daily exposure. Such studies would be based on comparison between populations exposed to similar daytime noise and differing in their night time noise-exposure only.

Laboratory and field study results – why are they so different?
It has been stressed what appears to be a main difference between laboratory and field works: the frequency of nocturnal awakenings provoked by noise. As stated by Porter et al., "*In the home, awakenings are infrequent and only weakly correlated with noise. This is in marked contrast to the findings of laboratory works*" (Porter et al., 2000). Another view brings similar statement: "….*sleep of residents of neighborhoods near airports is not highly sensitive to nighttime disturbance by aircraft noise. Instead, the results indicate that*

relatively few nightitme noise intrusions disturb sleep, and that residential populations near airports seem well-adapted to nighttime noise intrusions" (Fidell et al., 2000).

But what is the weight of these statements confronted to the complaints of thousands of people living in the vicinity of major airports or busy freeways or railways and considering their sleep disturbance as unacceptable? It could not be that the most sensitive people are living there or that their complaints are feint while they often benefit from the proximity of these high employment areas? Therefore, it is certainly highly necessary to try to answer the question: "why such a discrepancy between laboratory and field results"? Methodological differences between the different approaches certainly cannot be the only possible explanation. Laboratory and field studies have often been opposed. They have their own advantages and difficulties, and they should always be regarded as complementary and not contradictory. Research allowing introduction of some specific but light laboratory techniques into the sleeper's own bedroom, should be encouraged. The key of long term effects of noise on general health would certainly depend on epidemiological approaches but also on well designed instrumental studies made in the home.

7. Conclusion

Sleep is a physiological state which needs its integrity to allow for a normal recuperative function of the living organism. Its reduction or disruption is detrimental on the long term as chronic partial sleep deprivation induces marked tiredness, increases low vigilance state and reduces daytime performance and quality of life. Sleep appears to be quite sensitive to the environmental factors, and quite specifically to ambient noise, as external stimuli are still processed by the sleeper sensory functions despite of a conscious perception of their presence. The large amount of research developed during the last 30 years has given a large variability of results and some of them appear to be quite controversial. In fact, the effects due to noise exposure depend on several factors and the absence of clear dose-effects relationships is certainly due to the complex interactions of these factors, including the noise characteristics, the individual sensitivity and the context of the explored living environment. However, the amplitude of the subjective complaints about sleep disturbance seems to have been increasing during the recent years. Therefore, it appears necessary to answer some specific questions which remain fundamental in order to understand if there exist and which could be the detrimental effects on health and quality of life on the long term, for night time noise-exposed populations. If needed, the protection of these populations has to be obtained through new rules and enforcements which should take into account the growing importance of modern transportation systems.

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NOISE EXPOSURE FROM VARIOUS SOURCES
SLEEP DISTURBANCE
DOSE-EFFECT RELATIONSHIP ON CHILDREN

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Outline

Summary

This report summarized several studies on the extra-auditory effects of ambient noises on sleeping children. In relation to ambient noise, specific changes were reported in both sleep quality and quantity. Some of the effects were shown to have a dose-response relationship.

I. Introduction

Most of the information available on the effects of noise on people come from studies on young adults. There is a large body of knowledge that is concerned with the auditory and the extra-auditory effects of noise. Noise can interfere with sleep, can be a source of annoyance, and can act as a stressing agent. Other effects of noise, such as cardiovascular or autonomic effects to name a few, are less well understood and continue to be the subject of much debate and controversy.

It is possible that some of the information obtained from adults does not apply to children, and that there could be situations which only affect children, or affect them differently, and for which no data are available (Mills 1975). The present report, therefore, focuses only on those effects of noise exposure during sleep that may be more deleterious to fetuses, infants, children and adolescents; that may have possible health, and/or educational implications; that may have a high incidence; and that are amenable to investigation. The effects of noise on sleep and awakening from sleep are discussed along with gaps in basic knowledge.

In accordance with the title of this review, various noteworthy health-related topics of noise will not be addressed. These include the role of noise exposure and hearing loss or the topic of noise and speech communication.

This document relies largely on excellent summaries of the topic available in the scientific literature. The literature search was conducted with the use of PubMed and MedLine, with the key-words sleep, noise, infant or children. Likewise, personal experience in the dose-effect relationship of noise on arousal from sleep in infants is reported.

II.   Background

II.I. Noise

Noise is undesirable sound. Sound in vibration in a medium, usually air. Sound has intensity (loudness), frequency (pitch), periodicity, and duration.

- The loudness of sound in measured in decibels (dB), a logarithmic scale (Committee 1997). Since the human ear is more sensitive to the damaging effects of high frequency sound than to low frequency, a better correlate with noise-induced hearing loss can be obtained when low frequencies are filtered out. Filtered sound level, measured on a so-called A-weighted scale, is designated dB(A). Room conversation produces 60 to 70 dB(A), levels of 60 to 65 dB(A) often require the speaker to increase the voice level and vocal effort. Levels of 75 dB(A) often require the talker to shout (Mills 1975). Noise level outside of apartments near a busy freeway range from 52 to 84 dB(A), and inside the apartments from 52 to 70 dB(A). Rock music produces 100 to 120 dB(A).

The sound pressure level from a source of noise is inversely proportional to the square of the distance from the source. Environmental noise is expressed as a day-night average sound level (DNL). For the protection of the public health, the US Environmental Protection Agency has proposed a DNL of 55 dB during waking hours and 45 dB during sleeping hours in neighborhoods, and 45 dB in daytime and 35 dB at night in hospitals (American 1974).

- The frequency of sound is measured in cycles per second, designated hertz (Hz). The young human ear is sensitive to a frequency range of 20 to 20,000 Hz (American 1974). White noise, the auditory counterpart of white light, has equal energy in each frequency in the audible range.

II. II. Sleep

Sleep is cyclic in nature and comprises a number of stages. Stage I, characterized by low voltage, mixed frequency EEG (2 to 7 Hz) is a brief period following the awake state and is a prelude to the more prevalent Stage 2 (Non Rapid Eye Movement sleep, or NREM), which occupies approximatively 50% of the total sleep period. In this stage, 12 to 14 Hz sleep spindles and K complexes occur against a background Stage I pattern. Stages 3 and 4, also known as deep or delta sleep, are characterized by slow, high amplitude EEG waves, typically 2 Hz or less and in the range of 75 uV. These stages are usually observed in the early one-third of the night. The final stage, REM (rapid eye movement), occurs mainly in the last half of the night and is similar to Stage I, except that it is accompanied by dreaming, eye movements and muscle activity. This cycle of stages is typically repeated every 90 to 120 min, with decreasing Stage 4 activity as the sleep period progresses. The proportion of sleep stages changes with maturation. In newborns and young infants, an indeterminate sleep stage is scored, that includes both Active (REM) and Quiet (NREM) sleep characteristics.

II. III. Sleep-wake recording

II.III.A. Recording techniques

Some studies were conducted in the natural home environment of the children. Most studies on infants exposed to auditory stimuli have been, however, conducted in pediatric sleep laboratories to evaluate the infants' arousal thresholds to environmental noises. Monitoring were usually carried out in a quiet, dimly lit room at an ambient temperature ranging from 21° to 24°C (69.8°F to 75.2°F). All patients slept supine, without restraints. They were observed continuously during recordings. Their behavior and nursing interventions were charted. Feeding was administrated based on demand. The following variables were usually recorded simultaneously: scalp electroencephalograms with central, temporal and occipital leads, electro-oculograms, digastric electromyogram, and electrocardiogram. Respiratory movements were measured with the use of thoracic and abdominal strain gauges, and airflow by oral and nasal thermistors. Body movements were recorded by actigrams or piezoelectric sensors. Oxygen saturation was recorded continuously by a transcutaneous sensor. The data were collected on standard or computerized polygraph recorders.

II.III.B. Sleep scoring

In most standard laboratories, every 30-second period of the recordings was scored as NREM, REM, indeterminate sleep or wakefulness, according to criteria in the literature. Sleep efficiency was defined as the time spent sleeping divided by the total recording time,

multiplied by 100. Scoring was usually done visually by at least two independent scorers to ensure reliability. Scoring discrepancies among scorers were discussed and codes thus agreed upon were used in the data analysis.

In order to study 'arousals', appropriate definitions must be used for infants. The scoring method of arousals in adults edited by the American Sleep Disorder's Association can be applied to children, but not to infants. Since 1998, an international work force, the European Pediatric Wake-Up Club, has elaborated a method for the scoring of arousal in infants aged between 1 and 6 months. An awakening is scored when the infant cried and/or opened the eyes. These definitions were used in most studies.

II.IV. Auditory arousal and awakening thresholds

Awakening threshold reflects the tonic state of an unknown mechanism, or mechanisms, which permit sleep to continue in the face of stimuli which normally elicit responses during wakefulness, but also permit awakening to the most "urgent" stimuli. Furthermore, either this or a closely related mechanism also "evaluates" the signal in terms of past experience and "decides" whether an awakening is required. Such an adaptive mechanism represents the product of "careful" natural selection and deserves attention as a fundamental biological phenomenon. The clinical importance of malfunction of this mechanisms, as in the easily disturbed sleep of insomniacs, is apparent (Rechtschaffen et al. 1966).

II. IV. A. Auditory stimulation techniques

In several studies, white noises of increasing intensity were presented for 3 seconds via a loudspeaker to study auditory arousal thresholds, at some distance of either ear. White noise was chosen by the researchers to avoid any artefactual response of the sleeper exposed to familiar noises (Oswald 1960). It is not known, however, whether an infant distinguishes familiar noises from new auditory stimuli. The sound level was increased by 10 dB, ranging from 50 dB (A) to 100 dB (A). The time between each presentation was 1 minute. An auditory challenge was interrupted when the infant awakened, as defined by opening of the eyes and/or crying, or when a stimulation level of 100 dB (A) was reached. In most study, care was taken to avoid habituation by repeating the signal too frequently.

II.IV. B. Scoring of arousal and awakening

An arousal response was scored if within 10 seconds of the start of an auditory stimulation, polygraphic changes were seen indicating that the child had aroused, as defined above. Arousal thresholds were defined by the lowest auditory stimuli, expressed as dB(A), needed to induce an arousal. An auditory challenge was interrupted when the infant awakened, as defined by opening of the eyes and/or crying, or when a stimulation level of 100 dB (A) was reached.
An arousal response was scored if within seconds of the start of an auditory stimulation, polygraphic changes were seen indicating that the child had aroused, as defined above. Arousal thresholds were defined by the lowest auditory stimuli, expressed as dB(A), needed to induce an arousal.

II. IV. C. Factors that modify auditory arousal thresholds

By the time that most studies were conducted in infants, it became progressively evident that arousal and awakening thresholds are influenced by a variety of factors. These significantly modify the response to ambient noise by sleeping infants. Some factors inhibit the arousal response, while others enhance the response.

II. IV. C. 1 Prenatal and perinatal factors

- Age of gestation.
In 97 healthy infants, auditory awakening thresholds decreased significantly from the 44th to the 60th postconceptional week (Kahn et al. 1986). Awakening thresholds were defined as the infant opening the eyes and/or crying. Mean awakening thresholds dropped from 98.5+/-11 at the 44th postconceptional week to 83 dB(A) by the 60th postconceptional week.

- Cigarette smoke
To evaluate the effects of cigarette smoke on polygraphic arousal thresholds, 26 newborns were studied with polygraphic recordings for one night: 13 were born to mothers who did not smoke, and 13 were born to mothers who smoked (over 9 cigarettes per day) (Franco et al. 1999). Another group of infants with a median postnatal age of 12 weeks were also studied: 21 born to non-smoking mothers and 21 born to smoking mothers. The auditory arousal thresholds of the infants of both age groups were measured with the use of auditory challenges of increasing intensity, administered during REM sleep. More intense auditory stimuli were needed to induce arousals in newborns (p=.002) and infants (p=.044) of smokers than in infants of nonsmokers (mean value of 84+/-11 dB(A) for smokers and 81.6+/-20 for nonsmokers). Behavioral awakening (infants opening the eyes and/or crying) occurred significantly less frequently in the newborns of smokers (p=.002) than of nonsmokers.

It was concluded that newborn and infants born to smoking mothers had higher arousal thresholds to auditory challenges than those born to non-smoking mothers. From the present findings, it appeared that the impact of exposure to cigarette smoke occurred mainly before birth.

IV. II. C. 2.   Postnatal factors

The following postnatal factors modify arousal from sleep:

- Age
Several studies showed a progressive decrease in arousal threshold with age (Figure I).

- Sleep stage

In infants, auditory stimuli have generally indicated increased responses during active as compared with quiet sleep (Busby et al. 1994).

- Time of the night
In 31 infants, the arousal thresholds decreased across the night (mean value of 67+/-12.5 dB(A) in the 1st part of the night, for 51+/-3.5 in the 3rd part of the night; p=.017) (Franco et al. 2001). Similar findings had been reported in adult subjects (Rechtschaffen et al. 1966).

- Body position during sleep

To investigate whether prone or supine sleeping was associated with a different response threshold to environmental stimuli, 25 three-month-old healthy infants with a median age of 9 months were exposed to an auditory challenge while sleeping successively prone or supine (Franco et al. 1998). Three infants were excluded from the study because they awoke while their position was being changed. For the 22 infants included in the analysis, more intense auditory stimuli were needed to arouse the infants in the prone position (median of 70 db(A), range values 50 to more than 100 db(A)) than in the supine position (median of 60 db(A), range values 50 to 90 db(A)) (p=.011). Arousal thresholds were higher in the prone than in the supine position in 15 infants; unchanged in 4 infants; and lower in the prone position in 3 infants (p=.007). It was concluded that infants show higher arousal thresholds to auditory challenges when sleeping in the prone position than when sleeping in the supine position. The findings could not readily be explained. The difference in arousal thresholds could be related to difference in chest wall mechanoreceptor responses, or differences in blood pressure and/or central baroreceptors responses.

- Ambient room temperature

Two groups of healthy infants with a median age of 11 weeks were recorded polygraphically during one night: 31 infants were studied at 24°C and 31 infants at 28°C. To determine their arousal thresholds, the infants were exposed to white noises of increasing intensities during REM and NREM sleep (Franco et al. 2001). The arousal thresholds decreased across the night in the infants sleeping at 24°C (p= .017). The finding was not found for the infants sleeping at 28°C. When analysing the arousal responses according to time of the night, it was found that the auditory thresholds were significantly higher at 28°C (75+/-19 dB(A)) than at 24°C (51+/-3.5 dB(A)) between 03:00 hr and 06:00 hr (p=.003). These findings were only seen in REM sleep.

- Sleeping with the head covered by bedclothes
To evaluate the influence of covering the face of sleeping infants with a bed sheet, 18 healthy infants with a median of 10.5 weeks (range 8 to 15 weeks) were recorded polygraphically for one night (Franco et al. 2002). They slept in their usual supine position. During sleep, a bed sheet was gently placed on their face during 60 minutes. With the face free or covered by the sheet, the infants were exposed to white noises of increasing intensities during REM and NERM sleep. Compared to face free, during the face-covered periods, the infants had increases in pericephalic ambient temperature (p<.001), increases in REM sleep (p=.035) and body movements (p=.011) and a decrease in NREM sleep (p<.001). Respiratory frequency was increased in both REM (p=.001) and NREM (p<.001) sleep. With their face covered, the infants had higher auditory arousal thresholds (mean of 76+/-23 dB(A)) than whith the face free (mean of 58+/-14 dB(A)) (p=.006). The difference was seen in REM sleep only. A positive correlation was found between pericephalic temperature and arousal thresholds in REM sleep (r=.487; p=.003).

- Short sleep deprivation

Following short sleep deprivation, a study reported that in infants there was no measurable change in arousal propensity by auditory stimuli (1 kHz pure tone, delivered in the midline of the cot, from 50 dB and increased in 3 dB steps to 100 dB) during quiet sleep (Thomas et al. 1996). Another study was undertaken to evaluate the influence of a brief period of sleep deprivation on sleep and arousal characteristics of healthy infants (Franco et al. submitted).

Thirteen healthy infants with a median age of 8 weeks (range 7 to 18 weeks) were recorded polygraphically during a morning nap and an afternoon nap in a sleep laboratory. They were two hours sleep-deprived, either in the morning or in the afternoon before being allowed to fall asleep. Six infants were sleep-deprived before the morning nap and seven before the afternoon nap. During each nap, the infants were exposed to white noises of increasing intensities in REM sleep to determine their arousal thresholds. Following sleep deprivation, the infants tended to have less gross body movements during sleep ($p = .054$). They had a significant increase in obstructive sleep apneas ($p = .012$). The infants'auditory arousal thresholds were significantly higher following sleep-deprivation (mean of 76+/-13.5 dB(A)) than during normal sleep (mean of 56+/-8.4 dB(A)) ($p = .003$) during REM sleep. It was concluded that short-term sleep deprivation in infants is associated with the development of obstructive sleep apneas and a significant increase in arousal thresholds.

- Pacifiers and breastfeeding
Fifty-six healthy infants were studied polygraphically during one night: 36 infants used a pacifier regularly during sleep; 20 never used a pacifier (Franco et al. 2000). Thumb users or occasional pacifier users were not included in the study. The infants were recorded at a median age of 10 weeks (range 6-19 weeks). To evaluate their auditory arousal thresholds, the infants were exposed to white noise of increasing intensity during REM sleep. Polygraphic arousals occurred at significantly lower auditory stimuli in pacifier-users than in nonusers (mean of 60+-11.6 with pacifiers, for 71+-15.3 without pacifier; $p=.010$). Compared to nonusers, pacifier-users were more frequently bottle-fed than breastfed ($p=.036$).

Among infants sleeping without a pacifier, breast-fed infants had lower auditory thresholds than bottle-fed infants (mean of 67.7+-13.0 breast-fed, for 77.7+-17.5 bottle-fed; $p=.049$). The question of how a pacifier contributes to protect the sleeping infant might be best explained by the observed loss of the pacifier early after sleep onset. This could contribute to disrupt the infant's sleep and favor arousals.

II.IV. C. 3. Factors that modify auditory arousal thresholds: Conclusions

Various factors modify auditory arousal responses from sleep in healthy infants. Some inhibit arousals while others enhance the response. To evaluate the effect and dose-effect relationship on children therefore requires the careful determination of confounders that may bias studies and lead to conflicting results.

Additional confounders should be added to the list of factors that modify arousal thresholds. These include past experience with the stimulus (Rechtschaffen et al. 1966), or the presence of meaning in the noise as both of them are of critical importance in determining the persistence of physical reactions to the noise (McLean and Tarnopolsky 1977). These are the reasons which lead most sleep-wake researchers to use white noises to stimulate the sleeping child.
Knowledge of these variables does little to clarify the physiological determinants of the awakening response, because we have little better idea of how such variables are related to possible physiological determinants than we have for the awakening response itself (Rechtschaffen et al. 1966).

These findings however, underline the significant dose-response relationship between ambient noise and arousal or awakening from sleep in infants.

III. Noise and sleep in children

III. 1. The fetus

The human fetus spends most of its time in a state equivalent to sleep, similar to that recorded in newborn infants. The healthy fetus in utero was shown to react to external noises. This is the result of the development of the human cochlea and peripheral sensory end organs. These complete their normal development by 24 weeks of gestation. Sound is well transmitted into the uterine environment. Ultrasonographic observations of blink-startle responses to vibroacoustic stimulation are fist elicited at 24 to 25 weeks of gestation, and are consistently present after 28 weeks, indicating maturation of the auditory pathways of the central nervous system (Committee 1997). The fetus reacts to 1 to 4 seconds of 100 to 130 dB of 1220- to 15000-Hz sound. The hearing threshold (the intensity at which one perceives sound) at 27 to 29 weeks of gestation is approximatively 40 dB and decreases to a nearly adult level of 13.5 dB by 42 weeks of gestation, indicating continuing postnatal maturation of these pathways.

Teratogenic effects have been described in animals prenatally exposed to noise (Committee 1997). These were associated with higher levels of cortisol and corticotropin hormones in the exposed animals. No such effects could be demonstrated in humans, in whom studies on the relation between exposure to noises during gestation and shortened gestation or lower birthweights were inconclusive or conflicting. It is possible that in these studies, noise could be a marker of other risk factors (Committee 1997). In conclusions, most studies on the effects of noise on perinatal health have been criticised, as being hampered by serious methodological limitations, both in terms of the measurement of exposure and outcome, and failure to control for other known determinants of the outcomes under investigation. The lack of properly controlled studies makes it difficult to draw conclusions about which effects ambient noise have on perinatal outcomes (Morrell et al. 1997).

IV.2.   Newborn infants

A large number of investigations have been concerned with the responses of asleep newborn infants to acoustic signals. Many of the studies arise from a large and general interest in child development as well as from a need for hearing tests of infants (Mills 1975).

Infant incubators produce continuous noise levels of between 50 and 86 db (linear) (American 1974). Oxygen inlets produced an additional 2 dB (linear). Slamming of incubator doors and infant crying produced 90 to 100 dB(A) (American 1974). It was shown that inside incubators, background noise level is about 50 dBA and can reach 120 dBA (Committee 1997). Much of the energy is located below 500 Hz, between 31 and 250 Hz (Mills 1975).

Ambient noise appear to influence the quantity and quality of the sleep of newborns. Some newborns appear to be particularly responsive to ambient noises. Sleeping premature, anoxic, or brain-damaged infants detect intruding sounds better than sleeping, healthy, or term babies (Mills 1975).

Newborn infants spend most of their time sleeping. Some studies have documented hearing loss in children cared for in intensive care units (Aaron 1996, Gädeke 1969, Committee 1997). Noise and some ototoxic drugs act synergistically to produce pathological changes of the inner ears of experimental animals (neomycin, kanamycin, sodium salicylate…). The relationship with the infant's clinical condition and associated treatments has however not yet been clearly defined. Infants exposed to sound levels of incubators are usually premature, on drugs, and in very poor health. Moreover, the exposures are continuous. A weak infant could spend weeks sleeping in such noise level without rest periods away from noise (Mills 1975).

High noise levels may be associated with other types of responses. In young infants, sudden loud noise (of approximately 80 dB) environmental noise induced hypoxemia.

Noise reduction was associated in neonates with increases in sleep time, in particular in quiet sleep (Committee 1997). It also resulted in fewer days of respiratory support and oxygen administration. Premature infants cared with noise reduction had a better maturation of electroencephalograms.
A Committee on Environmental Health of the American Academy of Pediatrics concluded that high ambient noises in the NICU changed the behavioural and physiological responses of infants (Committee 1997). For all the above observations and considerations, sound in infant intensive care units should be maintained under 80 dB(A) (Graven 2000). Among other recommendations, pediatricians were encouraged to monitor sound in the NICU, and within incubators, where a noise level >45 dB is of concern.

III. 3. Infants (1 month to 1 year-old).

Some studies of the effect of external noises on the sleep-wake reactions of infants were conducted in their natural home environment. The reactions of babies to aircraft noise were studied by means of electroplethysmography (PLG) and EEG (Ando and Hattori 1977). The recordings were done in the morning, in the infants' sleeping rooms. The infants were exposed to recorded noise of Boeing 727 at take off. The noise was presented at 70, 80 and 90 dB(A) in the peak level at the position of the babies'heads. The subjects, who had not been awakened by exposure to aircraft noise, were exposed to music (Beethoven's 9th Symphony) in levels of 70, 80 and 90 dB(A). The frequency ranged between 100 Hz and 10 kHz. It was found that the babies whose mothers had moved to the area around the Osaka International Airport before conception (Group I; n=33) or during the first five months of pregnancy (Group II; n=17) showed little or no reaction to aircraft noise. In contrast, babies whose mothers had moved closer to the airport during the second half of the pregnancy or after birth (Group III; n=10 or IV; n=3) and the babies whose mothers lived in a quiet living area (Group V; n=8) reacted to the same auditory stimuli. The babies in groups I and II showed differential responses on whether the auditory stimuli were aircraft noise or music. Abnormal PLG and EEG were observed in the majority of babies living in an area where noise levels were over 95 dB(A). It was concluded that the difference in reactivity to aircraft noise may be ascribed to a prenatal difference in time of exposure to aircraft noise. The reactions diminished after the sixth months of life in group I and II, and the ninth month in groups III-V. This phenomenon may be explained as habituation to aircraft noise after birth. However, in all groups, no habituation occurred for a noise level over 95 dB(A) (Ando and Hattori 1977). This study was critized, as the authors did not adjust for several important determinants of birthweight, such as prematurity and the mother's age, weight, smoking status or socioeconomic status (Morrell et al. 1997).

Noise levels may be constantly high in pediatric units. The mean noise levels measured in a center of a surgical recovery room were 57.2 dB(A), while those measured at the patients'heads were 65.6 dB(A) (American 1974). In a medical unit (6-bed wards containing 5 infants between 3 and 17 months) peak sound levels were recorded on the pillow of the cot for 12 min (Keipert 1985). Infant crying produced 75 to 90 dB(A) and a beeper around 76 to 78 bB(A). Peak noise levels recorded at the nurses'station were about 78 dB(A) for telephone, 80 for infant crying, public address system, adult talking, and up to 90 dB(A) for child talking (Keipert 1985).

In a study was conducted on infants exposed to 50 to 80 dB(linear) in the range of 100 to 7,000 Hz (American 1974), a level of 70 to 75 dB (linear) for three minutes led to obvious disturbance or awakening in two thirds of the children. All infants awakened after 75 dB(linear) for 12 minutes.

In other studies conducted on the effects of awakenings and arousals, it was shown that white noise intensity was significantly lower to elicit polygraphically scored arousals than to induce awakenings (Franco et al. 1998).

III. 4. Toddlers – Preadolescents (8 to 12 years old) – Adolescents (13 to 18 years old)

Developmental variations in auditory arousal thresholds during sleep were investigated in four groups of normal male subjects : children (n=6; 5-7 years old), preadolescents (n=10; 8-12 years old), adolescents (n=10;13-16 year old), and young adults (n=10; 20-24 years old) (Busby et al. 1994). Arousal thresholds were determined during NREM and REM sleep for tones (3-s, 1,500-Hz pure tones delivered in an ascending series of increasing intensity, 5-dB increments beginning at 30 dB SPL ("Sound pressure level") re 0.0002 dynes/cm2 until awakening or maximum intensity of 120 dB) presented via earphone insert on a single night following two adaptations nights of undisturbed sleep. Age-related relationships were observed for both awakening frequency and stimulus intensity required to effect awakening, with awakenings occurring more frequently in response to lower stimulus intensities with increasing age. In children, 43.1% of stimuli induced awakenings, in preadolescents 54.8%, adolescents 72% and adults 100% (X2=60.37; p<.001). Partial arousals (brief EEG desynchronization and/or EMG activity with the subjects returning to sleep) occurred in 9.8% of children, 4.8% of preadolescents, 12.2% adolescents, 0% adults. Although stimulus intensities required for awakening were high and statistically equivalent across sleep stages in non-adults, higher intensity stimulus were required in Stage 4 relative to Stage 2 and REM sleep. Frequency of awakening increased with age, whereas stimulus intensities required to effect these awakenings decreased with age. These relationships were maintained for individual sleep stages. These results confirm previous observations of marked resistance to awakening during sleep in preadolescent children and suggest that processes underlying awakening from sleep undergo systematic modification during ontogenic development. The observed resistance to elicited awakening from sleep extending up to young adulthood implies the presence of an active, developmentally related process that maintains sleep (Busby et al. 1994).

In another study, 5- to 7-year-old children were shown to be 10-15 dB less sensitive to pure tones than 22- to 30-year-old adults (Mills 1975). Another report on 8-12 year-old male hyperactive and normal children showed that these children were awakened with auditory stimulus intensity levels of up to 123 dB SPL ("Sound pressure level"), much higher than values reported for adults (range of 50-85 dB) (Busby et al. 1994).

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In a study on 4 children (2 males), aged 5 to 8 years old on the effects of simulated sonic booms (68 dB(A) near the subjects' ears), 94.1% of the subjects showed no change, 5.9% had shallower sleep, but none aroused or had or behavioural awakening. In general, the frequency of arousal or behavioural awakenings and of sleep stage changes increased with age (up to 75 y) (Lukas 1975).

In a prospective longitudinal investigation, which employed non-exposed control groups, effects of aircraft noise prior to and subsequent to inauguration of a new airport as well as effects of chronic noise and its reduction at an old airport (6 to 18 month post relocation), were studied in 326 children aged 9 to 13 years (Bullinger et al. 1999). The psychological health of children was investigated with a standardized quality of life scale as well as with a motivational measure. In addition, a self-report noise annoyance scale was used. In the children studied at the two airports over three time points, results showed a significant decrease of total quality of life 18 month after aircraft noise exposure as well as a motivational deficits operationalized by fewer attempts to solve insoluble puzzles in the new airport area. Parallel shifts in children's attributions for failure were also noted. At the old airport parallel impairments were present before the airport relocation but subsided there after (Bullinger et al. 1999).

In a study, the effects of ambient noise on autonomic responses could be demonstrated in children. In 6 to 12 year-old children exposed to intermittent traffic noise during four nights (at a rate of 90 noises per hour; peak intensity of the noise, 45, 55 and 65 dB(A) varied semi-randomly) and two quiet nights: heart rate was affected and relatively higher in noise during REM and Stage 2 than during delta sleep (Muzet et al. 1980, in Abel 1990).

IV.3. Sleep deprivation in children

The effects of sleep deprivation were evaluated in children. The findings only indirectly pertain to this general report, although repeated noise-induced sleep disruption favors sleep deprivation.

In another study, 15 healthy infants aged 78+/-7 days were studied during two nights; one night was preceded by sleep deprivation (kept awake for as long as possible beyond their habitual bedtime: median onset 150 min; range 0-210 min) (Thomas et al. 1996). Thirteen slept supine, 12 were breastfed, 4 were from smoking parents. Following sleep deprivation, infants maintained a greater proportion of quiet sleep (44 vs 39%; p=.002). There was no measurable change in arousal propensity by either graded photic (stroboscope) or auditory stimuli (1 kHz pure tone, delivered in the midline of the cot, from 73 dB and increased in 3 dB steps to 100 dB) during quiet sleep.

In 49 Finish children (26 boys) aged 7 to 12 years interviewed, together with their parents and school teachers, and recorded for 72 h with a belt-worn activity monitor during weekdays.
The objectively measured true sleep time was associated with teacher-reported psychiatric symptoms. The decreased amount of sleep was associated more with externalising than internalizing types of symptoms (aggressive and delinquent behavior, attention, social, and somatic problems) (Aronen et al. 2000).

In a survey, we could show that out 1000 Belgian school children, 9 to 12 year old, those with poor sleep (insomnia) were also showing more frequent poor school performance (failure to comply with expected grades) than good sleepers. The sleep problems were present for more than 6 months, and the learning problems can be considered to result from a long-term effect of sleeping poorly. The relation between poor sleep and noisy environment was however not evaluated (Kahn et al. 1989).

V . Conclusions

This report summarized several studies on the extra-auditory effects of ambient noises on sleeping children. In relation to ambient noise, specific changes were reported in both sleep quality and quantity. Some of the effects were shown to have a dose-response relationship (Figure II).

Several limitations to the present report should be discussed. Firstly, we do not know whether the inferance that is often made that the effects of noise might develop with a longer exposure time (Abel 1990) is correct. Serious cardiorespiratory or autonomic changes, such as increases in blood-pressure could only develop following long-time exposure starting from childhood. This, in fact, has never been documented, nor has the extent of intersubject variability, due to difference in susceptibility. Secondly, we have no information to evaluate whether adaptation to ambient noise could limit the effects observed during short-term experiments. Thirdly, as the existing research data are applicable to generally healthy children, we do not know how the reported findings could be applied to ill children, children receiving medical treatments or very young premature infants. Finally, as most studies were conducted in laboratory controlled environments, we do not know the correlation between these studies and the effects of noise in the home. The multifactorial effects of environment on sleep and arousal controls could be much more complex than expected. On might predict that, as for adults, the effects of noise on the child's sleep and health are very complicated and depend upon the spectrum and level of the noise, temporal aspects of the noise, psychological responses to the noise, and the nature of the evaluation technique. The complexity of the conditions related to sleep-wake controls was illustrated by the review of confounding factors affecting auditory arousal thresholds.

Despite these limitations, it can be concluded that, based on the evidence available, the extra-auditory effects of noise could be pervasive, affecting the children's physical and psychological well-being. Changes in sleep quantity and quality together with autonomic reactions are seen when a child is exposed to ambient noise during sleep. Ambient noise exerts a dose-effect relationship on changes of sleep-wake behaviors. These reflect modifications induced within the brain of the sleeping child. It remains, however, to be determine what pervasive effects long-term exposure to ambient noise have on the child's development, health and well-being. Evidence should also be defined to support an enforcement of strategies for noise reduction at the source as suggested by some studies. Noise-induced health effects on children, a clinical and public health concern, should be evaluated by further studies.

VI. Future research topics

It appears that important aspects of the responses of sleeping children to environmental noises need further evaluation. Some of the potentials for further researches are summarized as follows:

- There is interest in the collection of experimental data in noise-controlled environments to define a dose-response curve to increasing noise intensities. The curves should be defined according to age groups (newborns, infants, children…).
- The evaluation of the long-term effects of poor sleep in children exposed to noisy sleep environments should be conducted.
- The potential for the development of adult insomnia in previously poor sleeping children should be evaluated.
- The age at which children distinguish noise sources and subsequently demonstrate different effects should be determined.
- The consequence of an exposition to continuous noises should be studied in children.

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Figure I   Age-related arousal thresholds in children.
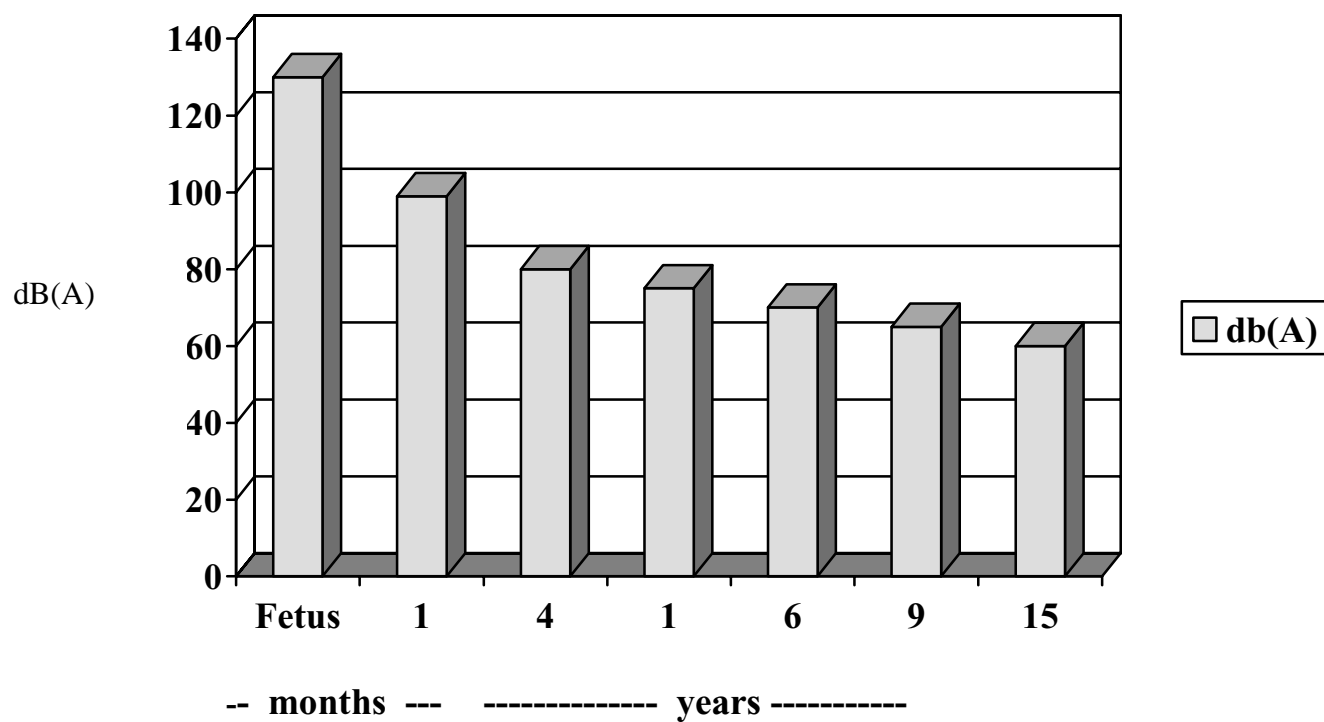
Figure I.

Sources: Committee on Environment Health of the American Academy of Pediatrics 1997;

Busby 1994; Franco et al. 1998, 1999, 2000; Hattori et al. 1977; Kahn et al. 1986.

Figure II

AROUSAL AND AWAKENING IN CHILDREN

Review of the literature

N°	dB(A)	% responses	Type of responses	Reference
1	80	70	Nenonates motor response	Steinschneider 1967
2	60	5	Neonates startle response	Gädele 1969
	70	10		
	80	20		
	100	60		
3	60	7	Neonates startle response	Ashton 1967
	65	10		
	70	40		
4	80	70	Child awake	Semczuk 1967
5	100	70	Child awake	Busby 1994
6	100	76	Preadolescent awake	
7	100	86	Adolescent awake	
8	60	100	Adult	
9	120	72	Infant awake	Kahn 1986
10	75	75	Infant awake	Gädeke 1969

Arousal/Awakening in children
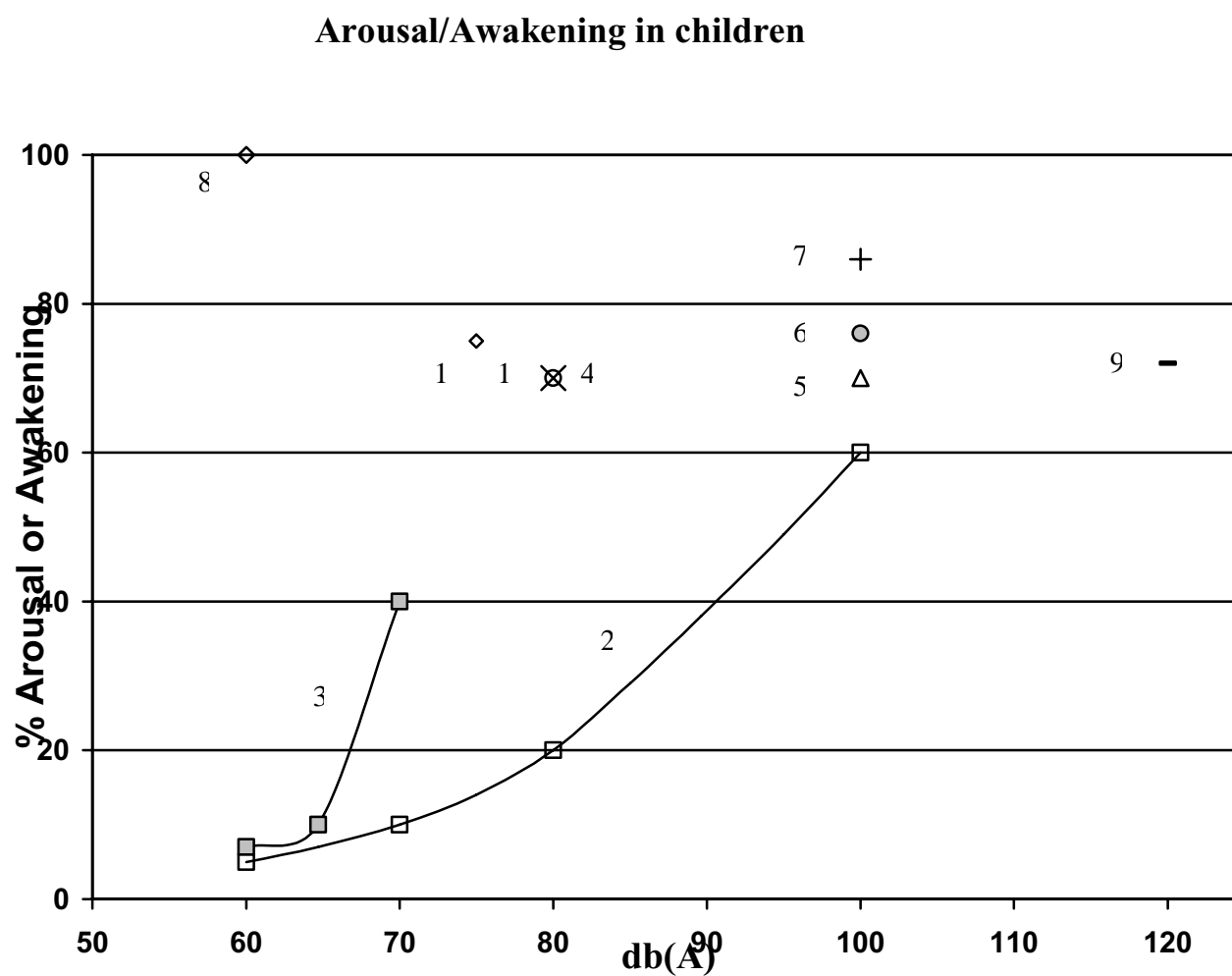
Figure II

Estimation of hearing damage from noise exposure

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Executive Summary

1. Exposure to loud noise leads to a worsening of hearing sensitivity, ringing noises in the ears or both either temporarily or permanently.
2. Hearing thresholds better than or equal to 20dBHL across audiometric frequencies 0.25-8kHz are considered normal
3. Hearing impairment on the basis of hearing threshold changes is an average hearing threshold of 25dB or more across 0.5,1 ,2 and 4kHz.
4. 75dBA Leq 8h limit is defined as giving 0dB threshold shift at 4kHz-the most sensitive noise effect frequency. 85dBA exposure on average would yield a threshold shift of 5dB at 4kHz, the minimum detectable change, which was therefore accepted as the first action level for safety.
5. Studies support model as showing 83dBA giving a 5dB shift at 4kHz after 10 years of exposure, 87dBA giving 11dB shift and 90dB producing a shift of 15dB.
6. Individual susceptibility for noise effects means that the range of impairment is wide.
7. The effect on hearing threshold is based on total acoustic energy integrated over total exposure time as the principle factor responsible for effect on hearing. Non-Gaussian noise may be more harmful. Time course and spectral content are largely unaccounted. Equal energy giving equal effect is not borne out by studies.
8. Hearing impairment is also considered possible without any significant change in audiometric threshold change.
9. Audiometric threshold shift at 4kHz may not be the most sensitive indicator as otoacoustic emissions show a more direct and early effect of noise exposure. Auditory efferent control involved in the non-linear characteristics of cochlear function may be first affected by noise exposure.
10. Identification of vulnerable individuals must be a priority.

Hz H

1. Introduction

Noise is the most common preventable cause of acquired hearing loss. Noise from many sources pollutes our environment at work, home and even during leisure pursuits. It is becoming an inevitable part of daily life for a large number of people, sometimes avoidable, sometimes not and sometimes self-inflicted or self-invited. Due to the high variability in individual susceptibility it is almost impossible to predict the extent of hearing damage for a particular individual on the basis of their exposure conditions. The prevalence of hearing impairment in the general population is around 15% but in those exposed to occupational noise it reaches over 50% (Goldie 1992).

Impact of noise on hearing sensitivity

Exposure to loud noise shifts thresholds of hearing either temporarily which recovers after a few hours or days or permanently where no recovery is seen 30 days after exposure ceases. The temporary threshold shift (TTS) results from metabolic, excitotoxic and functional overloads due to over-stimulation whereas permanent threshold shift (PTS) occurs after unrecoverable damage to outer hair cells in the cochlea.
It is generally accepted that over 95% of subjects do not show any TTS with noise exposure at levels between 65-70dBSPL but thereafter TTS rises linearly up to 120dBSPL. Steady prolonged exposures increase TTS logarithmically as function of time until it asymptotes (Miller 1974). Impulsive components in the noise lead to delayed TTS and longer time before total recovery. A comparison of the TTS from energy equivalent exposures but repeated with rest periods produce a lower TTS than that from continuous exposure. Repeated daily occupational noise exposures or a single high level exposure may result in a PTS. The magnitude of PTS varies greatly across subjects but is generally dependent on noise level integrated over the 8hour day and the number of days and years of occupation in the noise. The rate of progression of hearing loss in the characteristic noise notch of 3-6kHz is higher in the first ten years of exposure and in younger subjects, 40-50 years. Thereafter, the rate of progression of hearing loss is slower and may be largely dependent on ageing processes. Younger subjects working in noise show lower susceptibility than those who start work in noisy conditions later in life (Wageman 1967). Presence of impulsive noise in a continuous noise background results in a greater loss of hearing. With impulses above a critical level of 125dBSPL mechanical damage may become more significant than metabolic, PTS is related to increasing peak level rather than to total energy of exposure (Henderson et al 1986).

Damage risk criteria

Damage risk criteria specify the risk of hearing loss from various levels of noise.
In order to establish the risk, an acceptable level of hearing loss in a noise exposed population has to be defined relative to an unexposed but otherwise equal group.
The definition of a so-called normal group also poses problems as to whether this group should be an unscreened group with respect to occupational, social or disease related effects. However, screening to eliminate risk factors may lead to very good normative values leading to an overestimation of acquired hearing loss in an individual. Conversely an unscreened control population may underestimate the magnitude of acquired hearing loss.
Clinically it is accepted that an average hearing threshold less than or equal to 20dB across all frequencies (0.5-8kHz) may be considered "normal ". However, the acceptable low fence for hearing loss is variable in terms of the accepted frequencies in consideration of a noise induced loss ranging from an average hearing threshold across 500, 1000, and 2000Hz of 25dB or for OSHA and the Mine Safety and Health Administration (MSHA) an average of

25dB at 1000, 2000, and 3000 Hz whilst NIOSH criterion uses 1000, 2000, 3000 and 4000 Hz. The WHO meeting on deafness agreed that impaired hearing would equate to an average threshold of 26dBHL or greater over 0.5,1,2 and 4kHz. It is also clear that

hearing impairment does not accurately predict hearing disability. It is possible for auditory disability to occur with "normal" hearing threshold. Highson et al (1996) found 0.5% of University students complained of auditory difficulties although their hearing thresholds were better than 20dBHL.

Models have been derived to estimate the extent of hearing loss from occupational noise exposure for populations but not for individuals although they may be applied to individuals in terms of statistical probabilities. This means that an individual's hearing levels may be compared to a population to estimate, on the basis of a similar exposure history, whether the individual's hearing threshold levels are within the range of loss to be expected for selected population percentiles.

If the individual shows greater loss than that shown for the most susceptible allowed percentile (0.05) then either the individual is one of the five from a hundred who is very susceptible or other causes may be involved.

Models may also be used to predict the rate of change of hearing at different audiometric frequencies and compared with the individual's own actual change of hearing over time.

Main contributing factors in a model are the effects of age and noise exposure to provide an overall hearing loss with a correction factor, which controls for the maximum permissible loss to be a constant by varying the rate of progression of each component

(ie age or noise) and allowing only one to dominate at a time. As the models rely on occupational exposure to continuous noise over an 8-hour working day over a 5 day week for a 40 year working life-time, this report will consider their suitability in assessing hearing impairment due to social noise and consider the primary assumption of the model that total acoustic energy is responsible for the effect on hearing and that intensity of noise may be traded for time without altering the effect on hearing.

Current international population-based standards define normal hearing in terms of "audiometric zero" (ISO 389, 1994) and normative hearing thresholds as a function of age and gender (ISO 7029, 1984) as well as criteria for estimation of hearing loss due to noise exposure (ISO 1999, 1990) with normative thresholds for otologically screened population (ISO A) and unscreened (ISO B) populations. There is a 2dB difference at 6kHz between the ISO and ANSI standard calibrations.

Has "normal" hearing in the population worsened?
Does social noise lead to a notch in hearing at 6kHz?

Dips or notches at specific frequencies such as 4kHz or 6kHz with overall average across frequency range within the accepted "normal" limits need consideration.

In terms of social environment noise, 6kHz has been shown to be particularly vulnerable particularly in young people exposed to loud music. Thus 6kHz may be considered important in the low fence for defining noise induced hearing loss from social environment exposure.

It has been suggested (Borchgrevink et al 2001) that the normal thresholds for young people, known as the audiometric zero may be too restrictive as many audiometric surveys from a number of countries show the median hearing thresholds of 18-20 year olds not to be zero dB but of the order of 5dB for most audiometric frequencies from 0.25 to 8kHz and for higher values around 13dB for 6kHz.

An alternative explanation is that there has been an overall deterioration in the hearing of young people due to social/leisure noise. If this were so, then changing the zero may conceal possible socioacusis.

High frequency hearing threshold shifts have been recorded in conscripts on entry in Sweden (Rosenhall et al 1993), Norway (Borchgrevink 1993), Canada (Pelausa et al 1995) and Italy (Merluzzi et al 1997); in adolescents in Germany (Becher et al 1996), France (Meyer-Bisch 1996), Japan (Inoue et al 1996) and the Netherlands (Passchier-Vermeer et al 1998). The Niskar et al (2001) study suggests that 6kHz is an important frequency to watch in children 6-19 years of age. Lutman and Davis (1994) reported a mean of 15.4dB at 6kHz (with a standard deviation of 7.6dB) and a mean of 4.1 dB at 1kHz, which would appear as a 11.3dB notch at 6kHz. However, ANSI standard data show the right ears to have a mean of 4.1dB with a standard error of 0.1 at 1kHz and a mean of 9.1dB (SE:0.2) at 6kHz, which would appear as a 5.3dB notch at 6kHz. Another explanation which has been suggested (Lutman 1998) for the discrepancy in hearing thresholds at 6kHz is the possible differences in the resonance characteristics of TDH 39 and TDH 49 headphones.
A number of studies have shown that social or leisure noise leads to high frequency loss with the greatest shifts around 3-6kHz. Passchier-Vermmer et al (1998) show that pop-music exposure leads to the largest shift at 6kHz.

The Nord-Trondelag Norway audiometric survey (1996-1998) of 50,773 unscreened invited subjects in the age range 20-101 years with a mean age 50.2 years (SD =17.0 years) showed that the mean hearing thresholds were not significantly different across gender at 1kHz but were poorer in males from 3kHz with maximal differences of around 20dB at 3-4kHz for subjects aged 55-74 years. For subjects aged 20-24 years the mean hearing loss was greater than 10dB at 6kHz. This was interpreted by Borchgrevink et al (2001) as either indicating that the reference thresholds at 6kHz are too restrictive or it reflects noise related socioacusis. The male median thresholds at 4kHz were few dB poorer than the ISO A up through age group 45-54 years, indicating that the database ISO A (screened)- with certain adjustments-could serve as reference for the younger unscreened population. The worst hearing 10%, the 0.10 fractile, of males showed poorer 4kHz thresholds than ISO A with larger slope for increasing age.
In a cross-sectional study of 68,632 US Navy and Marine Corps hearing conservation program between 1995-99, it was observed that men had worse levels of hearing than OSHA age-corrected values (Bohnker et al 2002).

Exposure-Effect relationships for occupational noise

Following a review by Guignard in 1973, the US Environmental Protection Agency (EPA) established a level of 75dBA continuous broadband noise exposure sustained for 8 hours a day (or 70dBA for 24 hours) as the lower limit value for detectable noise induced permanent threshold shift (NIPTS). It was considered that exceeding these limits would have the potential to cause NIPTS greater than 5dB at 4kHz- the most sensitive audiometric frequency, in up to 10% of the exposed population after a cumulative duration of 10 years.
An equivalent noise level was derived to limit damage, on the basis of the assumptions that a change in hearing threshold less than 5dB is not significant, that 4kHz is the most sensitive indicator of noise effect, that a range of susceptibility exists in the population and protection of 96% of the population would be acceptable. The appropriate level was
Leq,8h =75dBA for an 8hour exposure per day for 250 working days a year for lifetime exposure of 40 years leading to a maximum of 5dB NIPTS.

The 75dBA limit was accepted into the ISO standard 1999(1990) as the lower limit of its applicability giving a threshold shift of zero dB at 4kHz. The standard set the values for NIPTS at audiometric frequencies from 0.5 to 6kHz attributable to noise exposures over 8hour working days for periods from 0 to 40 years. The daily exposures ranged from 75 dBA

to 100dBA allowing a calculation of median NIPTS and statistical distribution. The daily noise exposure level Lex,8h of ISO 1999 is identical to the daily personal noise exposure level Lep,d. Lower limit of noise threshold values giving zero dB shift in hearing threshold vary with frequency, being 77dBA for 3 and 6kHz, 80 dBA at 2kHz and 89 at 1kHz. An exposure of 80dBA gives a NIPTS of 1dB after 10 years but requires 85dBA exposure to give a NIPTS of 5dB at 4kHz. Thus the ISO 1999 calculation procedures indicates that an Leq,8h of 80dBA will produce little effect, whereas 85dBA will produce a measurable effect at 4kHz.

Robinson et al (1994) reported negligible noise induced threshold shift at 75dBA and between 75 and 85dBA long term exposure had some effect but could only be shown statistically in groups. It was therefore inferred that exposure below 80dBA for years should not result in any detectable hearing threshold shift.

Age related hearing loss

Ageing effects on hearing include the environmental aspects as well as genetic and degenerative components. Ageing affects highest frequencies first whereas noise alone affects the region of 3-6kHz as notch in hearing sensitivity.

For an individual above the age of about 25 years, there is probably an element of age associated hearing loss but this can only be ascertained once all other possible causes of hearing impairment have been considered.

Gates et al (2001) examined a 15-year pattern of change in age-adjusted pure tone thresholds with no additional occupational or recreational noise exposure. In the group with the greatest noise notch there was deterioration at 2kHz suggesting that the noise damaged ear does not "age" at the same rate as the non-noise damaged ear. The deterioration at 2kHz indicates that the effects of noise damage may continue after the noise exposure has ceased. Mills et al (2001) compared noise and age effects on hearing showing that both are highly variable across people. They indicate that noise affects the outer haircell function and non-linear properties of the cochlea whereas ageing effects are primarily due to neural degeneration with compromised blood supply and metabolism, but essentially normal sensory cells and non-linear functions of the cochlea.

There is a considerable variation in the many studies examining the effect of age on hearing loss, most of the variation is related to subject selection and ethnic variations.

The International Standard ISO 7029 gives the values of age associated hearing loss as deviations relative to the median thresholds of young otologically normal subjects.

The standard gives the generating equations as functions of age and percentile for each sex. Robinson (1988) produced a set of results for a typical population as opposed to a very screened population for the ISO standard. The results are expressed as threshold deviations from median normal hearing at age 20. The traditional approach was to consider ageing effects and noise effects to be additive but further studies have indicated a more complex relationship between ageing and noise effects. Therefore the use of ISO 1999 standard as a simple apportioning measure for age and noise effects in individuals does not seem appropriate.

Estimation of Hearing Loss from Noise Exposure

The percentage of people likely to suffer from a 50dB hearing loss with 90dBA Leq over a ten year period of exposure is 5% and over a lifetime of exposure this rises to 11%, if however, the exposure level is raised to 100dBA the figures rise to 17% for ten years and 32% for life-time exposure. This raises the issue of susceptibility as 68 of the 100 have not been affected to the same degree of loss. The prediction of the extent of hearing loss resulting

from exposure to noise in an individual is difficult as a number of variables such as age, gender, race, initial hearing level and individual susceptibility (which may depend on a number of factors including genetic, vascular sufficiency, efficiency of sound transmission, effectiveness of acoustic reflex action, levels of protection from antioxidants, melanin, magnesium etc) as well as the characteristics of the noise in terms of level, duration and pattern play a part in the hearing threshold elevation at particular frequencies.

If the initial hearing level of the individuals are not known, the extent of hearing loss in exposed workers is estimated by comparison with those of a control group of non-exposed workers whose age, gender, history of exposure to environmental and leisure noise are similar which may not be the case. Another method is to assume that the workers would have had a typical deterioration in hearing with age if they had not been exposed to noise and subtract the age component but this assumes that the noise and age are additive which may not be the case. Another way may be to assume that the hearing thresholds measured in the exposed workers directly reflect the effect of noise and ageing, environmental and leisure noise do not exert any great influence but this is clearly not the case.

The use of models (ISO 1999 and ANSI S3.44) to estimate the extent of hearing loss on a statistical basis is possible at a basic level including age effects and the assumption that once noise exposure ceases there is no further deterioration in hearing. A number of studies (Passchier-Vermeer (1968); Robinson et al (1973) and Yerg et al (1978) show a degree of consistency in the estimated noise induced hearing loss at 4kHz produced by at least a 10 year exposure at various levels for 8hours a day for 250 days a year.

Robinson et al (1973) found that textile workers from an 83 dBA environment showed a mean loss about 5dB greater than a control group who worked in 70dBA or below and a later study by Yerg et al (1978) showed an average loss of 11dB in workers whose daily A-weighted exposure levels were about 87dB. Burns and Robinson (1970) conducted a study of 759 workers in various industries showing that increasingly higher level noise exposure produced an increasingly faster rate of hearing threshold change over the first 10-15 years and thereafter the rate of progression of hearing loss was not significantly different across different exposure levels or no exposure implying the change to be largely governed by ageing effects. Thus the rate of change of the median hearing level is dependent on the intensity of exposure and occurs in the initial 10 year period of exposure. From their figures it was considered that a 90dBA 8h exposure limit would result in an average of 15dB loss at high frequencies in a typical person. Some occupational limits were set on this basis whilst others set 85dBA considering that if the average loss was 15dB then in some cases it may be as much as 30dB and in order to protect the vulnerable individuals a lower exposure limit would be preferable.

Furthermore it has been recognised that the median hearing level shifts slightly more with age than the worst 10 percentile, which implies that ears with the best hearing are the most likely to be affected (Ward, 1976).

The loss of hearing that can be attributed to many years of daily 8hour exposure to a steady/continuous noise in a subject with initial hearing within normal limits and who is also exposed to an average amount of social noise during those years can be estimated from the earlier studies and the ISO and ANSI standards but it is also known that a single exposure to a horn or firecracker may result in a similar loss in the high frequencies.

Does equal energy mean equal risk to hearing?

The equal energy approach assumes that the important determinant responsible for hearing impairment is the total exposure energy, which is the product of intensity of noise and duration of exposure, and that one may be traded for another. For example 85dBA for 8hours

may on the basis of equal energy be equated to 88dBA for 4 hours on the basis of an exchange rate of 3dB or a doubling of intensity and hence halving of the exposure time. The equal energy principle assumes that the time pattern of noise during the exposure time is not relevant to hearing loss. Thus total energy can be integrated over time with personal dosimeters even if the levels are varying over time. This has been adopted by the ISO 1999 standard so that the equal energy principle applies to estimation of hearing loss.

Unfortunately several studies show that the temporal pattern and impulsive noise in combination with steady noise has a greater effect on hearing than that predicted by the equal energy principle. Short bursts of high noise levels with quiet periods between bursts may equate in energy to a steady level of constant exposure for a given duration but the effects on hearing are different in the two exposure conditions. The short bursts with rest periods produce much less damage. The short-term recovery that occurs during quiet periods of the intermittent exposure serves to reduce the permanent effect (Ward 1991). The American OSHA standards set a trading value of 5dB per halving of exposure instead of 3dB in order to allow for intermittent exposure levels. Thus trading 90dBA for 8hours with 95 for 4 hours up to 115dBA for 15 minutes. Each of the exposures results in a time weighted average (TWA) of 90dBA. This is analogous to the LA8hn that results when the exposure is evaluated using the 3dB trade-off. The difference at 115dBA between OSHA recommendation of 15 minutes and ISO equal energy equivalence of 1.6 min shows the variation between different exchange rates. The 3dB trading value is recommended by the American Conference of Government Industrial Hygienists (ACGIH, 1999) but 4dB is used by the US Navy. The 3dB is the most protective.

There are very few studies, which have examined the variation in the effect on hearing in relation to the steady versus intermittent exposures.

In terms of impulsive noise, a critical maximum is considered to be 140dBSPL which should not be exceeded. It is considered that susceptible individuals may suffer damage from 1 minute at 130dB or 10 seconds at 135dB or 2 seconds at 140dB (Ward 1991b) although the spectrum of the noise is an important factor. Very low frequency energy is considered less damaging than energy centred around 3kHz (Price 1981).

Hearing impairment without hearing threshold shift?

Hearing loss can only be judged with respect to a defined normal range. The clinically accepted range of normal hearing is from 0 to 20dBHL across all audiometric frequencies. However, the presence of continuous tinnitus or an inability localise sounds accurately or to understand speech in noisy backgrounds or having physiological auditory response abnormalities with normal audiometric thresholds may constitute "hearing impairment." It is clear from the above that there are two aspects to hearing, one is the intensity of the sound information and the other is the timing associated with the sequence of information conveyed by the sound, for example in speech. The intensity and timing of sound are both important for hearing whereas the dose-response relationship is only concerned with the intensity of sound or noise. The basic measure of noise does not consider its temporal sequence as being important and thus leaves out a crucial component of hearing effect. It only concerns the spectrum of noise and the equal energy principle assumes that partitioning of continuous noise over time into higher level shorter duration bursts would yield the same effect in terms of the hearing but this is not always the case. Temporal characteristics of exposure are clearly important in the physiological response from the cochlea.

Usually noise induced hearing loss is accompanied by an abnormal loudness perception (loudness recruitment), which means that although the threshold of hearing is elevated (faint sounds not being heard) the louder sounds appear as loud to these people as they would to normally hearing individuals. Thus the dynamic range of hearing in subjects with NIHL is

considerably reduced. Thus clarity of speech becomes more important than mere amplification. In addition some sounds may be perceived distorted (paracusis). Another feature is the possible presence of a constant ringing noise in the ears (tinnitus). Tinnitus is a very common feature of over-stimulation of the ears, teenagers experience tinnitus after rock and pop concerts but in most cases it is short-lived but in some it may be constant and unrelenting. It may be the first symptom of noise exposure in addition to muffled hearing (Hetu and Fortin 1995; Axelsson and Prasher 1999).

The slight loss of hearing (eg 10dB averaged over 2-4kHz over both ears) may be sufficient in leading to an inability to understand speech fully in normal conditions. If the hearing loss exceeds 30dB, this may result in noticeable social handicap.

Statistical Metrics in the evaluation of noise exposure and effect on hearing

In terms of the noise exposure, different types of noise environments may have similar sound pressure levels and spectra but very different temporal patterns in terms of the distributions of peak noise components. Accurate characterisation of noise has been the major obstacle in relating exposure to effect. The current practice estimates the hearing loss due to noise exposure on the basis of the total integrated level of acoustic energy over a given exposure duration. There are large variations in the responses across individuals to even a very precise noise exposure. Statistical measures of the range of hearing loss on the basis of 8 hour continuous noise exposure for 5 days a week for 40 years may be computed.

The ISO 1999 (1990) which, relates noise exposure to noise induced hearing loss in statistical terms uses total acoustic energy as the measure of noise contributing to the hearing loss. Lei et al (1994) have shown from a number of animal studies that total energy measure is inadequate in estimating noise induced hearing loss. Hamernik et al (2001) have shown that the energy-based metric is only suitable for Gaussian noise, while many industrial/ military and other environments are non-Gaussian and better represented by an energy metric in combination with the statistical metric, kurtosis, and may be better in identifying exposures that have a high potential to cause hearing loss than the traditional energy metric. The non-Gaussian noise is more hazardous to hearing than the Gaussian noise with the same spectrum and SPL.

A-weighted noise measure and risk of hearing loss

The weighting of noise measures (dBA and dBC scales) assume that the certain frequencies within the noise spectrum have greater harmful effect than others and furthermore predict equal hearing loss for different frequencies at the same weighted intensity. Equal dBA values but different spectra (ie different dBC values) assume equal risk on the basis of dBA values. According to Hellstrom and Dengerink (2001) the validity of these assumptions is not clear. Subjects exposed to one third octave bands of filtered noise with equal dBA levels showed a greater TTS for 2kHz than at 200Hz. The TTS after simultaneous exposure at 2kHz and 200Hz bands was significantly lower than either alone. Low frequency exposure may protect against that of higher frequency.

Applicability of ISO standard to environmental noise

The ISO standard 1999 (ISO 1990) provides a means of calculating NIHL in populations exposed to all types of occupational noise (continuous, intermittent, impulse) but high noise levels can occur in recreational settings such as open-air concerts, motor sports, shooting ranges, discos, with personal music players, toys, and fireworks. It is possible, therefore, to use the ISO standard for environmental and leisure time exposures. It is considered that long-term exposure to L_{Aeq} 24h of up to 70dBA will not result in hearing impairment.

In the standard, the relationships between L_{Aeq},8h and NIHL are given for frequencies of 500 Hz to 6kHz and for exposure times up to 40 years. These relations show that NIHL occurs predominantly in the high frequency region of 3-6kHz, the effect is largest at 4kHz. With increasing L_{Aeq},8h and increasing exposure time, NIHL also occurs at 2kHz. But at L_{Aeq} 8h levels of 75dBA and lower, by definition will not result in NIHL. The ISO standard specifies hearing impairment in statistical terms with median values and percentile fractions between 0.05 and 0.95. The extent of NIHL depends on the value of L_{Aeq},8h values , and the number of years of exposure and for higher levels, individual susceptibility has a significant effect on

the rate of progression of NIHL. Equal energy princple is used to determine exposure at other than L_{Aeq} 8h. For example L_{Aeq} 16h is L_{Aeq} 8h plus 3dB. L_{Aeq} 24h would be L_{Aeq},8h plus 5dB.

Evidence for use of ISO

There is some evidence that the method is applicable to hearing impairment due to environmental and leisure noise. Smoorenburg (1998) has shown that with shooting noise of L_{Aeq} 24h values of up to 80dB induces the same hearing loss as an equivalent occupational noise exposure. Similar results have been observed with motor bike noise. Hearing loss in adults and children from the age of 12 have been assessed by L_{Aeq} on a 24h basis for a variety of environmental and leisure noise (Passchier-Vermeer,1993) including discotheques and concerts, personal music players (Ising 1994; Struwe et al 1996; Passchier-Vermeer et al 1998), orchestral and brass bands (van Hees 1992). The results appear to be in agreement with values estimated by the ISO standard 1999 method on the basis of adjusted time.

Evidence against use

Exposure to noise with known characteristics such as duration and time can be used to estimate the extent of resulting hearing impairment. However, a number of factors indicate that a direct application of ISO standard is not suitable as data from animal experiments indicate that children may be more vulnerable in acquiring NIHL than adults (although some (Lower et al 1997) would disagree), at high instantaneous sound pressure level mechanical damage to the ear may occur. Occupational limits in adults are set at 140 dB peak but in children peak levels should not exceed 120dB peak. For shooting noise L_{Aeq} 24h over 80dB, an increased risk of NIHL is indicated from TTS studies. The risk of NIHL is increased when exposure is combined with vibrations, chemicals or asphyxiants. In these cases long term exposure to L_{Aeq} 24h of 70dB may induce hearing loss. It is uncertain whether the relationship in ISO standard 1999 are applicable to environmental sounds having a short rise time. Military low altitude flights may reach an Lamax values of 110-130dB within seconds after onset of sound. In addition the questioning of the appropriateness of the equal energy principle, the A-weighting system, relative differences in the sound transfer functions would indicate that many doubts remain about the validity of using current models for the environmental noise but no alternative approaches are available to provide a better model.

Dose-Response relationship

In order to establish the relationship between noise dose and its effect on hearing, firstly, the dose or noise immission has to be accurately recorded, secondly the assumption has to be accepted that total noise energy is the primary cause of hearing impairment irrespective of the time structure and spectral content of noise, thirdly it has to be accepted that change in audiometric threshold is a sensitive enough measure for recording the effect on the individual's hearing. On the basis of these assumptions, attempts have been made to derive statistical distributions of audiometric threshold change at various frequencies for a given exposure integrated over a standard 8-hour working days for a number of years. There are various problems with this approach.
1.Time course and spectral structure of noise are important factors in hearing impairment
2.Audiometric threshold change may not be the most sensitive indicator of the effect on auditory system
3. The effect of the interaction of the ageing processes and noise on the auditory system is not well understood.

Early signs of vulnerability and noise damage

Early signs of noise effects on hearing including the presence of tinnitus, muffled hearing, distortion of speech, speech recognition in noisy environments, poor sound localisation, intolerance of loud sounds, altered frequency selectivity, altered temporal integration, altered auditory efferent function, loss or reduction in otoacoustic emissions may provide an alternative to change in audiometric thresholds as measures of the effect of noise on the auditory system. All or some of these observations may precede any change in audiometric thresholds and thereby provide an early indication of altered auditory function. A number of studies (Prasher and Sulkowski 1999; Sliwinska-Kowalska et al 1999;Cianfrone et al 1998; Attias 2001; Prasher et al 2001) now indicate that screening for early noise damage may be possible using otoacoustic emissions rather than waiting for a deterioration in pure tone audiometric thresholds to confirm auditory damage.

Vulnerable Groups

It is possible that mothers-to-be and babies are more susceptible to damage from excessive noise exposure. On the basis of vascular and metabolic changes with noise overstimulation, it is possible that those individuals with pathologies that increase vascular insufficiency such as those with hypertension, diabetes, cardiovascular disease, heavy smoking may be more vulnerable. Those with low level of melanin, low level of magnesium, pre-existing hearing loss, simultaneously exposed to heat, vibrations, industrial chemicals, on ototoxic drugs may be more vulnerable.

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Noise Exposure from various sources: Effects on Children's Hearing

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Introduction

Young and old are being put at risk with the increasing noise around us whether it is at home, from our leisure pursuits or at work. Noise pollution and its effects are taken for granted. There is little awareness of the consequences of spending an ever- increasing amount of time engaged in noisy pursuits or living in noisy conditions.
There are environmental areas where noise appears unavoidable as on busy streets, on trains, underground trains, aircraft, on construction sites, sports venues but others such as pop-concerts, discotheques, night-clubs, shooting clubs, motor sports, cinemas, arcade games, personal cassette players and for the very young from toys and fireworks may be avoidable.

Noise induced hearing loss is by no means restricted to occupational settings – noise levels associated with impairment can be experienced during children's school activities, social/ leisure activities or from general transport or neighbourhood noise in the community. Over 25 years ago the US Environmental Protection Agency estimated (von Gierke 1975) that the noise level for school children in USA the Lex, 8h average was 82dBA. 20 years ago Siervogel (1982) provided measures from dosimeters ranging from 81-89dBA Lex, 8h with some exposures above 95dBA, Lex, 8h.

Hearing loss is defined as an increase in the threshold of hearing sensitivity. Acoustic trauma may produce a sudden loss of auditory sensitivity but exposure to a continuous or low level of noise results in a slow and cumulative effect, which leads to a progressive loss of hearing. An internationally accepted noise level that does not cause a temporary or permanent hearing loss is 75dBA. Damage risk criteria for noise are only available from industrial settings and vary between countries, mostly from 85-90dBA, for a life-time of work in noise. For recreational noise exposure, there are no such risk criteria but it seems appropriate not to exceed the industrial noise requirement (Axelsson 1998). It is important to appreciate that a single high-level impulsive sound may be sufficient to give a permanent hearing loss and/or permanent tinnitus.

There is very little information concerning noise sensitivity in young people. It is also important to note that children cannot observe or describe that they have acquired a hearing loss- at least not before six years of age (Axelsson 1998). Children who suffer slight acoustic trauma with hearing loss and tinnitus are not likely to report this to their parents. Therefore early intervention may not occur.

Extent of the Problem of Noise

According to the European Environment Agency's report *Europe's Environment* about 450 million people, 65% of European population are exposed to noise levels above 55dBA, which may result in annoyance, aggressive behaviour and sleep disturbance. A further breakdown shows some 113 million exposed to levels greater than 65dBA and around 10 million to noise levels above 75dBA, which can potentially result in increased hearing loss. The higher the level of noise and the longer that an individual is exposed to the noise, the greater is the risk of damage to hearing and the greater the prospects of the emergence of tinnitus, a constant ringing or buzzing in the ears or head.
Noise induced hearing loss (NIHL) among children is a serious public health problem as it has a major impact on speech, language, cognitive, social and emotional development. According to American Academy of Otolaryngology, some 3m children in the USA have some difficulty hearing. A recent study (Niskar et al 2001) estimated the national prevalence of NIHL among children aged 6-19 years of age, during the period 1988-1994 in the US from

a representative sample of 5249 children and found 12.5% (approximately 5.2 m) to have a noise induced hearing threshold shift in one or both ears. This analysis is the first to estimate noise induced threshold shift (NITS) among school-aged children in USA. NITS was defined using three criteria: (1) threshold values at 0.5 and 1kHz less than 15dBHL, (2) maximum threshold value at 3, 4 and 6kHz at least 15dB higher (poorer) than in (1), (3) threshold value at 8kHz at least 10dB better than the maximum value in (2). These three criteria describe a noise notch pattern. Boys had a higher prevalence (14.8%) of NITS than girls (10.1%). Children aged 12-19 also had a higher prevalence (15.5%) compared to 6-11 year olds (8.5%). The American National Hearing Conservation Association has reported that in a survey of 110 children aged 6 to 14 years, the average noise level during the day was 90dB and in the playground these levels reached 115dB.

This report examines the noise from various sources, which may have an impact on the children's hearing.

Sources of Noise Exposure and their effects on hearing

Toys
Cap pistols, mock mobile phones, percussion instruments, even pastel shaded squeaky toys can generate high levels of noise. According to Axelsson (1998) toy mobile phones produce sound levels over 100dBA with the worst telephone producing levels of 122dBA at the ear of the user. The Human pain threshold is 120dBA. For hand held and squeaky toys the sound levels range from 78-108dBA, being measured at a distance of 10cm. Toy weapons such as percussion caps produce impulsive sounds in excess of 140dBA. Many toy guns emit levels that are similar to the original with peak levels of 150-160dBC. Yaremchuk et al (1997) tested 25 toys and found peak sound levels ranging from 81-126dBA at 2.5cm and 80-115dBA at 25cm from the toy.
The relationship between noise exposure and hearing damage is based on occupational noise exposure for adults, which states that for adults a regular daily noise exposure should not exceed the equivalent of 80dBA for 8hours and the peak level should not exceed 140dBC. Lower et al (1997) indicate that there is no compelling evidence that children are more sensitive and hence the adult limits may be applied equally well to children. On this basis and using the equivalent energy principle with the assumption that toys will be used for no more than 2.5 hours per day at a distance of 25cm, they suggest that the time averaged noise level produced by the toy in continuous use or over a cycle of use should not exceed 85dBA Leq at 25cm and the peak level should not exceed 120dBC at 25cm. Lower et al (1997) measured noise levels from 178 toys, showing that all cap guns, bursting balloons, party poppers and toy drums exceeded the peak limit of 125dBC at 25cm, all headphones and earphones when used at full volume exceeded their limit of 93 dBA on an artificial ear, 69% of musical instruments had time averaged levels that exceeded 85 dBA at 25cm, 60% of close-to-the-ear toys exceeded the limit of 85dBA at 2.5 cm, 16% of hand-held table top and floor and cot toys exceeded the time average noise level of 85dBA Leq at 25cm. 21% of the squeeze toys exceeded the SEL limit of 92dBA for 10 squeezes. Thus a considerable number of toys currently available on the market exceeded their own limits whilst others (Leroux and Laroche 1991, 1992) have recommended more strict upper noise level limits for toys of 75dBA or 95dBA (peak) regardless of duration. Extensive studies by Axelsson and Hellstrom (Axelsson et al 1991; Axelsson and Jerson 1985; Hellstrom et al 1992) Hellstrom et al 1992) have also shown that certain toy noise levels far exceed the safety limits even for adults. It has also been considered that the worst-case scenarios (close to ear) should be considered in setting limits

Axelsson (1998) has argued that sound levels produced by children's toys are usually underestimated in their ability to do damage. As the heads and ear canals of children are much smaller than those of adults, the amplification of sound is more marked in high frequencies in children than in adults according to studies by Hellstrom (1998). The external ear canal resonance frequency is significantly higher at birth at about 6kHz and decreases with age to adult values around 2.7kHz by the second year (Kruger 1987). This means that the relatively high- pitched sounds from the toys, which are also more harmful for hearing, are more amplified in the ear canals of children. In addition the lower level of sound heard by the parent when the toy is held at arm's length may be considered by them to be safe but with high pitch resonance of the child's ear canal with the toy held close to the ear may give a much louder and harmful sound. No differences in the safety limits are available for the children in view of the different ear canal characteristics and the greater sensitivity to damage shown in the early stages of development.

A study of 20 cases of acoustic trauma from toy cap pistols involving boys in the age range 6-11 years showed significant high frequency loss and suffering from continuous tinnitus which was detrimental to family life and performance at school. It was also noted that a single shot close to one ear can damage both ears in young children.

Children are exposed to many sources of noise, in addition to toys therefore the total exposure needs to be considered but the energy equivalence measure for toy sounds is another matter of concern.

A number of actions have been suggested by the Protection Against Noise (PAN) Group examining the issue of toys:

- Lower the frequency of sound emitted by toys
- Lower the intensity of sound from toys, particularly electronic toys
- Determine age-specific safe levels of sound that any individual may be exposed to without incurring damage to hearing
- Provide legislation for toy noise safety for manufacturers
- Educate young children and their parents about the dangers of high intensity sound emitting toys

Noisy Toy Case Report

A 39 month old infant with previously documented normal hearing suffering acoustic trauma from a bicycle horn activated at his ear. The child had a 50dB notch at 4kHz six days after the incident but improved to 30dB after six months. The horn was shown to produce 143dB peak SPL, a sound level clearly associated with a high risk of damage (McMillan and Kileny 1994).

Fireworks

Plontke et al (2002) have estimated the incidence of acoustic trauma due to new year's firecrackers in Germany as 9.9 per 100,000 inhabitants. The incidence for the 6-25 years age group was much higher at 28 per 100,000 with a maximum of 107 per 100,000 for 19- year-old men. These incidences indicate a major public health problem of firecrackers and medical economic costs associated with a permanent sensori-neural hearing loss.

Fireworks can produce impulses reaching peak levels, measured at the ear in excess of 160dB when fired at a distance of 2m (Smoorenburg 1993). These levels are potentially hazardous to the ear as the damage risk criteria for impulse sounds is that, for 10 impulses, the peak levels should not exceed 149 dB (linear peak) and the A-weighted impulse (integration time 35ms) should not exceed 125dB(A, imp) at the ear for 10 impulses.

Gupta and Vishwakarma (1989) have in their study of Deepawali fireworks in India have shown an average sound level (at a distance of 3m) to be 150dB. They also found that 2.5% of a target group of participants had a 30dB hearing loss with the
9-15 year olds most affected.

Scandinavian studies analysing children's hearing before and after the new year or National Day celebrations, both of which are associated with the annual peak use of fireworks (Bentzen et al 1964; Gjaevenes et al 1974; Djupesland 1975) show a number of children with hearing loss, particularly boys in the 10-15 year range.

The level of impulsive sounds from cap guns and firecrackers with powder exploding is severely underestimated due to the short duration of sound. This also means that the protection afforded by the acoustic reflex may not be activated.

It is important to remember that a single firecracker explosion close to the ear can cause permanent hearing loss or permanent tinnitus.

Arcade Games

Electronic arcade and computer games produce high levels of sounds. Some virtual reality headgear with ear phones deliver images and sound at very high levels. Mirbod et al (1992) reported that noise levels measured at three centres reached 90dBA with the more intense noise levels occurring in the frequency range 0.5-2kHz. The computed noise levels ranged from 93.3-96.6dBA and it was estimated that such levels may cause 4-8dB temporary threshold shift at 4kHz in an individual with less than an hour of exposure to such levels.

Shooting

Many teenage boys join shooting clubs. Reports on hearing in people who shoot compared to non-shooters have consistently shown poorer hearing (Hanner and Axelsson 1988; Taylor and Williams 1996). Stewart et al (2001) examined the effect of recreational gun fire noise on hearing in workers exposed to occupational noise found that shooters had hearing loss which was poorer by 5-10dB compared to other workers. Nondahl et al (2000) also report recreational firearms use is associated with marked high frequency loss.

Sports

Noise from international raceways, jet match, drag racing, motorcross, speedways, and go-karts have been measured showing A-weighted sound pressure levels at around 10m distance to be between 97 and 100dB. The noise measurements of motorcycles range from 85 to 96dBSPL at around 30m from the trackside. Roberts (1999) has observed that regardless of the category of racing vehicle the difference between the maximum noise level and LAeq was about 13dB and between the average maxima and LAeq was 7dB. The Public Announcement systems at race-tracks produced music and announcements at the same level as the racing vehicles.

The noise levels in the cockpits of powered gliders pose a risk to hearing of pilots. In extreme cases, according to Stueben (2001) a time of only 20 seconds exposure to cockpit noise of a retractable propulsion unit glider may be sufficient to cause permanent hearing loss. Charakorn et al (1998) studied 91 sport shooters and found 9.4% suffered from hearing loss between 3-8kHz with the severity relating to years of shooting.

Car racing noise levels can be up to 130dBA but Lindemann etal (1985) found no noise induced hearing loss in racing drivers. It was thought that they were well protected and on average only raced for 15-180 hours per year. However those working in pits showed distinct hearing impairments.

Loud Music

Listening to music is a pleasurable experience and should pose no threat to hearing if listened at levels below 75dBA. However, in the last two decades, with the emergence of hi-fi equipment capable of delivering distortion free sounds at extremely high levels has meant a new trend in music listening habits encouraging youngsters to listen to pop and rock music at disturbingly high levels capable of damaging hearing. Furthermore, the availability of portable personal listening devices, such as the cassette and disc players, has meant that high levels of music can be delivered directly to the ears via headphones allowing the user to listen for prolonged periods of time. "Pump up the volume" is a phrase common on radio and in night clubs emphasising the importance of the high levels as part of the enjoyment. The emphasis is on loudness. The louder the better, that seems to be the message, but unfortunately not for the ears

In a recent Swiss survey (Mercier et al 2001) of 700 young people it was found that 79% attend discotheques, 52% concerts and 35% techno parties. For 53% of them the noise exposure (Leq) was 87dBA or more. 11% of the 700 had a hearing loss and over 35% judged the music level at all events as too high whereas only 3% thought it was too low. It appears that high levels of sounds are not demanded by the young people.

There is widespread concern about the effect of loud music on young people.

Job et al (2000) examined the hearing of 1208 young Frenchmen between 18-24 years in 1997. 60% were exposed to atleast one source of loud noise. 15% had high frequency loss. ^% had suffered from acoustic trauma. Those with a history of otitis media hearing impairments were significant in personal stereo users (>1 hour per day), pop/rock concerts (> twice per month) and those who worked in noisy places.

Zenner et al (1999) also report that leisure noise represents a serious risk to hearing from toy guns and amplified music whether through ear phones or at discotheques or pop-concerts.

Davis et al (1998) demonstrated that 23% of young adults were exposed to potentially dangerous levels of social noise in the late 1990s compared to only 7% in the 1980s- a greater than three-fold increase in a decade. In Norway in the early 1980s 30,000 eighteen year olds entering military service had their hearing tested and 15% were found to have a significant

hearing loss in the high frequencies which is characteristic of damage from noise such as rock concerts and night clubs.

Today increasing numbers of young people go clubbing for hours at a time on a weekly basis for many years as well as attending rock concerts and listening to personal stereos from a very young age. This combination of noisy leisure activities produces a cocktail of noise exposure, which represents a serious risk to hearing. As well as being exposed to a whole range of social noise, many young people find themselves working in noisy occupations either traditional industries or service industries such as bars, restaurants, or clubs.

Rock Concerts
Rock concerts consistently top the league table of noisy activities. A Swedish study (Axelsson 1998) recorded levels of between 97 and 110dBA. A French study (Meyer-Bisch 1996) recorded sound levels exceeding 110dBA and in the USA from 110dBA to a staggering 150dBA. Sound levels such as these represent serious risk of permanent damage to hearing. The UK Goverement's Noise at Work regulations state that employees should be protected from noise levels above 85dBA. Thus at 97-110dBA audiences at rock concerts are being exposed top sound levels well beyond the level considered safe at work. However there is no legislation in place to protect the consumer (the concert goer), the vast majority of the public remain unaware of the risk. A number of studies (shown in Table 1) have examined the effect on hearing of young people exposed to various levels of music.

Meyer-Bisch (1996) found alarming differences in levels of hearing problems between those who regularly attend rock concerts and young people in general. Tests demonstrated that 44% of those attending concerts once a month had symptoms such dullness of hearing or tinnitus compared to only 11% of those who were not frequent concert attenders. A 1999 UK survey reported 73% of 18-25 year olds attending rock concerts complaining of dullness of hearing, tinnitus or both. Joktulppo et al (1997) estimated that 50% of Finnish teenagers were exposed to levels of leisure noise, which may be harmful to hearing and 70% reported temporary tinnitus after leisure noise exposure. The incidence of hearing symptoms seemed to be linked to increased noise dose. Another study (Axelsson et al 1994) testing 500 eighteen year old Swedish male recruits found 14% had hearing beyond the normal limit. An evaluation of music listening habits of 10,000 young people (Babisch et al 1994; Ising et al 1997) has confirmed the risk and shown that 10% of pupils aged 10-17 years may have a permanent noise induced hearing loss greater than 10dB.

Metternich and Brusis (1999) examined 24 subjects after acoustic trauma from attending a rock concerts.67% had a hearing loss as a result of a single exposure at a rock or pop concert, 17% from discotheques, and 12% from parties and 4% from personal cassette players. The majority showed losses of between 40-60dB in the 3-4kHZ region. 58% had a unilateral loss with tinnitus,21% had a bilateral loss and tinnitus. In 8% there was unilateral tinnitus and in 13% bilateral tinnitus without a hearing loss. Risk of continuous tinnitus from short term exposure is higher than having hearing loss according to their findings.

Although there are no legally binding limits it is considered undesirable by the Health and Safety Executive for the Event Equivalent Continuous Sound Level (Event Leq) in audience areas to exceed 107dBA or the peak sound pressure to exceed 140dB but this is much flouted. It is recommended that the audiences should not be allowed within 3m of any speaker at outdoor events and if the Event Leq is likely to exceed 96dBA it is good practice to warn audiences about the risk to hearing in audience publicity as for example in advertising, posters and notices and tickets but this is extremely rare.

Although rock concerts produce some of the highest levels of social noise and can have a significant impact on hearing, they are not the sole source of potential hearing damage. On

average, young people go to night-clubs and listen to personal stereos more frequently than they attend rock concerts.

Night-Clubs

Noise levels in night-clubs are of particular concern in the context of the increasing popularity of rave and club culture in the late 1990s. Many young people go clubbing every weekend for extended periods. The advent of "all-nighters" (night clubs that stay open for 12 hours or more) means that exposure to levels of sounds in excess of 100dBA, for periods of 8 hours or longer , on a weekly basis, is not uncommon.

Noise levels in European night-clubs have revealed levels between 95 and 110dBA. An American summary of sixteen studies in to night-club noise (Clark 1991) found levels as high as 120dBA, well in to the danger zone. Exposure times have also increased with the spread of recreational drugs use on the club scene which enables clubbers to remain on the dance floor for longer periods, raising the risks even more. A study of 13-19 year olds in Germany who attend night-clubs and discos once a week had a clearing hearing loss of 4dB compared to no measurable loss in their peer group (Babsich and Ising 1989).

A similar study in France (Meyer Bisch 1996) found evidence of tinnitus and hearing loss in 47% of regular clubbers compared to a figure of only 14% for those who attend less frequently or not at all. The most recent UK study (Davis et al 1999) reported that 66% of those attending night-clubs had dulled hearing, tinntuis or both.

A number of studies (Ulrich and Pinheiro 1974; MRC 1985; Clark and Bohne 1986; Daneneberg et al 1987) have shown the presence of temporary loss of hearing sensitivity (temporary threshold shift, TTS) in subjects after attending a discotheque. The consensus appears to be a TTS of up to 30dB at around 4kHz, which recovers after a few hours or sometimes days. The TTS clearly indicates the damaging sounds experienced by the disco-goers although generally permanent hearing loss has not been reported but other auditory symptoms such as hypersensitivity to sounds and tinnitus are more widespread. A recent questionnaire survey (Meecham and Hume 1999) of post night-club music exposure induced tinnitus showed that of the 494 students, 87% attended night clubs and 80% had post exposure tinnitus, in 22% tinnitus lasted longer than 2 hours. There was a significant association between attendance at night clubs and the duration of tinnitus. Davis et al (1999) tested 346 subjects aged 18-25 years who had a history of social noise exposure from night clubs, concerts, and personal stereos, 19% had a significant social noise exposure, with a major component from nightclubs with personal stereos contributing some exposure. Of the 328 who attended nightclubs, 66% reported temporary dullness of hearing, tinnitus or both .20% of those with significant social noise exposure had reported tinnitus compared to 7% of those with no significant noise exposure. This represents a significantly increased (odds ratio of 3.45) likelihood of tinnitus after social noise exposure.

The influence of a single exposure to amplified music (4 hours at 97dBA) on hearing in young volunteers (18-25 Years) was assessed by Mazelova et al 2001). After music exposure a significant elevation of audiometric thresholds across 1-5kHz was observed as well as a decrease in transient and distortion product emissions. It has also been shown that employees of night clubs suffer from tinnitus or hearing loss which correlate with sound intensity of the exposure (Gunderson et al 1997; Lee 1999). Lee et al (1999) report that employees such as disc jockeys, bartenders, waiters, cashiers and security officers are exposed to at least 89dBA Leq for their work shift. 41.9% had early sensori-neural hearing loss and 21 % had tinnitus compared with 13.5% and 2.7% of controls respectively. Sadhra et al (2002) in a similar study of student employees in University entertainment venues found that security staff were exposed to a mean personal exposure level greater than 90dBA with maximum of 124dBA. 29%of subjects showed hearing worse than 30dB

In the context of mounting evidence that such symptoms may be the pre-cursor of longer term hearing problems, these finding indicate that up to two thirds of those attending may be at risk of developing premature hearing problems.

Personal stereo players

Personal stereo players (PSP) are now a common feature of European youth culture. The levels of sounds emitted by these players can range from 60dBA to 110dBA, which are clearly in the range that pose a potential risk to hearing. The compact disc players with their increased dynamic range in comparison with the cassettes can enhance the risk to hearing by reaching sound levels of 125-127dBA with an Leq (1 hour) of 110dBA (Loth et al 1992). The average levels reported by one study are 95dBA for women and 97dBA for men whereas others report (Flechlin et al 1998) average levels around 83dBA. The levels are raised in certain listening environments such as on public transport or when jogging or during aerobic exercises as the noise in the surrounding areas is high forcing the listener to increase the level in order to hear the music above the extraneous noise.

Personal stereos generally expose individuals to lower sound levels than attendance at rock concerts or night clubs but individuals listen to personal stereos for longer periods and start at an earlier age thereby increasing the risk.
A study of 10-23 year olds who used personal stereos found that almost one in ten users had selected a volume setting higher than 95dBA. Volume levels also tend to be raised in certain environmental conditions such as on public transport or when jogging or during aerobic exercises.
Advances in digital technology mean that the volume levels personal stereos can produce are rising too. Manufacturers are now producing digital CD and minidisk players which are capable of delivering distortion-free sound levels up to 127dBA compared to 105dBA for conventional cassette players.

Since 1996, Switzerland has had a regulation of A-weighted sound level limit of 100dB for music at concerts and 93dB in discotheques. Hohmann et al (1999) examined the cumulative effect of personal stereos, concerts and discotheques on hearing in 347 young people, showing that with a weekly Leq measure less than 85dB, 58% had tinnitus and 30% a hearing loss, which increased to 65% and 37% for levels between 85-90dB and for over 90dB to 75% and 46%. For a cumulative 5 year period the respective figures were 62% with tinnitus and 29% hearing loss for <85dB , 66% and 46% respectively for 85-90dB and 72% and 45% for over 90dB. According to the ISO standard only 10% of 15-26 year olds should have a hearing impairment of at least 15dB in the frequencies between 3 and 6kHz. The percentage of people suffering from tinnitus or hearing loss is correlated with increasing weekly exposure. The linear trend of increasing probability of hearing loss with increasing cumulative exposure was highly significant.

It has also been reported recently (Job et al 1999) that subjects with previous history of otitis media appeared to be at greater risk of acquiring hearing loss with the use of personal stereos although this has been disputed (Davis et al 1999)
A study conducted during 1996-97 by Passchier-Vermeer (1999) on the music listening habits of 405 subjects aged 12-30 years and their effect on hearing and tinnitus, found that over 68% had observed tinnitus or dullness of hearing during and after pop-music activities. She examined the relationship between exposure to pop music through headphones and hearing threshold levels based on the relative hearing threshold levels of those subjects relative to the median hearing threshold levels of the male/female reference groups.

Music Exposure and Hearing Loss at 6kHz

ISO 729 specifies cumulative distributions of relative hearing threshold levels of reference groups of male and female subjects as a function of age and Passchier-Vermeer (1999) found that those of 20 year olds did not differ from the hearing thresholds observed in her study. The hearing thresholds in the pop music listening group were not higher than the ISO reference groups, which are assumed not to have any undue noise exposure. However, this does not exclude a small fraction of the group having a hearing loss. The question that was raised is whether the model in ISO 1999 can be applied to pop music listening. The group was exposed to an A-weighted level of 95dB at most and for a period not exceeding 10 years. According to the ISO 1999, no hearing loss should be expected at 500, 1000, and 2000Hz which corresponded with the findings in her study. At frequencies above 3kHz pop music induced hearing loss was somewhat different from the relationships of occupational noise induced hearing loss. Observed pop-music induced hearing loss in the study of Passchier Vermeer (1999) was more accurately described by ISO 1999 for frequencies a half-octave lower. This implies that unlike occupational hearing loss, pop-music induced hearing loss has its maximum at 6kHz with somewhat less pop- music induced hearing loss at 4kHz.

Time–weighted Average measure and Hearing Effect

Traditional measurement, evaluation and assessment of noise exposure do not differentiate between various sources of noise. Occupational noise exposure assessments are based on an 8-hour exposure of acoustic energy equivalent to that of continuous noise. The time-weighted average is calculated on the basis of the 3dB rule without any consideration of the time structure of the noise events. Strasser et al (1999) compared the acute hearing-physiological effects in ten subjects for four different types of noise and music exposures (white noise, industrial noise, heavy metal music, classical music), which were equivalent in energy with a mean A-weighted level of 94dB over an hour (which is equivalent to 85dBA for 8h). For white noise the mean threshold shifts were roughly 20dB, which dissipated by 100minutes after exposure. For industrial noise, the values were 22dB with restitution taking 130minutes. With heavy metal music the shift is also around 20dB with recovery after 120 minutes. For classical music the threshold shift is around 11dB and recovery took 55minutes. The integrated restitution temporary threshold shift (IRTTS) as an overall assessment shows that industrial noise and heavy metal music cause threshold shifts that are approximately 50% higher than those from white noise or classical music. Moreover the threshold shifts from classical music were only about one quarter the magnitude of the threshold shifts from industrial noise or heavy metal music.

Energy Equivalence of different sounds

The concept of the energy-equivalence and dose maximum are used to calculate theoretical maximum permissible levels. According to Strasser et al (1999) an energy-equivalent evaluation of acoustic stress leads to grave misrepresentations of the true physiological cost. Their studies (Hesse et al 1994, Strasser et al 1995) have shown that splitting a continuous noise exposure of 85dB over 8 hours in to energy equivalent impulse noise leads to drastic increase in threshold shift. Impulse noise of 5ms over 8 hours which resembles actual work patterns led to an increased TTS values which were highly significant but would not have been problematic but the restitution time which was about 2 hours for continuous noise was dramatically increased to around 10hours. Furthermore, impulse noise, which is irrelevant in terms of energy levels, when added to a continuous noise was not free from consequences for hearing although rating level had only increased from 85dB to 85.4dB. The peak levels also appear not to have a bearing on TTS as the classical music had peak levels higher than the other two types of music/noise.

Thus it is clear that equivalent acoustic energy levels of different sounds do not yield the same physiological responses and hence are not equivalent in terms of response.

Orchestral Music and hearing- a special case?
It has been shown (Blum 1995) that around 25% of all orchestral musicians have some hearing problem especially brass players in whom it is considered to be a number one occupational hazard. It is thought that in their usual seating position the brass players are exposed to an energy equivalent continuous noise level of around 90-95 dB for an hour. During solo rehearsals trumpets and bass drums reach A-weighted levels up to 130 and almost 140dB respectively with approximately 40cm distance between musician and instrument. Marquardt and Schacke (1998) provide a comprehensive survey of sound exposure of orchestra musicians, which indicates that they are regularly exposed to sounds likely to cause hearing loss but the audiometric studies show little evidence of this.

Early detection of damage from loud music
Early detection of hearing damage is important so that further deterioration can be halted, for example by limiting exposure to loud sounds.
One of the difficulties in using pure tone audiometry to monitor the effect of noise exposure is that 30% of outer haircells may be damaged before a hearing loss is detectable Bohne and Clark 1982). Recent studies (Desai et al 1999; Xu et al 1998) suggest that otoacoustic emissons may provide a means of detecting haircell damage early, even before any change is observable in pure tone audiometric thresholds.
A number of studies as indicated below have shown the emissions to be valuable in detecting changes in subjects exposed to loud music.
LePage and Murray (1998) showed that there is an effect on the auditory system as evidenced by the decline in otoacoustic emissions (sounds recorded in the ear canal) in subjects using personal stereo players heavily. Recently, Prasher et al (1999) conducted hearing tests on 116 subjects in the age range of 23-59 years from Camden Council in London for a BBC Watchdog-Healthcheck programme. The people tested thought that their hearing was normal but 24 of the 116 subjects were found to have a slight to mild hearing loss. The mean across the audiometric frequencies for 15 subjects was between 16-25 dB and for 9 between 26-40 dB. In addition 14 subjects had reported tinnitus but had normal hearing. These are surprising findings given that all the subjects were unaware of any hearing deficits. A large number of these subjects admitted to loud music exposure from various sources of up to 20 hours a week. Praties and Prasher (1999) have also observed that 8-15 hours after a single discotheque attendance the otoacoustic emissions were still significantly reduced in amplitude, particularly in those with history of loud music exposure.
Otoacosutic emissions provide a direct indication of the effect of over-stimulation on outer haircell activity and therefore an early indication of the effect in an individual. The change in emissions can be observed prior to any change in audiometric thresholds.

How loud is too loud?
What is clear is that sounds below 75dBA are unlikely to cause any hearing loss. What is less clear is the precise level at which particular individuals will have hearing loss if exposed to that level for a given time. This is due to the wide variability in susceptibility of individuals to hearing damage, depending on many factors including genetic influences, previous ear diseases, age, social and environmental factors.
However, it is abundantly clear that ears exposed to higher and higher levels of sounds for long periods of time are at greatest risk of damage. One simple indication of whether the noise level around one is too high is whether one has to shout to be heard by a person near

you. Levels above 115dBA should not be tolerated for any duration and those of an impulse nature, not above 140dB peak. Above these levels risk of immediate damage is high especially if the noise is very close to the ear.

Statutory Noise Limits
Switzerland was the first European country, in 1996, to introduce statutory noise limits for public music events, 93dBA for concerts and discotheques. The French National assembly decided in 1996 to limit the sound levels of personal music players to 100dBA.

Dose-response relationship for noise and hearing in Children
A number of questions remain to be answered before a dose-response relationship may be attempted for noise and hearing. These are as follows:

- Are children more sensitive/susceptible to noise than adults?
- Should the children's limits be set different from the adult limits?
- Should the upper limit be set such that it leads to an identifiable loss of hearing after 8hour per day for 250 days for 40 years exposure?
- Is 6kHz a better indicator of music-induced loss of hearing in young people?
- Is Leq an appropriate measure for noise experienced in a child's environment?
- Is dBA an appropriately weighted measure of the noise environment?
- Is the time pattern or sequence of noises important for hearing loss?

TABLE 1

Authors	Study	Results
Job et al 1999	Personal stereo use and previous otitis media	Increased loss of hearing and tinnitus in subjects with previous otitis media
LePage et al 1998	N=1724 total; n=240 for personal stereo users only Otoacoustic emissions	Emissions decline in relation to personal stereo use
Mostafapour et al 1998	N=50; 18-30 years, Personal Stereo users	28% had a 3-6kHz notch of 15dB or more.
Passchier-Vermeer et al 1998	N=405 pupils 14-21 years, personal stereo users	10% have pop-music induced hearing loss of 3dB
Jokitulppo et al 1997	Questionnaire survey	51% exposed to levels detrimental to hearing
Meyer-Bisch 1996	1364 subjects; PCPs, discos, rock concerts	Statistically significant increase in hearing threshold if PCP use > 7 hours/week. Auditory suffering in 2 of 3 attending rock concerts compared to 1 in 8 controls
Ising et al 1995	N=569 ; 10-17 years ; Personal cassette players and discotheques	5% of PCP users expected to have hearing loss of 20dB after 5 years. Increased number if discos are added.
Ising et al 1994	681 subjects 10-19 years; PCPs	Listening at 60-110dBA; 0.3% expected to develop hearing loss at 25 years of age.
Vittitow et al 1994	12 subjects; TTS after music with and without exercise	TTS greatest with music plus exercise
Wong et al 1990	487 subjects 15-24 years; PCP users	Mean listening time 4.5 hours per week. Greater risk at 85dBA compared to 70dBA
West et al 1990	60 subjects 15-23 years; amplified music	Decrease in frequency resolution earliest sign of damage
Babisch et al 1989	3133 subjects 16-20 years: Discotheques	Those with hearing loss greater than 30dB had spent significantly more time in discos than others
Rice et al 1987	60 subjects ; PCP users	5% listen at levels with risk of damage to hearing
Swanson et al 1987	Influence of preference for music on temporary threshold shift (TTS)	TTS(music preferred)<TTS noise<TTS (music dislike)
Catalano et al 1985	190 subjects; PCPs	31.4% equalled or exceeded maximum dose allowed by OSHA criteria in the workplace.
Carter et al 1982	944 subjects 16-20 years	No hearing loss but if exposure continued some risk by mid twenties
Axelsson et al 1981	581 boys :PCPs	15% had threshold greater than 20dB at at least one frequency

TTS - temporary threshold shift   PCP - Personal Cassette Player   OSHA - Occupational Safety and Health Administration

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APPENDIX

Sound Scale

Pressure changes in the air are perceived as sound by the ear, which can detect sound pressures around 20uPa and has a range of 10 million times up to 200 Pa. This vast range is better represented using a logarithmic scale, the decibel (dB) scale, which is based on a ratio of the sound pressure level to a standard reference pressure of 20uPa. The sound pressure levels thus produced range from 0dB (just audible) to 120dB (pain threshold). Various levels commonly encountered are shown below.

Noise Measurements
Sound level meters use different frequency weighting networks to take into account the fact that the Human ear responds best in the frequency range 20-20kHz. Noise measurements in relation to auditory effects are measured using A-weighted scale dBA. The measurement of the A-weighted equivalent continuous sound level or time average sound level, L AeqT in dB is the notional continuous sound level over time T, contains the same amount of energy as the actual fluctuating sound being measured. Noise exposure is a combination of noise level and duration. A doubling of duration will increase the Leq level by 3dB which doubles the exposure. Increasing the level by 3dB and halving the exposure time leaves the Leq unchanged. This is known as the 3dB exchange rate, in that time may be traded for intensity. Leq levels may be given for the whole time of an event such as a concert or workshift.

Effects of noise on hearing

Hearing acuity is also measured on a dB scale using pure tone stimuli presented at octave intervals from 125Hz to 8kHz (Pure tone audiometry , PTA). Hearing threshold is the level at which the sound is just audible to that subject. The hearing threshold is considered within the normal range if it lies between 0 and 20dB across the frequency range. Loss of hearing sensitivity results in raising of hearing thresholds which after exposure to noise may be temporary resulting in what is termed a temporary threshold shift (TTS) or permanent resulting in a permanent threshold shift (PTS) or hearing loss. In addition, other effects such as tinnitus or ringing in the ears or head may be experienced by the subject. This may last from a few minutes to being permanent. Other early signs may be loss of clarity of a sound or speech, difficulty in understanding speech in noisy conditions. The damage from noise takes two different forms depending on the level and duration of the sound. An impulsive sound such as an explosion may result in direct mechanical damage to the outer haircells in the inner ear after damaging the eardrum and the middle ear components. There may be pain and immediate loss of hearing sensitivity. In contrast continuous noise or music may lead to chronic damage of the sensory haircells in the inner ear through metabolic means leading to their dysfunction or death. The temporary threshold shift after an exposure to noise may result from the overstimulation leading to the cells becoming fatigued. If the overstimulation occurs over a long time or too frequently without a rest then this may lead to the cells becoming starved of appropriate nutrition leading to their death and if sufficient numbers die this leads to permanent loss of hearing sensitivity as they do not regenerate.
One of the difficulties in using pure tone audiometry to monitor the effect of noise exposure is that 30% of outer haircells may be damaged before a hearing loss is detectable Bohne and Clark 1982). Recent studies (Desai et al 1999; Xu et al 1998) suggest that otoacoustic emissons may provide a means of detecting haircell damage early, even before any change is observable in pure tone audiometric thresholds.

Noise exposure – Productivity, learning and concentration in adults

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Abstract

There is a lack of well-controlled studies on the relationship between noise and productivity, in a narrow sense of that word. Whatever relevant information there may be on this issue must be sought under other headings in the research literature, in the first hand performance and cognition.

A general finding in studies of the effects of noise on cognition and human performance is that the noise levels has to be high to produce a reliable effect on performance, and/or that the task performed has to be complex or cognitively demanding (cf Smith, 1989, 1992). Tasks that are simple and repetitive are unaffected by noise, and if the task is boring, simple enough or well learned, noise may even improve performance. Thus, a search for productivity gains and economic returns as a result of lowered noise levels, must be focused on tasks that to a large extent tax cognitive abilities. With this restriction imposed, there is not a sufficient number of studies to generate empirically well founded dose-effect relationships between noise and cognitive performance of adults across a wide range of noise doses.

However, if the basic interest is the relative gain in cognitive performance by lowering the noise dose, rather than the absolute performance at different noise levels, the relevant information is in the slope or 1st derivative of the noise-effect relationship. Plotting the noise-effect slopes for a few specific cognitive functions from different studies, will, if the grouping of the slopes come out in a coherent and orderly way, set a platform for statements about gains in cognitive performance as a result of lowered noise levels.

Comments on the theoretical properties of dose-effect functions
The general forms of noise dose-effect relationships are shown in Figure 1. The curve to the right (solid lines) is taken directly from FICON (1992), which summarized empirical findings on noise annoyance. The curve to the left (dashed line) is generated from the same equation as the right curve by adding10 L_{dn}-units. However, in the present context the relationships are meant to depict the general form of noise effects on just any performance or response. Differences between different effects are assumed to mainly be a parallel shift of the function along the abscissa or ordinate, and only to a minor degree a shift in the slope of the function.

Figure 1 – Two hypothetical dose-effect relationships between noise dose (L_{dn}) and percent effect (% Effect). Adapted from FICON (1992)

The curves depicted in Figure 1 are the accumulated effects at a given noise dose (L_{dn}). This distribution function can be derived by integrating a corresponding normal distribution density function. On the assumption that a normal distribution correctly describes the underlying continuum, some general remarks can be made about these and related dose-effect functions.[7]

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[7] Note, that even if it is assumed that the cumulative dose-effect curves for individuals are closer to a square-wave than to a normal distribution, a normal distribution for a larger sample may follow when the group average of the individual curves are formed.

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1. They have their greatest change in response (% Effect) per one unit change in noise level (Ldn) where the slope of the curve has its maximum value, which is where the 1st derivative has its maximum, which is around the L_{dn}-point where there is 50% Effect.

2. At the beginning of the dose-curve, there is only a small change in response per dose unit.

3. At the end of the dose-curve, when the effect approaches 100%, there should also be only a small change in response per dose unit. Quite a few dose-effect curves that have been proposed in the research literature show monotonous increases in the slope with increasing L_{dn}, and no point of diminishing returns. This is contrary to theoretical expectations, but is compatible with the assumption of an underlying normal distribution, if it is assumed that the curves with monotonous increases in slope only depict a restricted lower L_{dn}-range and do not include any points above the L_{dn}-point with the maximum slope).

4. Along the middle part of the ordinate (20-80% Effect), the ratio of change in response to one unit change in dose is rather narrow. In Figure 1 this ratio is around 3.

5. A parallel shift of the dose-effect curves along the abscissa, does not change its slope, i.e., does not change the 1st derivative.

6. A parallel shift of the dose-effect curves along the ordinate, does not change its slope, i.e., does not change the 1st derivative.

Thus, the estimates of how much can be gained in productivity and cognitive performance in adults by lowering the noise dose, can under the given assumptions, be reduced to locating an upper and lower L_{dn}-point and assess the slope of the line connecting them.

Transforming the measurement scales of the responses
The ordinate in Figure 1 is a measure of percent Effect, which as a rule is not reported in the original studies. However, in studies where two or more different noise levels have been reported and compared in how they affect performance, a crude <u>ratio</u> of performance improvement when switching to the lower noise level can be computed and entered into Figure 1 as a straight line downwards from the higher of the L_{dn}-values observed.

Figure 2 – Two hypothetical dose-effect relationships between

noise dose (L_{dn}) and percent effect (% Effect), and lines

depicting estimated slopes from different studies

As an example, in a study by Enmarker, Boman & Hygge (2002) long term recall (open-ended questions) and recognition (multiple choice questions) of a text read under 66 and 38 L_{Aeq} road traffic noise was studied. The mean recall scores for a group of teachers were 4.9 and 7.7 respectively. The improvement thus was 57%, stretching from 38 to 66 L_{dn}, which equates to close to 2 for the slope of the line below 68 L_{dn}, and shown as line 1 in Figure 2. For the recognition task the improvement was 8%, which is shown as line 2 in Figure 2.

There are pitfalls in making this crude conversion from performance scores to a cumulative curve with percent Effect, and in inferring percent impairment during a 24-hour day-night average implicit in the L_{dn}-measure from a 15-min exposure. However, the idea of pursuing this type of analysis is worthwhile. If the analysis comes out in an orderly way, some insights

may be gained from the underlying ideas, however crude the conversions were. One important criterion of the usefulness of this analysis is if the slopes for the interpolated straight lines are fairly equal within response types in comparable L_{dn}-regions, but differ between response types.

Response types

In the section above, results from an experimental study on recall and recognition in a memory task was employed as an example. Reviews of noise effects in other cognitive tasks (Cohen, Evans, Stokols & Krantz, 1986; Davies & Jones, 1985) noted that for serial reaction time tasks, tracking tasks, psychomotor tasks, vigilance, and various selective and sustained attention tasks, noise levels generally must be well above 85 dBA to produce significant impairment. This high noise level is well beyond conventional criteria for noise annoyance (see Figure 1), and even if the noise does not impair the tasks at hand, the noise is in strong conflict with most comfort criteria and should be abolished for that reason, or for their risk to hearing.

Attentional tasks generally have show a fairly high resistance to noise exposure. Often no impairment is reported with increased noise levels (cf. Cohen, Evans, Stokols & Krantz, 1986, p. 146 ff.). Notable exceptions are Hockey (1973) who showed more selectivity (approx. 12%) under noise (100 dBA) than in quiet (70 dBA) in a paced task, which is plotted as line 3 in Figure 2. Jones, Smith and Broadbent (1979) reported effects of noise (85 vs. 55 dBC continuous noise) on omission errors in a visual vigilance test. The ratio of performance in noise and quiet were approx. 3.0, which roughly corresponds to line 4 in Figure 2. Enmarker, Boman & Hygge (2002) reported a 13% increase in omission errors in a search and memory task. The corresponding line is entered as line 5 in Figure 2.

Memory and reading – field studies with children. There are no field studies of adults, noise, memory and reading, but there are such studies for children. Even though there are obvious discrepancies between children and adults, plotting the lines for children onto Figure 2 will add to the general picture of noise dose-effect relationships for cognition and could corroborate the findings for adults. In the Munich study of children (Hygge, Evans & Bullinger, 2002), children improved their long-term recall memory by approx. 25% when the old airport was closed. At the new airport the recall deteriorated by approx. the same amount from before to after the airport was taken into operation. The change in L_{Aeq} noise levels at the old airport from before to after was around 14 dBA. At the new airport the change was around 9 dBA. The corresponding lines (6, 7) are entered in Figure 2, and have about the same slope as recall for adults (line 1).

For the children's reading tasks in the Munich study the results were similar to those for recall, i.e. improvements when the old airport closed and impairments when the new airport opened. The corresponding lines are entered in Figure 2 (lines 8 and 9), and group together with the recall measures with regard to slope.

The noise levels reported for the Munich study are outdoor levels in contrast to the indoor levels given for the other studies in the present text. Thus, line 6-9 in Figure 2 should be shifted to the left by the amount of the sound insulation properties of the school buildings. Since that insulation factor is not known for the actual buildings, it was not done in Figure 2.

Memory – a study with young adults. The same procedure and experimental conditions as in the teacher study by Enmarker, Boman & Hygge (2002) was also employed in a study of young adults aged 18-20 (Hygge, Boman & Enmarker, in press). The results in the two studies were similar, but the degree of impaired recall from road traffic noise was more marked for the teachers than for the young adults. The lines for young adults are entered as lines 10 and 11 in Figure 2.

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Irrelevant sound and speech (ISS). Until now we have discussed noise in general without any reference to differences between noise sources in producing negative effects. However, such differences have been documented. In an experimental study (Hygge, in press) on children impairment in recall to noise sources of equal L_{Aeq}-levels were stronger for aircraft noise than for road-traffic noise, which in turn is stronger than for railroad noise.

When the noise is other people talking, the debilitating effects may be more dramatic than for transportation noise. Several well-replicated studies have shown that performance is impaired is speech is played back while subjects read and memorize verbal material (see e.g. Tremblay, Nichols, Alford & Jones (2000) for a recent overview). The effect or irrelevant speech is rather independent of its intensity, and has been reported from noise levels below 60 dBA. The meaning of the speech also seem to be unimportant, since the negative effect has been found with foreign languages, backward speech, as well as non-speech signals that have been made to have an acoustical variation in the signal that is similar to natural speech. This negative effect of speech and speech-like sounds seem to be on memory rather than on perception.

However, most of the research on ISS has employed a serial short-term memory recall task, and the pronounced negative effects seem to be more marked for serial recall tasks than for memory tasks that don't have a strong serial component. For instance, in the study by Enmarker, Boman & Hygge (2002) reported above, there was, in addition to the road-traffic noise group, also a irrelevant speech group, where the speech noise had the same L_{Aeq}-level as the same dBA vs. time envelope as the road-traffic noise. Recall and recognition scores for the irrelevant speech group were very close to those for the road-traffic noise group, and the same was true for the attentional search and memory task. Therefore the effects of irrelevant speech on recall, recognition and attention in Enmarker, Boman & Hygge (2002) have been inserted in Figure 2 with the very same values as for road-traffic noise (lines 12-14). In doing this and by drawing a straight line with a fixed slope for the dose-response relationship involving ISS, some doubt is expressed on extending the stated abruptness of the ISS-effect just below 60 dBA for serial short-term memory to long-term memory tasks that do not rely on serial memory.

Noise aftereffects – motivation. Studies of aftereffects of noise are concerned with how performance is affected after the noise has been shut off. The task performed in the first phase of the experiment, when noise is present, is unrelated to the task performed in the second phase, which is in silence. Thus, there is nothing to be learned from the first noisy phase that can be used in the second silent phase. In such studies there is no learning situation, but any effects of the noise on the subsequent tasks in the silent phase, must have to do with a more general impact on motivation and persistence. Glass and Singer (1972) introduced studies on the aftereffects of noise. In the first phase of the experiment one group was exposed to noise while working on a relatively simple cognitive task, such as or adding numbers or finding the letter A in a lists of letters or words. Compared to a silent control group this noise did not affect how good these tasks were performed. After the noise was shut off, the subject switched to another task, often endurance in solving insoluble geometrical puzzles, and sometimes proof reading of a text prepared with errors. Having encountered noise in the first phase reliably impaired the performance of these tasks. In addition to a silent control group and a noise group, Glass and Singer also had a noise group where the predictability of the noise bursts was high or where the subjects were given control over the noise source. Predictability was manipulated by letting the noise bursts come at fixed intervals and with fixed duration. Perceived control of the noise was introduced by a button next to the subject and the instruction to use it to shut off the noise if it became too disturbing, an opportunity almost no subject took advantage of. The predictability of the noise bursts or having been given perceived control over the noise reduced the noise aftereffects to that of the silent control group.

After Glass and Singer published their original work, a number of studies have replicated the aftereffects. More generally it has been shown that the aftereffects of uncontrollable and/or unpredictable stress is not restricted to noise, but has been shown also for indoor environment variables, crowding and work load (Cohen, 1980).

In the same way as for the ISS-effects there seem to be an abrupt rather than gradual onset of the aftereffects with increases in noise levels. Another similarity to the ISS-studies is the fact that quite a few of the noise aftereffect studies that have reported significant effects resulting from the manipulation of the control dimension have employed sounds that have irrelevant speech as an important ingredient.

Conclusions
In evaluating Figure 2 the important thing is to look at the slopes of the lines from the different studies. The placement of the line in relation to the abscissa and the ordinate is not as important as the slope of the lines.

The studies on recall and reading cluster together and have slopes around 2. Studies on recognition and attention also group together and have slopes on the region of .25.

Thus, for recall and reading in noise it can be expected that a reduction of the noise level by 5 L_{dn} would result in improved performance by something like 10%, at least when the reduction starts within the region 65-80 L_{dn}. For attentional tasks and for recognition memory, a 5 L_{dn} reduction in noise level is expected to only result in 2-3% improvement of the response.

On the surface of it, it looks as if the left dashed dose-effect curve in Figure 2 can be applied to recall and reading, and that the dose-effect curve to the right (solid lines) comes closer to the noise effects on attention and recognition.

However, as evidenced by the results from ISS-studies and aftereffect studies, the character of the noise source and the motivational effects induced by the setting in which the noise occurs, are important determinants of the response magnitudes that are not easily incorporated into the quantification of the noise dose.

Lastly, the approach outlined in the present paper, employing the slope or the 1st derivative of does-effect functions, is at a preliminary stage. The strengths and weaknesses of the approach will become clearer when the effort is taken to add more empirical studies into the analyses.

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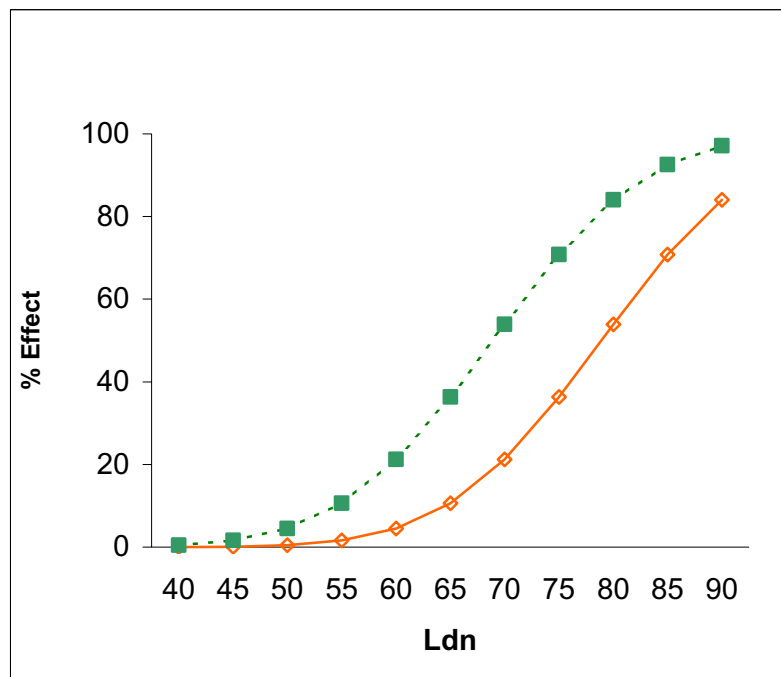
Figure 1. Dose-effect curves adapted from the USAF annoyance function in FICON 1992 (solid line) and by adding 10 L_{dn} to that function (dashed line).
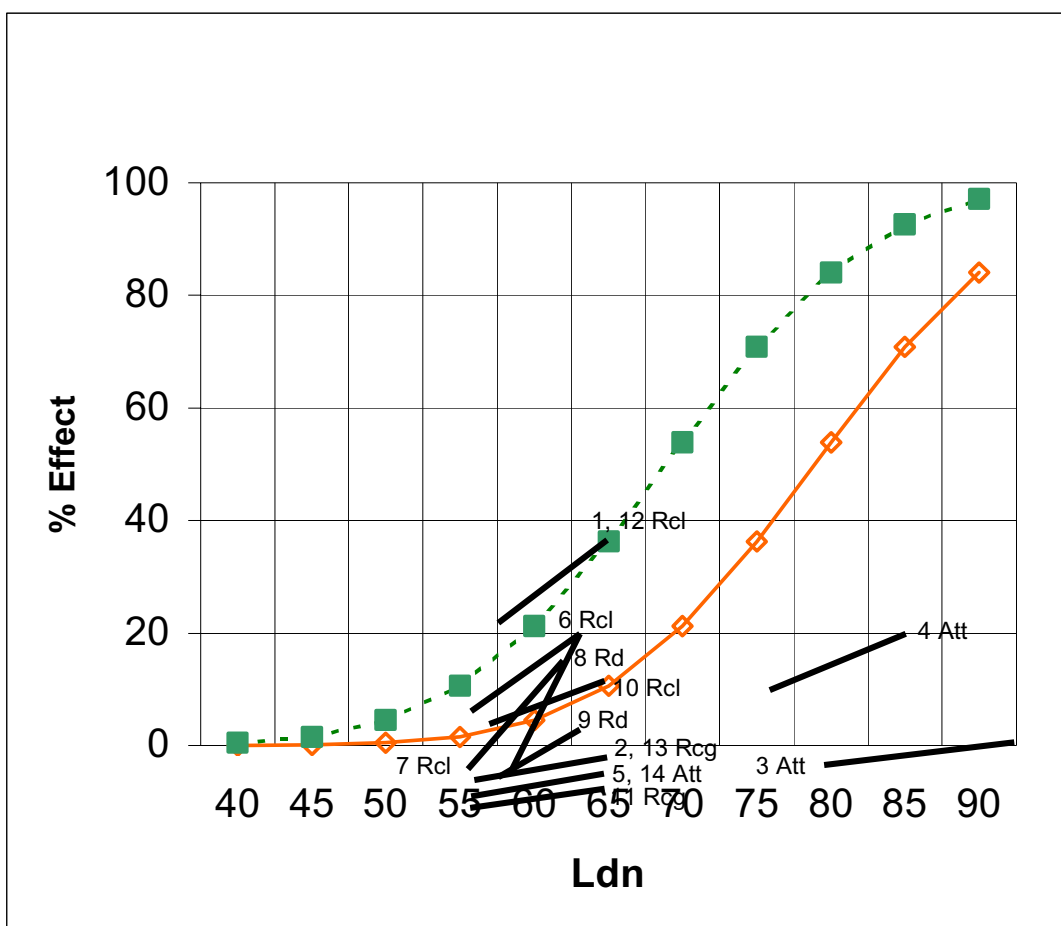
Figure 2 – Hypothetical dose-effect curves and approximated results from different studies. Rcl = recall, Rcg = recognition, Rd = reading, Att = attention.

Studies indexed by numbers

1   Recall, Enmarker, Boman & Hygge, 2002

2   Recognition, Enmarker, Boman & Hygge ,2002

3   Attention selectivity, Hockey, 1973

4   Attention vigilance, Jones, Smith & Broadbent, 1979 exp 4

5   Attention, search and memory task, Enmarker, Boman & Hygge, 2002

6   Recall children, Old airport, Hygge, Evans & Bullinger, 2002

7   Recall children, New airport, Hygge, Evans & Bullinger, 2002

8   Reading children, Old airport, Hygge, Evans & Bullinger, 2002

9   Reading children, New airport, Hygge, Evans & Bullinger, 2002

10   Recall young adults, Hygge, Boman & Enmarker, in press

11   Recognition young adults, Hygge, Boman & Enmarker, in press

12   Irrelevant speech, recall, Enmarker, Boman & Hygge, 2002

13   Irrelevant speech, recogntion, Enmarker, Boman & Hygge, 2002

14   Irrelevant speech, attention, search and memory task, Enmarker, Boman & Hygge, 2002

Noise exposure from various sources - cognitive effects on children

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Executive Summary

- Children are vulnerable to noise effects because noise may interfere with learning during a critical developmental period, and children have less capacity than adults to anticipate, understand or cope with stressors.
- Tasks that involve central processing and language comprehension, such as reading, attention, problem solving and memory appear most influenced by noise exposure.
- Noise effects have been studied in both preschool and primary school aged children
- In school children exposed to noise, deficits in sustained attention, visual attention, concentration, poorer auditory discrimination and speech perception, memory impairment and poor reading ability and school performance have been demonstrated.
- Intervention studies suggest that noise reduction may improve cognitive deficits.
- In the Munich study impairments in reading comprehension and long term memory declined after the Old Airport was closed but appeared in a new group of children exposed to noise after the new airport opened.
- Noise exposure reduces motivation in difficult tasks and has equivocal effects on mental health.
- Studies of standardised reading tests in large numbers of schools exposed to a gradient of noise exposure suggest a dose-response association between noise and reading comprehension.
- Laboratory experiments suggest cognitive impairments may be greater at high noise intensity.
- Aircraft noise exposure is related to greater noise annoyance responses in children.
- Noise exposure at home as well as at school may impact on children's learning.
- Evidence on groups of children more at risk for cognitive effects attributed to noise is equivocal
- Impairment of cognitive functions by noise may be mediated by impairment of attention, auditory discrimination and speech perception. Teacher communication difficulties and learned helplessness may also explain cognitive deficits related to noise.

Introduction

Studies on whole populations often do not find substantial associations between environmental noise exposure and wellbeing and health. Nevertheless, there is considerable concern about the effects of noise and some studies suggest substantial effects of noise. This apparent paradox may be explained by differential susceptibility to noise effects across the population. Susceptibility within the population may be explained in several different ways. Either in terms of settings where noise is particularly disturbing (eg hospitals, schools), or vulnerable people (e.g. those with existing physical or mental illness, or withdrawing from drugs) or critical periods: life stages where because of rapid developmental progress, or failing faculties, exposure to noise may be especially stressful or, finally, associated with task performance in which noise may especially interfere. The best evidence of increased vulnerability to noise comes from studies of children where there may a combination of critical life stage, school context and learning tasks vulnerable to interference by noise. Children may also be more susceptible to environmental stress than adults for a variety of other reasons including: less cognitive capacity to understand environmental issues and anticipate stressors and a lack of well-developed coping repertoires (Cohen et al, 1986; Evans et al, 1991). It is possible that impairments of early childhood development and education by environmental pollutants such as noise, may have life long effects on achieving academic potential and health (Evans et al, 1991).

Studies in the laboratory have found that experimental exposure to noise may influence performance on complex tasks in adults, may also impair memory, and may lead to the adoption of different performance strategies when exposed to noise (Smith & Broadbent, 1992). This work led to the examination of the effects of noise on cognitive performance in children.

Cognition

The most consistent effects of noise found in children are cognitive impairments, though these effects are not uniform across all cognitive tasks (Cohen et al, 1986; Evans et al, 1991; Evans & Lepore, 1993). Tasks which involve central processing and language comprehension, such as reading, attention, problem solving and memory appear to be most affected by exposure to noise (Cohen et al, 1986; Evans & Lepore, 1993;

Evans et al, 1995; Hygge, 1994). The effect of environmental stressors with high processing demands on cognitive tasks is widely accepted in the environmental stress literature examining the effects of a wide range of environmental stressors on cognition (Cohen et al, 1986; Smith, 1989).

Noise effects in pre-school children

In pre-school children, Wachs & Gruen (1982) have accumulated data across cross-sectional and longitudinal studies indicating an inverse association between noise levels at home and cognitive development in children from 6 months to 5 years of age. Measures of cognitive development affected by noise include mental representations of objects, the use of objects as tools to achieve goals, and relating words to objects (Evans and Lepore, 1993).

Noise effects in school children

Most research has, however, been carried out in primary school children, aged 5 to 12 years. This is a critical learning acquisition period for children in which future learning patterns are established. The effects of chronic noise exposure at home and school have also been examined in recent well designed studies that have direct relevance to health of children in the community.

In environmental noise studies, examining the effects of chronic aircraft, rail and road traffic noise on school children's cognitive performance, the following results have been found in children exposed to high levels of environmental noise:

1) Deficits in sustained attention and visual attention (Haines et al, 2001a; Hambrick-Dixon, 1986; Hambrick-Dixon, 1988; Heft, 1979; Karsdorf and Klappach, 1968; Kyzar, 1977; Moch-Sibony, 1984; Muller et al, 1998; Sanz et al, 1993).

2) Difficulties in concentrating for noise exposed children compared to children from quieter schools according to teachers' reports (Crook and Langdon, 1974; Ko, 1979; Ko, 1981; Kryter, 1985).

3) Poorer auditory discrimination and speech perception (Cohen et al, 1973; Kyzar, 1977; Cohen et al, 1980; Cohen et al, 1986; Evans et al, 1995; Evans and Maxwell, 1997).

4) Memory impairment for tasks that require high processing demands (Fenton et al, 1974; Evans & Lepore, 1993; Evans et al, 1995; Hygge, 1994; Hygge et al, 1996).

5) Poorer reading ability and school performance on national standardised tests (Michelson, 1968; Cohen et al, 1973; Bronzaft and McCarthy, 1975; Maser et al, 1978; Bronzaft, 1981; Lukas et al, 1981; Green et al, 1982; Evans et al, 1995; Evans and Maxwell, 1997; Haines et al, 2001a,b).

Some of the earlier research studies examining noise effects in children have methodological flaws that limit the conclusions that can be drawn from the data. Problems with these studies include: lack of prospective studies, in fact most studies were cross-sectional; lack of evidence of socioeconomic matching between noise exposed children and control samples of children not exposed to noise (Heft, 1979; Karsdorf and Klappach, 1968; Kyzar, 1977); inadequate sample sizes - a fault of many of the available studies; insufficient schools to exclude the effects of school quality confounding the effects of noise exposure on cognition (Cohen et al, 1980; Cohen et al, 1981; Cohen et al, 1986; Sanz et al, 1993; Haines et al, 2001a) and statistical techniques that were too crude (Sanz et al, 1993). The results from field studies that control for socioeconomic factors, show that chronic noise exposure is consistently and reliably associated with cognitive impairments in school children (Cohen et al, 1973; Cohen et al, 1980; Evans et al, 1995; Evans et al, 1998; Haines et al, 2001a).
This field of research in children was initiated by Cohen and colleagues who carried out a naturalistic field study of elementary school children living in four 32-floor apartment buildings located near an expressway (Cohen, Glass & Singer, 1973). The sample of 73 children were tested for auditory discrimination and reading level. Children living on lower floors of the 32-storey buildings (i.e. exposed to higher noise levels) showed greater impairment of auditory discrimination and reading achievement than children living in higher-floor apartments.

Using a similar naturalistic paradigm Bronzaft & McCarthy (1975) compared reading scores of elementary school children who were taught in classes on the noisy side of a school near a railway line with the scores of the school children in classes on the quiet side of the same school. They found that children on the noisy side of the school building had poorer performance on the school achievement tests than those taught in classes on the quiet side of the school. The mean reading age of children in the classes on the noisy side of the school was three to four months behind the children in the low noise exposed classes. A strength of Bronzaft & McCarthy's (1975) results is that they cannot be attributed to self-selection of children into one school rather than another, a methodological problem found in many field studies, because the noise effects were found in the same school. Neither could the results be explained by selection of more able children into quieter classrooms as children were not assigned in any systematic manner to classrooms on the noisy or quiet side of the school.

In further studies impaired performance on a difficult cognitive task was found in primary school children aged 8-9 years in a well-controlled naturalistic field study around Los Angeles Airport that involved both cross sectional (Cohen et al, 1980) and longitudinal analyses (Cohen et al, 1981). Cohen and colleagues (1980) concluded that their results were strikingly similar to those reported in the laboratory setting, but that replication was required before definitive conclusions could be reached. In a recent United Kingdom repeated measures field study these results were confirmed around Heathrow Airport comparing the cognitive performance and stress responses of children aged 9-10 attending four schools exposed to high levels of aircraft noise (>66 dBA 16hr Leq) with children attending four matched control schools exposed to lower levels of aircraft noise (<57 dBA 16hr Leq) (Haines et al, 2001c). Children tested at baseline were re-tested a year later at follow-up. The results indicated that chronic exposure to aircraft noise was associated with impaired reading comprehension and sustained attention after adjustment for age, main language spoken at home and household deprivation (Haines et al, 2001a). The within subjects analyses adjusting follow-up performance for baseline performance indicate that children's development in reading comprehension may be adversely affected by chronic aircraft noise exposure (Haines et al, 2001c).

The results of small scale comparisons between schools exposed to aircraft noise and less exposed schools may be compromised by variations in performance between schools unrelated to noise

exposure. Studies of routinely collected standardised tests and noise exposure information obtained from contour maps, although necessarily less precise in capturing true exposure and well controlled assessments of performance allow for a large number of schools to be studied economically. The results of such a study employing multi-level modelling to analyse routinely collected national standardised scores of school performance in relation to aircraft noise around Heathrow airport for 11,000 scores of children aged 11 suggested that aircraft noise is associated with school performance in reading and mathematics in a dose-response function. However, adjustment for social disadvantage, in terms of eligibility for free school meals, tended to eliminate this association. However, this may be overadjusting for factors that determine exposure to noise (Haines et al, 2002). Further details of this study is reported in the dose-response section. These performance results replicate an earlier study examining standardised school performance scores conducted around New York City airports (Green et al, 1982).

Stronger evidence to suggest the existence of noise effects on cognitive performance comes from intervention studies and natural experiments where changes in noise exposure have been accompanied by changes in cognition. To date, there have been three studies examining the effects of noise reduction on children's cognition: two intervention studies (Bronzaft, 1981; Cohen et al, 1981) with methodological flaws that limit their generalisability and one well-designed natural experiment: the Munich Airport Study (Evans et al, 1995; Hygge et al, 1996; Evans et al, 1998). The most convincing evidence for noise related cognitive effects has come from the prospective longitudinal natural experimental field research around Munich Airport in children with a mean age of 10.8 years (cross-sectional results, Evans et al, 1995; longitudinal results, Hygge et al, 1996). In 1992 the old airport in Munich closed and a new airport was opened. The cross-sectional results indicated an association between high noise exposure and poor long term memory and reading comprehension (Evans et al, 1995). Longitudinal analyses, after three waves of testing, indicated improvements in long term memory after closure of the old airport. Strikingly, these effects were paralleled by impairment of the same cognitive skills after the new airport opened (Hygge et al, 1996).

Motivation

One possible cause for decrements in cognitive performance among children exposed to high levels of aircraft noise may relate to the impact noise has on task motivation. Much of this research was initially stimulated by Glass and Singer's laboratory experiments in adults (Glass & Singer, 1972).
Chronic exposure to aircraft noise in the field has been associated with decreased motivation in school children (Cohen et al, 1980; Cohen et al, 1981; Cohen et al, 1986; Evans et al, 1995) although the results are not consistent (Haines et al, 2001a). In the Los Angeles Airport Study, motivation was measured as persistence on a difficult cognitive task that was preceded by a success or failure experience (Cohen et al, 1980). They found that children in the high noise exposed schools had poorer performance on soluble and difficult test puzzles and were more likely to give up on a difficult puzzle than the children in quiet schools (Cohen et al, 1980). A year later at follow-up they replicated these results, but did not find an effect of noise on rate of giving up carrying out the puzzle task (Cohen et al, 1981). With a new sample of school children around Los Angeles airport, Cohen and colleagues found that children in noisy schools failed a difficult puzzle more frequently and showed greater abdication of choice of rewards than the children from the quiet schools (Cohen et al, 1986). In Munich, children chronically exposed to high noise persisted less with an insoluble puzzle (Glass et al, 1972) than the control group of low noise exposed children (Evans et al, 1995). This motivation effect may either be independent or secondary to noise related cognitive impairments or may indeed contribute to noise related cognitive impairments.

Mental Health and Stress Responses
There have been only a few studies that have examined child psychological disorders in relation to noise. Nurmi & von Wright (1983) when studying the interactive effects of noise, neuroticism and learning in school children, found that noise during learning impaired the subsequent recall performance of children with high neuroticism scores and children with a high scores on state-anxiety. Poustka and colleagues (1992) studied the psychiatric and psychosomatic health of 1636 children aged 4 to 16 in two geographical regions that differed according to the noise made by jet fighters frequently exercising at low altitude. Psychological and neurological outcomes were not related to noise exposure. They found that certain associations with noise could be demonstrated in depression

and anxiety but only beneath the threshold of clinical significance. These results are unconvincing because the areas differed socioeconomically and the results were not adjusted for socioeconomic factors and also because there was no adequate measure of the noise exposure. Chronic aircraft noise exposure was not associated with anxiety and depression (measured with psychometrically valid scales), after adjustment for socioeconomic factors, in the Schools Health and Environment Study around Heathrow Airport (Haines et al, 2001a). However, in Munich, children living in areas exposed to high aircraft noise had lower levels of psychological well-being than children living in quieter environments (Evans et al, 1995). The longitudinal data from around Munich show that, after the inauguration of the new airport, the newly noise-exposed communities show a significant decline in self-reported quality of life, after being exposed to the increased aircraft noise exposure for 18 months (third wave of testing), compared with a control sample (Evans et al, 1998). 'Quality of life' impairment is a different, less severe impairment than mental ill-health. In the West London Schools Study chronic aircraft noise exposure was associated with hyperactivity measured by the Strengths and Difficulties Questionnaire (Haines et al, 2001b). As this was an isolated finding, not found in the earlier Schools Health and Environment Study, it needs further research to confirm or refute this finding. A recent Austrian study has found that exposure to road and rail traffic noise was associated with poorer classroom behaviour and poor self reported child mental health derived from the Kindl Quality of Life Scale (Lercher et al, 2002). However, ambient noise was only associated with poorer mental health in children with low birth weight or pre term birth. These studies suggest that overall noise is probably not associated with serious disturbance of child mental health, however it may affect child stress responses and sense of well-being and there is a need for further research.

Exposure-Response Relationships
Demonstration of dose- response relationships is an important element in confirming causal associations between noise and health outcomes. In general, noise dose is thought of in terms of noise intensity. It may also be reasonable to consider duration of noise exposure as another aspect of dose.

Studies of aircraft noise and standardised reading tests
There have been several studies analysing aircraft noise exposure and its relationship to scores on standardised reading tests and the lack of individual noise exposure data. The advantage of these studies is that large numbers of schools can be included but the disadvantage is the crudeness of the standardised tests. The first of these studies was carried out by Green, et al (1982) in New York relating noise exposure scores based on noise exposure forecast contours for New York City Airports and relating that to the percentage of students reading below grade level between 1972 and 1976. Naturally, social disadvantage will be a powerful predictor of poor reading and this was adjusted for in terms of the percent eligible for free lunch programmes as well as adjustments for the percentage of students in each of five ethnic groups, the absentee admissions and departure rates, the pupil teacher ratio and the percentage of teachers with five or more years experience, as well as the percent of teachers on pay scales which reflect the amount of their post school education. The percent of students reading below grade level in each grade was regressed on the independent variables for each of the years 1972-76 and for all five years combined. The partial regression coefficients for the noise scale variables were all positive and were statistically significant at the 0.05 probability level in 15 of 18 regressions. A summary coefficient, with appropriate weighting, of 0.62 (95% CI, in 0.51-0.74) was estimated, suggesting that a one unit increase in noise score would be accompanied by an increase of 0.62% in the number of students reading one or more years below grade level in an average school. The authors described the data as largely compatible with a linear dose response relationship between noise exposure and percent reading below grade level. The mean difference in the percent reading one or more years below grade level in the noisy schools, compared to the quietest schools, was 3.6% (95% CI 1.5-5.8).

There are several limitations to this study, the crudeness of the noise exposure scale, the possibility that pupils transfer from schools across noise zones and, therefore, have a varied history of noise exposure, the crudeness of the variables used to assess confounding and the aggregate nature of the statistics which fails to take into account individual differences in reading ability. Nevertheless, these results are striking and it could be argued that were the methodological errors soluble, the size of the effect would be likely to be larger, rather than smaller.

Case Study
A further study with similar methodology has been carried out recently around Heathrow Airport (Haines, et al, 2002). This cross-sectional study used United Kingdom national standardised scores (SATS) in Mathematics, Science and English from 11,000 children, approximately 11 years old, from 123 schools in three boroughs surrounding Heathrow Airport. The samples were in the final year of primary school and had completed the Key Stage 2 SATS exams in 1996 and 1997. The areas examined included the Boroughs of Hillingdon, Hounslow and Windsor and Maidenhead. Aircraft noise exposure, from aircraft taking off from and landing at Heathrow Airport,was assessed by the published 1994 Civil Aviation Authority dBA Leq 16 hr contour maps, indicating the average continuous equivalent sound level of aircraft noise within a particular area for 16 hour daily periods during 15th June - 15th September. Each school was classified into one of eight noise exposure levels from (<54 dBA Leq to a >72 dBA Leq). Multi-level modelling was used to assess the impact of aircraft noise exposure on SATS scores.

At the school level the following potential confounding factors were adjusted for in the analysis: percentage of pupils eligible for a free school meal, percentage of pupils statemented with special needs, percentage of pupils with English as a second language and type of school (Government, Church, Grant Maintained). At the individual level, the tests scores for English sub-tests, including spelling, handwriting, creative writing and reading, mathematics and science were also included and sex, year of testing and date of birth (1997 sample only) were also adjusted for.

In English there was a statistically significant trend of decreasing raw mean scores across increasing noise exposure. However, after adjustment for type of school, year of testing and sex of the child, the association was no longer significant. However, a closer analysis of the sub-scales of the four English tests showed that aircraft noise exposure affected performance on the reading test more than the other sub-tests, as might be expected from other studies finding impairments of reading comprehension associated with aircraft noise exposure (see Figure). As noise level increased by contour band, performance in reading dropped by 0.42 of a mark. However, after adjustment for social disadvantage, measured as the percentage of pupils eligible for free school meals, the noise effect was lost.
Noise level was also significantly related to mathematical performance which was not anticipated as mathematics was introduced as a control outcome (see Figure). As noise level increased by contour band, performance dropped by 0.73 of a mark. However, after adjustment for percentage of pupils eligible for free school meals the association became no longer statistically significant. There was no association between science scores and noise exposure.

The diminution of noise effects following adjustment for level of social disadvantage might be because socioeconomic status is confounding the association between noise and school performance. In this interpretation noise exposure could be a marker for a socioeconomic effect on performance. On the other hand, adjustment for social disadvantage might be over-adjustment because this statistical method does not take into account the broader ecological context in which environmental stressors, such as noise exposure, exist. In this case, noise exposure, as an aspect of the local environment, may be a mediating factor in the association of social deprivation and performance. Although this study shares many of the methodological limitations of Green's study, relying on aggregate exposure and outcome data, the standardised assessment tests do have better reliability, the multi-level modelling is a more appropriate statistical technique to assess these effects, and the opportunity to have the control outcomes of science and mathematics is an important methodological innovation. These studies do show strong associations between aircraft noise level and standardised school performance outcomes. However, it is difficult to prove from these studies that noise exposure is the causal factor in impairment of reading and also difficult to disentangle the effects of noise and social disadvantage on performance.

Short-term noise exposure in the laboratory
Another way that noise dose has been studied has been in 'classroom' laboratory experiments where the intensity of the noise exposure can be manipulated. In studies of 12-14 year old children, aircraft road, train or verbal noise were played back at 66dBA to each class and long term recall and recognition were assessed (Hygge, 1997). In further experiments aircraft noise and road traffic noise were played back at 55 dBA. At 66 dBA recall was impaired by aircraft and road traffic noise but not by train or verbal noise. At 55 dBA aircraft noise still impaired recall but road traffic noise did not.

On the whole these results suggest that memory impairments are related to the intensity of noise exposure, and that recall is disturbed more by aircraft noise than road traffic noise.

Noise annoyance reactions in children

Noise exposure has been linked to annoyance and diminished quality of life in children (Bronzaft & McCarthy, 1975; Cohen et al, 1980; Evans et al, 1985). This could be interpreted as a chronic affective response indicating impaired well-being or even physiological arousal and it is plausible that noise annoyance could be a mediating factor intervening between noise exposure and cognitive impairment. In the Schools Health and Environment study children from schools exposed to chronic aircraft noise had significantly higher annoyance scores than children from matched schools not exposed to aircraft noise (Haines et al, 2001a).

Noise annoyance in this study was measured with seven child adapted standard questions asking about four sources of environmental noise: aircraft noise, train noise, road traffic noise and neighbours noise at home. The validity of this finding was enhanced because children from high aircraft noise exposed schools did not differ from the low aircraft noise exposed school children in terms of annoyance to the other sources of environmental noise, where there was no reason to expect exposure to road traffic, train or neighbours noise would be different between schools. The effect of aircraft noise on annoyance remained after further adjustment for social class, as well as social disadvantage, age and main language spoken at home. Moreover, there was little association between parental annoyance and child annoyance, suggesting that the children's responses were not merely echoing the parental attitudes and responses. The association between chronic aircraft noise exposure and annoyance in 8 to 11 year old children was replicated in a further study of 451 children in schools around Heathrow Airport in the West London Schools Study (Haines et al, 2001b).

Noise Sources

The noise source in the majority of studies examining the cognitive effects due to noise has been aircraft noise (Cohen et al, 1980; Evans et al, 1995; Haines et al 2001a,b). Aircraft noise, because of its intensity, the location of the source, and its unpredictability is likely to have a greater impact on children's health and cognition than other noise sources. In particular, in aircraft flyovers the noise has an unpredictable rise time that may attract attention and distract children from learning tasks. In studies of adults, aircraft noise is generally more annoying than road traffic or train noise. This may partly be related to the greater fear or threat induced by aircraft noise sources than by road or rail noise sources. In addition, aircraft noise is usually more difficult to avoid than noise from terrestrial transport.

Nevertheless, train noise and road traffic noise have also been associated with cognitive effects and thus there is no reason to suppose that cognitive effects of noise are specific to aircraft noise (Cohen et al, 1973; Bronzaft and McCarthy, 1975). Traffic noise exposure is, however, more difficult to measure in field studies than train or aircraft noise. Exposure may vary by distance from the source, type of road, type of vehicle and time of day. Also because the road traffic noise source is usually close to the ground noise exposure may be masked by intervening barriers such as buildings that do not influence aircraft noise in the same way.

Periods and Times of Exposure

The assumption behind studies that select schools as the primary focus of noise exposure is that noise exposure during the school day has the most important effects on cognitive performance. However, primary age children attending noise exposed schools usually live in noise exposed homes (Haines et al, 2001a,b). In addition, the Munich study selected children on home, not school, noise exposure. It is not known, therefore, whether aircraft noise exposure outside school hours, perhaps especially in the early morning or late at night might not also have an impact on children's leaning and school performance. This is plausible for three reasons. First, effects on performance have been demonstrated in adults that persist after noise exposure has finished, secondly, noise exposure levels in the playground or on the journey to school may be louder than those experienced in school, and thirdly, learning, especially language development may occur as much at home as at school.

Another concern regarding noise sources is the metric chosen to assess noise exposure. There is convenience and easy comparability in selecting an averaged noise dose measure such as LAeq.

However, in pathophysiological terms it is not clear whether overall 'dose' of noise exposure is important in determining noise effects on cognition or whether the peak intensity of events, or the number of events may be more important. Mechanisms for noise effects that depend on frequent distraction by noise might be more influenced by number of noise events than overall noise energy levels. As long as noise events, say aircraft flyovers, reached a threshold of intensity to interfere with attention, the peak intensity of the noise events might not matter, However, in the West London Schools Study, the number of events (aircraft flyovers) had no more impact than overall LAeq (Stansfeld & Haines, 2000).

The effects of length of exposure
An important question is whether length of exposure to noise is associated with increasing effects on cognitive performance or whether a threshold is reached beyond which further noise exposure no longer has an addditional detrimental effect. The early follow up study of Cohen et al (1986) did suggest that the cognitive effects had increased over the follow up period of a year. The follow up of the Schools Environment and Health Study found that the difference in reading comprehension between the noise exposed and quiet schools increased during the year's follow up period (Haines et al, 2001c). This is not sufficient evidence to test whether there is a continuing decrement in performance with chronic noise exposure or a threshold effect - that would need several waves of follow up in a population where the noise remained moderately constant. However, even with the existing evidence it does seem that prolonged exposure is associated with greater effects on cognitive performance than shorter exposure periods although further evidence is needed to confirm this.

Identification of risk groups
Although there are overall trends showing that chronic exposure to noise is associated with impaired cognition over a range of functions, there may be individual differences in these effects. Some children in the population may be more vulnerable to noise effects than others. There is limited evidence that children who have lower aptitude (Maser et al, 1978; Johansson, 1983; Cohen et al, 1986) or other difficulties such as learning difficulties (Lasky et al, 1973; Glenn et al, 1978) and cerebral palsy (Laraway, 1985) may be more vulnerable to the harmful effects of noise on cognitive performance. The evidence is not conclusive because some studies have not found any noise effects with learning disabled and hyperactive children (Fenton et al, 1974, Nober, et al 1975; Steinkamp, 1980). However, the findings will depend on the sensitivity of the tests for the various populations.

Evans and Lepore (1993) claim that noise effects seem to be more pronounced in children from the upper elementary grades compared with their younger counterparts (Cohen, et al 1973, Evans et al, 1991, Green et al 1982, Lukas et al, 1981, Maser et al, 1978). Cohen and colleagues (1986) found that the longer the children had been attending the noisy schools, the stronger the effects. This age related trend may be due to several reasons. Children in the upper grades generally have had longer noise exposure. It is also possible that cognitive measures may be more sensitive for older children and thus more reliable in measuring the harmful effects of noise. Although Evans & Maxwell (1997) found a significant noise effect on reading in children in younger grades (grades 1 and 2), it may be that the earlier studies did not detect noise effects in younger children because it is harder to reliably measure reading and school performance in younger children. It is still an open question as to when noise exposure begins to affect children's cognitive functioning.

Given that there are known existing gender differences in various health and performance outcomes, it is possible that noise affects boys and girls differentially. Smith & Jones (1992) claim that there is inconclusive evidence for gender differences in adults. In children the pattern of results is equally inconclusive and contradictory. Hambrick-Dixon (1988) found that high levels of acute train noise significantly affected the attention of girls aged 5 -7 years, but had no effect on boys' attention. Christie & Glickman (1980) have also found that girls may be more distracted by acute noise exposure. In studies of young children and infants, it would seem that boys are more susceptible to chronic noise related problems in comparison with girls (Wachs, 1978; Wachs, 1987).

Possible Mechanisms of Noise Effects
The research evidence outlined above focused on how noise directly affected outcome variables but did not approach the question of how these variables might be linked. This leaves us with the critical question of how does one explain the link between chronic exposure to noise and these adverse effects

on child cognition and health? The theoretical understanding of child noise effects is very limited, and is largely based on acute experimental research with adults. Only three studies (Cohen et al 1973; Evans et al 1998; Haines et al 2001c) have actually tested the role of hypothesised mediating factors. The identification of mechanisms not only has relevance for theoretical understanding of noise effects, but also for intervention strategies to reduce the adverse noise effects (e.g educational interventions).

Children may adapt to noise interference during activities by filtering out the unwanted noise stimuli. This tuning out strategy may over-generalise to all situations when noise is not present, such that children tune out stimuli indiscriminately. This 'tuning out' response is supported by the findings that children exposed to noise have deficits in attention, auditory discrimination and speech perception (Cohen et al, 1973; Moch-Sibony 1984; Evans et al 1995). Under some circumstances these strategies may be detrimental and it has been hypothesised that the impairments in **attention**, **auditory discrimination** and **speech perception** may mediate the association between noise and child cognitive performance. There is preliminary evidence that the association between noise and reading performance is mediated by psycholinguistic mechanisms, specifically: auditory discrimination (Cohen et al, 1973) and speech perception (Evans et al, 1997). There is evidence that noise related reading effects are not mediated by sustained attention (Haines et al, 2001c) and sound perception (Evans et al 1997).

Teacher frustration and communication difficulties could also be mechanism for cognitive and motivation effects (Evans et al 1991). Chronic noise exposure may also affect communication in the classroom which makes it more difficult for children to learn and teachers to teach and may lead to frustration, interruption in speech and reduced instruction time (Bronzaft et al 1975; Bronzaft, 1981).

Learned Helplessness has been proposed as a mechanism to account for the motivation effects (Cohen et al 1980; Evans et al, 1993; Evans et al, 1995). The mechanism to account for the effects of noise exposure on children's annoyance is considered to be the same stress mechanism proposed to account for the adult noise effects. Most of the child noise research has been exploratory and cross-sectional, which means that future research needs to examine the explanatory power of these cognitive and motivation mechanisms. In addition, the inter-relationship between psychophysiological responses and cognitive noise effects needs to be examined.

Needs for further research

There is still a considerable amount to learn about these associations. Exposure-response relationships will be informative. Further clarification of dose-response relationships for both aircraft and road traffic noise exposure will be provided by new studies in progress, such as the RANCH Study. The impact of night time noise exposure on sleep and children's daytime performance has not been assessed. Most studies have been carried out at schools and have not focussed on home noise exposure. Moreover, night-time noise tends to less of a problem than day time exposure.

Long term effects are potentially very important and will need several waves of data collection to assess thoroughly. Another area that must be considered is whether other sources of noise within the classroom, such as children talking, or air conditioning fan noise, and the interaction with classroom acoustics, will affect learning. Additionally, it would be helpful to understand whether particular activities carried out by children are more or less influenced by noise and what children and teachers can do to overcome any such effects. Further studies are also needed on sound insulated schools to determine whether they have a protective effect against noise-related cognitive impairments.

Conclusions

There seems to be sufficient evidence that noise exposure impairs cognitive performance, especially for complex tasks such as reading comprehension and long term memory. There is also evidence from both laboratory studies and large field studies using standardised reading tests that these are dose-response relationships although the role of social deprivation in these studies needs to be explained.

Definite evidence for the mechanisms of cognitive impairments induced by noise is still awaited although, narrowing of the attentional focus, impairments of auditory discrimination and speech perception and communication difficulties in the classroom and learned helplessness seem to be plausible candidates.

Greater specification of dose response relationships is an important step towards confirming a causal role for environmental noise exposure in impairments of children's cognition. It this were combined with a greater understanding of the mechanisms underlying these noise effects the way would be open to develop interventions to reduce these effects and the rationale would be clear for the reduction of noise at source.

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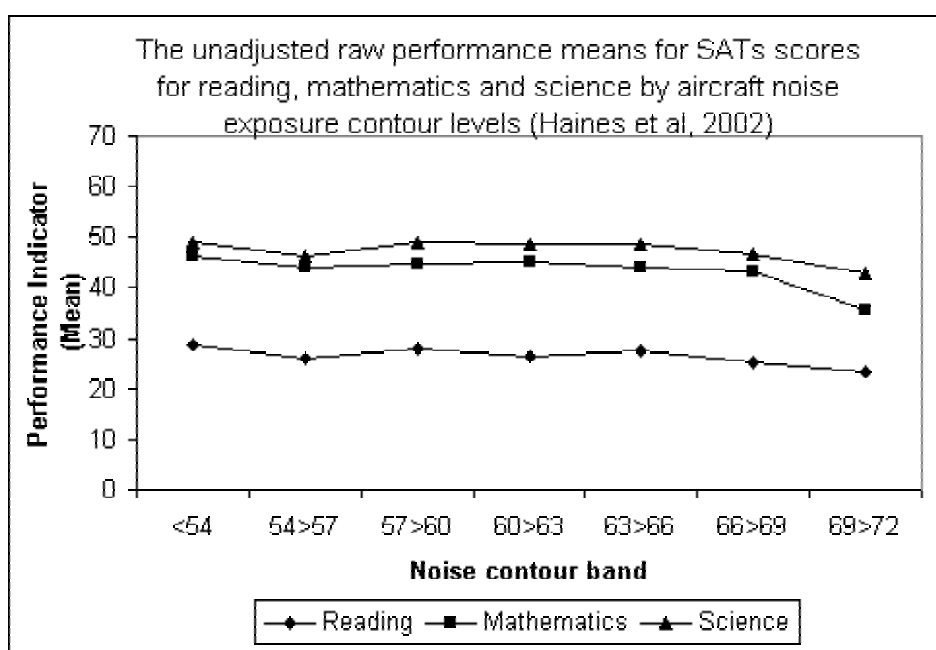
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Annex

Performance Indicator	Noise contour band						
	<54	54>57	57>60	60>63	63>66	66>69	69>72
Reading	28.5	26	27.9	26.5	27.7	25.2	23.5
Mathematics	46.4	43.8	44.8	45	43.8	43.1	35.6
Science	49	46.4	48.9	48.6	48.6	46.5	42.7

The unadjusted raw performance means for SATs scores for reading, mathematics and science by aircraft noise exposure contour levels (Haines et al, 2002)

Annex 2 - Countries / regions presentations

Dr Michionori Kabuto – Japan (WPRO)

Dr Debrashis Chakrabarty – India (SEARO)

Prof Paulo Zannin – Brazil (PAHO)

Mr Gilles Paque – European Union

Dr Ming Chen – China

A dose-response between nighttime indoor sound level due to road traffics and risk for insomnia in Japan

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In the present epidemiologic study, effects of nighttime road traffic noise on sleep were studied using a questionnaire and personal sound exposure monitor for roadside residents in the Metropolitan Tokyo in order to clarify the level-response relationships between actual sound exposure to road traffic noise during sleep and sleep quality in a daily-life setting, since quantitative analysis of this type has been scarce in Japan, and it seems important to get a clue to investigate further the seriousness of the effects as a public health problem.

Subjects and Methods

Subjects for the questionnaire survey were randomly selected 2,555 housewives in 4 study areas called as S, K, T and C, representing for residential, industrial, commercial and office area, respectively, to each of whom a questionnaire sheet was delivered by the researchers. Neighborhood major road, distance between residency and the road as well as type of residency (single-family or apartment house) were considered in selecting the above study areas and subjects. The completed sheets were mailed back from 1,154 (64%) but the data on 1,037 subjects were used for the following analysis (Table 1), since 117 subjects were excluded due to the medical history of hearing problems. In the table, the subjects were divided into 3 subgroups of A: their residency is 30m or more apart from the major road, C: their residency is faced to the major road and B: their residency is located in-between C and A.

Personal sound exposure levels were measured in L_{eq}(10min) for 24 hours of a weekday using a personal sound exposure meter (Rion NB-13A) and simultaneous time study was performed for 198 out of the above 1,037 women (Table 1). For the following analysis, a measure of sound exposure level during sleep, or L_{eq}(sleep) level, was calculated as an energy-averaged level of the L_{eq}(10min) values measured when the subject were sleeping on the time study record. The subjects, however, were requested to measure sound exposure levels during sleep near their heads in their own bedrooms. Outdoor- and indoor-sound levels were also monitored simultaneously using the same instruments as above for 25 women out of the 198 women for the personal monitoring.

Sleep quality in relation to road traffic noise were examined using the yes/no responses to the questionnaire, in which questions were structured to ask first whether there is any environmental noise causing psychological as well as behavioral effects and, if any, to ask about the sleep-related complaints ass mentioned in the results. The subjects, who claimed road traffic noise or intense sounds produced by motor-bicycles during nighttime as the most annoying sound, were regarded as people affected by road traffic noise and their yes-responses to the sleep-related questions were related to the noise.

Since it has been suggested that effects of sounds on sleep are affected by many factors such as age, individual susceptibility, fatigue, presence of stress events, stress-related personality, presence or history of diseases and so forth in addition to indoor sound derived from road traffics, questions related to all of them were also included in the questionnaire. However, the results of analysis of these variables will be reported separately.
For statistical examinations, "SAS" program in a main-frame computer in University of Tokyo was used throughout the present study.

Results

1) Effects of road traffic noise on sound exposure levels during sleep

The L_{eq}(sleep) levels were significantly higher in the subgroup C and B compared to A on the average only in the study area T and C (Table 2), where traffic volume during nighttime was relatively low (Table 1). The L_{eq}(sleep) levels also weakly correlated with outdoor sound levels measured simultaneously, both of which were expressed in L_{eq}(10min), in the study area S and K

but not in T and C (Table 3 and Fig.1). It is obvious, thus, that nighttime traffic volume, which could elevate significantly the group mean of sound exposure level during sleep, must be in-between 6,000 and 9,000 vehiches (v)/8 hrs at night and also that area, where L_{eq}(sleep) level is elevated due to road traffic noise, is restricted to a narrow area (less than 30m from road) when nighttime traffic volume is sound 9,000 v/8 hrs, but the L_{eq}(sleep) levels among people in the behind-area (30m or more from road) are also elevated when the volume is around 22,000 v/8 hrs. The elevation of the L_{eq}(sleep) levels due to road traffic noise, however, were not associated with other residential conditions (type of building, presence of window, location of sleeping room) or demographic backgrounds (age, occupation, number of family members), when examined with covariate analyses.

2) **Sleep quality in relation to L_{eq} (sleep) and outdoor road traffic noise**

Among all the subjects, percentage of yes-response to "woken up by road traffic noise"(Comp.1) was 26%, the most prevalent, followed by those to "keep windows closed at night avoid annoying sounds"(Comp.2),"can't sleep well"(Comp.3),"difficult to fall asleep"(Comp.4) and "sometimes taking sleeping drugs"(Comp5), which were 20, 11,10 and 3% respectively. The % yes-responses varied among the 4 study areas and the 3 subgroups but were significantly correlated with the corresponding mean l_{eq} (sleep) levels obtained from the data on the 198 women. In Fig.2 the % yes-responses by the 3 subgroups in the study areas of S and K, where it was found the L_{eq}(sleep) levels were elevated by road traffic noise, are plotted as a function of the corresponding mean L_{eq}(sleep) levels. Showing good correlations in cases of Comp.1, 2,3 and 5, but not for Comp.4 or "difficult to fall asleep"The minimum effective L_{eq}(sleep) levels", which were defined tentatively as the l_{eq}(sleep) level corresponding to the yes-response rate of 10% were calculated from the obtained regression lines, ranged from 34 dB (A) for Comp.1 to 44dB(A) for Comp.3 (Table 4).

On the other hand the minimum effective L_{eq}(sleep) levels were examined also using only the data on the 95 women in the study area S and K whose L_{eq}(sleep) was measured. As illustrated in Fig.3, the L_{eq}(sleep) levels widely distributed in both groups divided by yes-and no-responses, indicating a great variation in individual susceptibility. However, the minimum L_{eq}(sleep) levels, below which no more yes-response was observed, were identified as 34 dB (A) for Comp.1, 35 dB (A) for Comp.2, 34 dB (A) for Comp.3, 34dB(A) for Comp.4 and 43dB(A) for Comp.5, which agreed roughly with the minimum effective L_{eq}(sleep) levels derived from the group mean values. This was also true if the minimum effective levels are defined with the % yes-response of 10%, since the identified levels shifted only slightly. In the figure, it was also shown that the minimum L_{eq}(sleep) levels above which no response was observed anymore are 56dB(A) for Comp.1, 62 dB (A) for Comp.2 and 63dB(A) for Comp.3, whereas this level was not determine for Comp.4 and Comp.5 Moreover, the level-response relationships between the L_{eq}(sleep) levels and the % yes-responses were also found to be significant with the exception of Comp.4, which were also consistent with the above results from the group mean values (Fig.2), but suggested more clearly that Comp.1 is the most sensitive effect compared to other complaints.

Discussion

In the present results, prevalence of sleep-related complaints, especially about noise-induced awakenings, was correlated significantly with the L_{eq}(sleep) levels. The minimum effective L_{eq}(sleep) levels obtained through two types of examinations were almost   consistent with each

other, which also agreed with those in the existing field data, suggesting that L_{eq}(sleep) or other personal sound exposure levels are a useful measure to indicate nighttime road traffic noise conditions associated with its effects on sleep   generally. The good agreement may also suggest that the prevalence of sleep-related   complaints was not biased by the existence of road traffic noise as usually suspected.   Moreover, even if non-specific yes-response as common in a questionnaire study, was   taken into consideration (it was assumed to be 10 % in the results),[3,4] it could be   summarized that the minimum effective L_{eq}(sleep) levels should be around 35 dB(A) or   slightly above and that the standard level in Japan is low enough to avoid sleep disturbances due to road traffic noise.

It should be noted, however, that sleep disturbances have been related to peak sound levels rather than energy-equivalent continuous sound levels or L_{50} in some Swedish studies[5-7] and, therefore, the possible correlations among L_{eq}, L_{50} and peak levels should   be examined in more detail. It may be possible that number of peaks of more intense   sounds would increase with increase of traffic volume including heavy duty vehicles and   could cause awakening as suggested by the present results showing that the yes-response to Comp. 1 or "woken up by road traffic noise" is the most sensitive one compared to other complaints.

Moreover, among the minimum effective sound levels which were observed in experimental studies so far, Eberhardt et al. (1987)[5,6] reported   the lowest level, or 29 dB (A) in L_{eq} or 5 dB (A) lower than the level observed in the present study, with which deep-sleep was reduced and awakening was increased significantly compared to the controls with 27 dB (A) in $L_{eq.}$ However, since there may be a possible discrepancy between subjective complaints and objective indications based on EEG data,[5,8] a study is expected to clarify the possibility.

Another fact, which was clarified in the present study, was the minimum L_{eq}(sleep)   levels above which all the people are feeling sleep-related complaints, the lowest one of which was 56 dB(A) for Comp. 1. According to the regression line obtained for outdoor sound levels and personal exposure levels as shown in Fig.1, sound exposure level of 56 dB (A) is corresponded to outdoor sound level of 68 dB(A) in $L_{eq.}$ In our previous estimations based on the data of 1985 Traffic Census regarding number of population living roadside according to outdoor sound level was around a million or 1% of the total   population in case of 60 dB(A) and over in $L_{50.}$[9] Therefore, if the difference between L_{eq} and L_{50} levels as well as the possibility that part of population exposed to the noise of the identified minimum levels or below are also affected are considered, population whose sleep are affected by nighttime road traffic noise should be much more.

More frequent, although absolutely low, usage of sleeping drugs among people exposed to higher L_{eq}(sleep) levels compared to those exposed to lower levels was also   suggested as shown in Fig.2, which was not consistent in the other examination (Fig.4).

Thus, by the present study, new quantitative data showing the level-response   relationship for sleep-related complaints as a function of not only L_{eq}(sleep) level but   also outdoor sound level or nighttime road traffic volume on the neighborhood major   road were added to our current knowledge. The sleep disturbances expressed by the subject complaints as well as by the suggested frequent use of sleeping pills among the people exposed to road traffic noise exceeding the minimum effective level will be evaluated further especially from the aspects of physiological after-effects in an epidemiological study on insomnia.

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Table 1: Distribution of the subjects for questionnaire survey

Study area (landuse)	Number of subjects Subgroup				Traffic volume on the neighborhood major road (v/8 hrs at night)
	A	B	C	total	
S (residential area)	140 (29)	30 (13)	34 (8)	204 (50)	9,000
K (industrial area)	123 (19)	15 (9)	29 (17)	167 (45)	22,000
T (commercial area)	310 (34)	71 (8)	93 (18)	474 (60)	3,000
C (office area)	127 (22)	162 (11)	175 (10)	1,037 (43)	6,000
Total	700 (104)	162 (41)	175 (53)	1,037 (198)	

Note: number in the parenthesis shows the number of subjects whose personal sound exposure
        levels were measured.
   As for subgroup A,B and C, see Subjects and Methods.

Table 2: Mean L_{eq} (sleep) levels according to the study areas and subgroups

Study Area	Mean (±S.D.) L_{eq} level, dB (A) Subgroup			P for Difference #
	A	B	C	
S	40.2(5.4)	44.7(7.4)	50.2(3.3)	P<0.01
K	46.1(8.8)	49.6(7.9)	51.9(9.1)	P<0.01
T	43.1(7.1)	46.7(5.1)	47.1(6.9)	n.s.
C	42.2(6.4)	44.0(5.0)	45.2(6.3)	n.s.

#: significance was tested by ANOVA for the mean differences among 3 groups.

Table 3: Correlations between sound exposure level and outdoors level in L_{eq}(10min)
        during sleep

Study area	Correlation coefficient (r)	
S	0.43	(p<0.1)
K	0.46	(p<0.1)
T	0.26	(n.s.)
C	0.07	(n.s.)

Table 4: The minimum effective L_{eq}(sleep) levels identified using the regression lines
        as shown in Fig.2

Kind of complaints	The minimum effective L_{eq} dB(A)
Comp.1"woken up by road traffic noise"	34
Comp.2"keep windows closed at night"	41
Comp.3"can't sleep well"	44
Comp.4"difficult to fall asleep"	n.d.
Comp.5"sometimes taking sleeping drugs"	38#

n.d.: could not be determined.

#: since prevalence was very low, the minimum effective level was set at the yes-response rate of 1.0% instead of 10%, which was applied to other complaints.
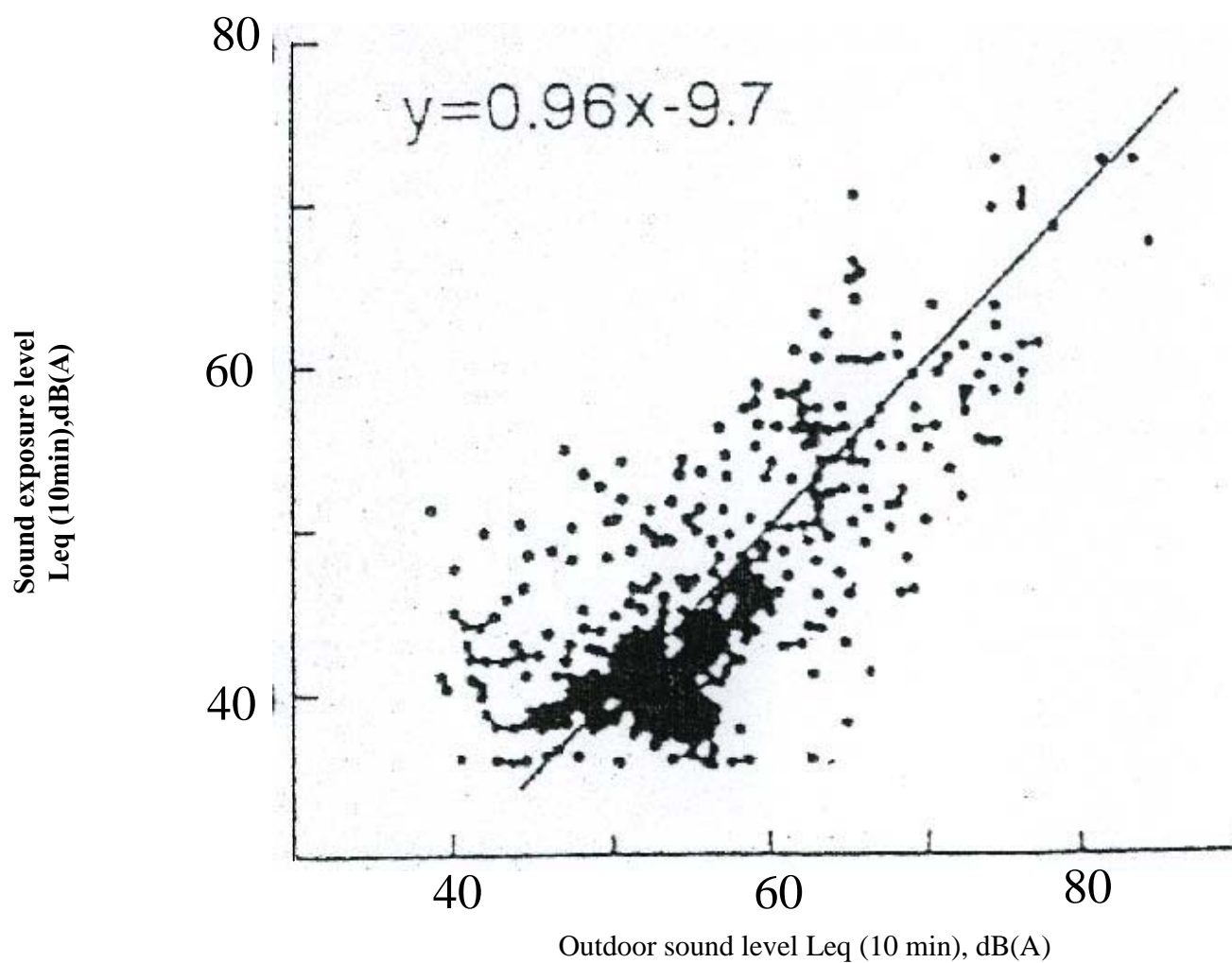
Fig.1:
Correlation between outdoor sound levels and sound exposure levels in
Leq (10min) measured simultaneously during sleep for the 95 woman living
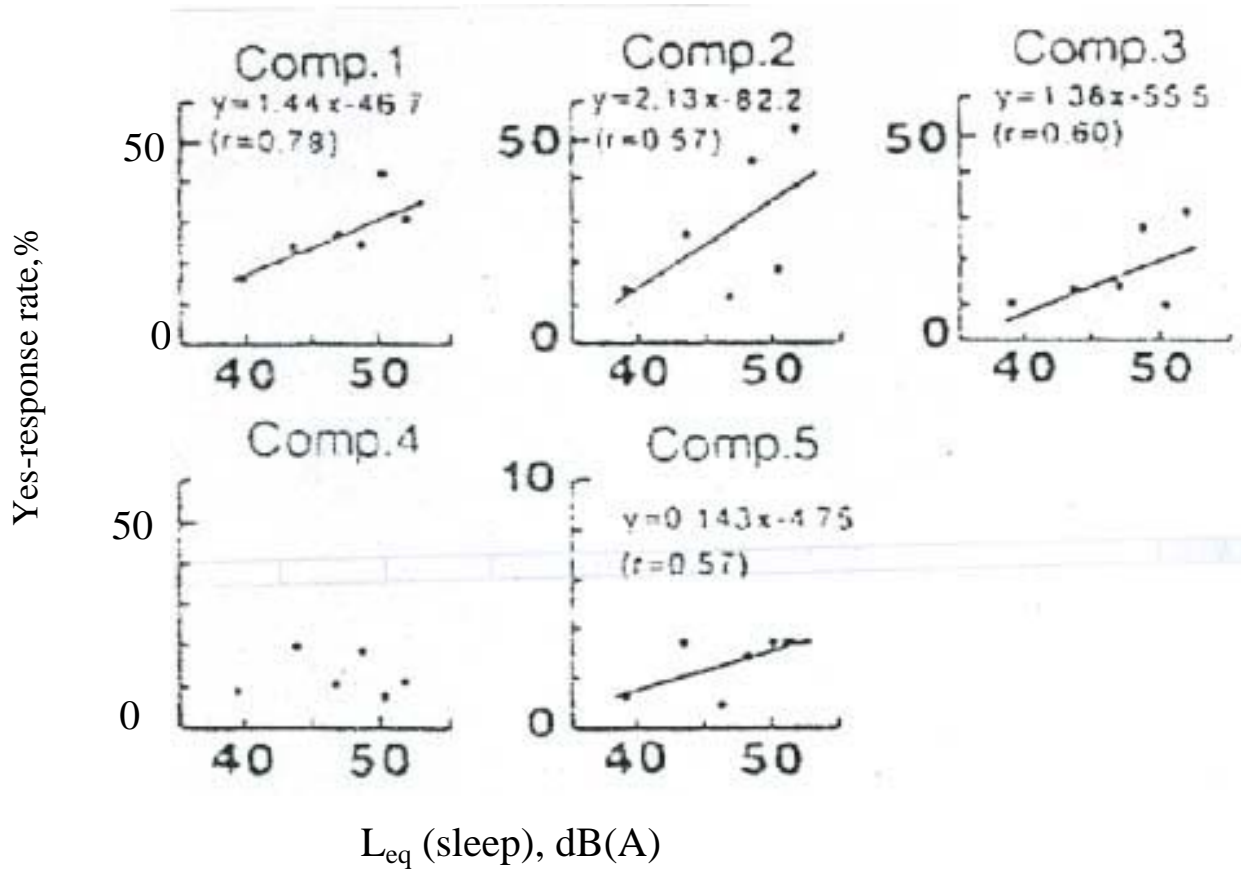in the study area S and K. The regression line as shown in the figure was
y=0.96X-9.7 (p<.001).

Fig.2:
Correlations between mean L_{eq}(sleep) level and percentage of yes-responses
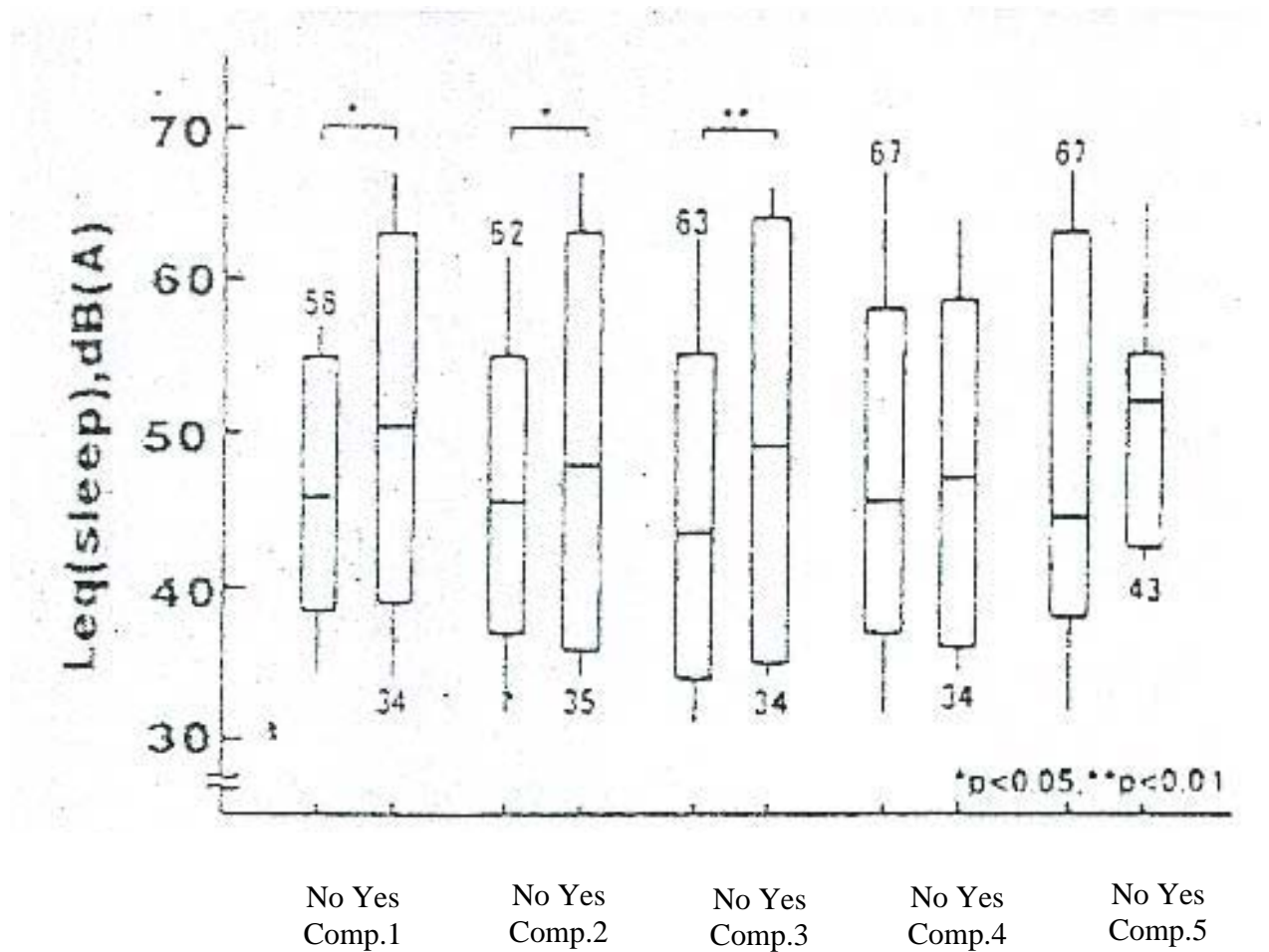for sleep-related complaints. As for Comp:1.5, see Results.

Fig.3
in the study area S and K. The box indicates the range from 10 %(lower) to 90%(upper) and the line in the box shows the mean level. The vertical bars shows the range from 0 %(bottom) and 100 % (top)
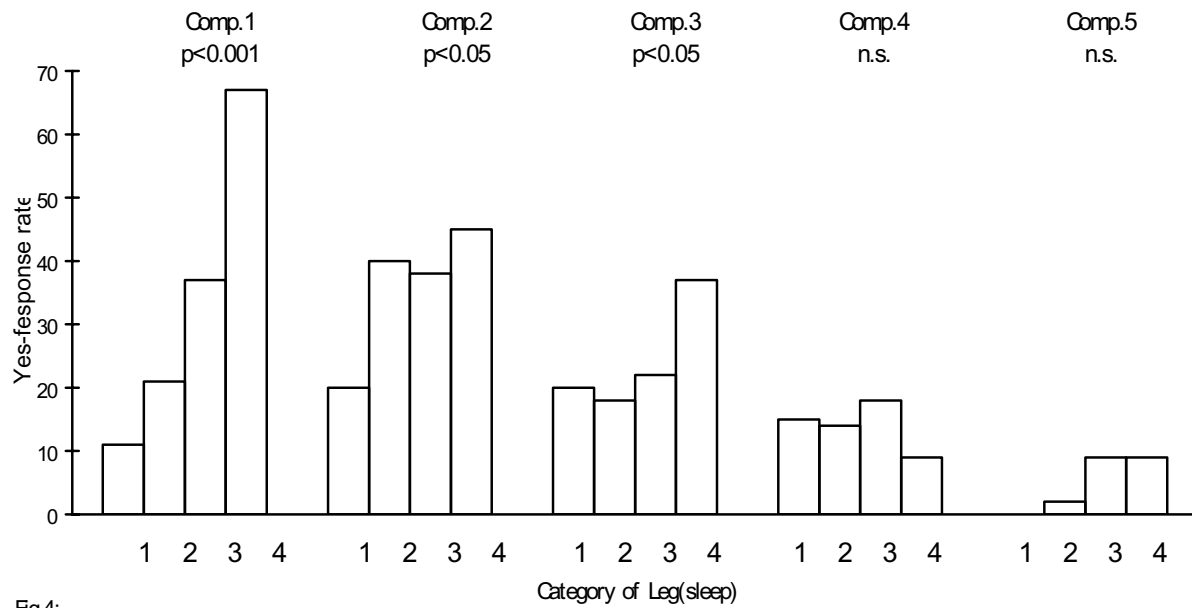
Fig.4:
Percent yes-response for Comp.1-5 according to 4 Leq (sleep) categories.
The category 1-4 indicate Leq(sleep) of ~34.9, 35.0-44.9,45.0-54.9 and 55.0-dB(A), respectively.

Noise Pollution—What have we done!

Dr Debashis Chakrabarty
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India

Introduction

In recent years noise has been identified as a great environmental pollutant along with air, water and other forms of pollution. Concerns about the ill effects of noise and subsequent adoption of legislative regulations to control noise in USA and European countries were formulated in the 'sixties and 'seventies of last century. But in the developing countries the control exercise was initiated only in the 'eighties. In India noise pollution was deemed to be an offence only recently through the promulgation of the comprehensive Air Act in 1981. Every industry, trade, transport and process using equipments, apparatus, material and methods that produce unwanted and unpleasant sound, constitute a source of noise. In India the major sources of noise are the road traffic, loudspeaker, Diesel Generator sets, vehicular horn, firecrackers, domestic appliances etc. Noise from these sources are affecting the urban people, which include interference with conversation and communication, sleep disturbance, hearing impairment and also may create stress in some individuals.

Road traffic noise:

Road traffic noise has been identified as the major source of noise in urban localities in India as it is the continuous noise to which a large majority of people are exposed for long hours of the day. Social surveys in several countries have shown that although noise from other sources like rail, aircraft etc are disliked by large number of people but greatest distaste was more for road traffic noise. The road traffic noise survey was carried out in different cities in India. The results of these studies when assessed and compared with earlier studies it showed a deterioration in the noise environment of major cities during the past decades.

Loudspeakers:

Loudspeakers are frequently used in India in temple, mosque, public meetings, cultural functions, social functions etc. West Bengal Pollution Control Board(WBPCB) took the initiative to monitor the festival noise problems due to indiscriminate use of loudspeakers and bursting of crackers in 1993. Till then every year WBPCB launched massive awareness campaign about the ill effect of noise pollution among the community with the help of the media and NGO. With the ground thus prepared came the landmark judgement in 1996 on Noise Pollution passed by the Hon'ble Justice B.P. Banerjee in the High Court, Calcutta. That judgement was based on Article 19(1)(a) of our Constitution which provides Fundamental Rights on all citizens to Freedom of Speech & Expression. This also includes freedom not to listen and/or to remain silent. It is a matter to consider whether the public are captive audience or listeners when permission is given for using loudspeakers in public and the person who is otherwise unwilling to hear the sound and/or the music or the communication made by the loudspeakers, but he is compelled to tolerate all these things against his will and health. If permission is granted to use microphone at a louder voice, such a course of action takes away the rights of a citizen to speak with others, the right to read or the right to know and the right to sleep and rest or to think. Subsequently the modalities in respect of use of loudspeakers in various occasions are being set up as per the Hon'ble High Court Order :

Norms Of Using Loudspeakers

Modalities in respect of use of Loudspeakers
(Re : High Court Orders dated 01.04.1996 & 24.02.1997 and The Noise Pollution Rules, 2000)

- Loudspeakers should not be allowed to operate after 9 p.m. and before 7 a.m. and the loudspeakers should be fitted with **Sound Limiter**.

- Loudspeakers should not be allowed to operate for any time in the silence zone, i.e. 100 mtrs. around the premises like hospitals, nursing homes, educational institutions and courts (Restrictions of use of microphone should be operative so far as school, educational institution, college, courts and library are concerned up to the working hours).

- During the time of the use of loudspeaker following noise level should be maintained.

	Area	Day time	Night time
1.	Industrial area	75 dBL$_{eq}$	70 dBL$_{eq}$
2.	Commercial area	65 dBL$_{eq}$	55 dBL$_{eq}$
3.	Residential area	55 dBL$_{eq}$	45 dBL$_{eq}$
4.	Silence Zone	50dBL$_{eq}$	40dBL$_{eq}$

  i)   **Day time** is reckoned in between 6 a.m. and 10 p.m.
  ii) **Night time** is reckoned in between 10 p.m. and 6 a.m.

- Loudspeaker should not be allowed to use without prior permission of the Local Police Station/Sub-divisional Officer/ District Magistrate as the case may be.

- During the time of any function in the street necessary passage should be remained open for passers by.

Mandatory Norms for Fixation of Sound Limiters with Loud Speakers

In the landmark judgement of Noise Pollution it was also clearly stated that the volume and noise level of loudspeakers should not exceed the level fixed up by the WBPCB which should be treated as "Registered Level" and the volume may be regulated in such a fashion so that it may reach to all persons in the audience not beyond that. In keeping with this in mind and to offer the better way to implement the restrictions on noise pollution of loudspeakers, Scientists of WBPCB in consultation with Engineers of Webel Mdiatronics Ltd. had developed the "Sound Limiter".

The Sound Limiter is a self-contained unit, built around reliable solid-state devices. The unit is easy to install and can be connected with a variety of Power Amplifiers of different rating. It does not require any external control. One LED provided at the front panel indicates the ON/OFF status of the unit. While the second LED indicates that Limiter Unit is in operation. When interfaced with the Amplifier the Sound Limiter unit feeds power to the Amplifier and a separate AC input for the Amplifier is not required. When interfaced with the amplifier, Limiter has

automatically brings down the output level of the loudspeaker noise at a specified limit whatever may be the power output level of the amplifier. The limit is pre-set internally at works. Intentionally the user has not been offered a choice to increase the level of the speaker output when the Limiter Unit is connected in between Amplifier and Speaker. One Limiter Unit is sufficient to limit and provide the identical output level of multiple speakers connected to a single Amplifier.

(Re : High Court Order dated 11.03.1998)

- Loudspeaker should not be used or let out without sound limiter for the purpose of use in open air.

- Sound Limiter will control the noise level of the loudspeaker as per the prescribe standards fixed up by the Environment (Protection) Act 1986.

Modalities in respect of use of Loudspeakers in Open Air Cultural Function
(Re : High Court Order dated 11.08.1998)

- Between 7 a.m. to 9 p.m. loudspeaker can be used in cultural or any other function maintaining the stipulated noise level.

- After 9 p.m. cultural function can be arranged, within a temporarily covered area, with sound absorbing materials provided.
   a) *Maintaining the ambient noise level outside the covered area, as prescribed under Environment (Protection) Act 1986.*
   b) *No loudspeakers should be fitted or operated outside such covered area and that only box type loudspeakers should be used inside the covered area.*
   c) *Before organising any cultural function permission should be obtained from the Local Police Authority and Sub-divisional Authority.*

- During the time of any function in the street necessary passage should be kept free for passers by.

Restrictions for Open Air Function During Examinations
(Re : High Court Order dated 11.08.1998)

- Three days before important examinations such as Secondary Examination or Higher Secondary Examination, where interests of a large number of students are involved, and till such examination are over any open air function should not be performed in the residential area at any time of such period, as notified by the West Bengal Pollution Control Board.

Modalities in respect of use of Loudspeakers by Political Parties
(Re : High Court Order dated 29.01.1998)

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- Loudspeakers should not be allowed to operate after 9 p.m. and 7 a.m. and all the loudspeaker should be fitted with Sound Limiter.

- Loudspeakers should not be allowed to use without prior permission of the Local Police Station/Sub-divisional Officer/District Magistrate as the case may be.

- During the time of any meeting in the street necessary passage should be kept free for passers by.

- Political parties can use loudspeaker one month before the general election from 7 a.m. to 10 p.m.

Generator Sets:

1. **Standards/Guidelines for control of Noise Pollution from Stationary <u>Diesel</u> Generator (DG) Sets**
   (G.S.R. 7, dated 22nd December, 1998)

2. Noise Limit for Generator Sets run with <u>Diesel</u>
   (G.S.R. 371(E), dated 17th May, 2002.)

3. **Noise Limit for Generator Sets run with <u>Petrol or Kerosene</u>**
   (G.S.R. 742(E), dated 25th September, 2000.)

Extension of dates for implementation of Noise Limits for Generator Sets run with petrol or Kerosene vide: G.S.R. 628(E), dated 30th August, 2001.

<u>Consent Administration of Diesel Generator Set</u>

The generator sets available in the market are of two types viz:

- Spark Ignition type run on petrol/kerosene as fuel (range 0.4 to 10 KVA)

- Compression Ignition type run on diesel as fuel (3--1000 KVA, larger size are generally used in large industries for captive power requirements)

Until now, noise limits for the following ranges have been notified:

Petrol/kerosene based all generator sets - 85dBA sound power level.
   (MoEF, GOI - notified vide G.S.R. no.742(E), dated 25th September, 2000)

Diesel based generator sets:
- > 5 KVA, noise limits at users end notified vide G.S.R. no. 7, 83(B), dated 22nd December, 1998, which states that mandatory acoustic enclosure/ acoustic treatment of the DG room.

- 15-500 KVA, noise limits at manufacturing end notified vide G.S.R. no. 7, 83(A),

dated 22nd December, 1998, which is 94+10$\log_{10}$ (KVA) dBA.

- Noise limit for diesel generator sets (upto 1000 KVA) manufactured on or after the 1st July, 2003 shall be 75 dB(A) at 1 metre from the enclosure surface vide G.S.R. no. 371(E) dated 17th May, 2002.

Notification issued for bringing the use of Diesel Generator set(s) of capacity 15 KVA and above for non-industrial use i.e. for residential buildings, commercial buildings, office complex, cinema hall, Bank, educational institutions etc. under the consent administration. Any person/organization using Diesel Generator set(s) of capacity 15 KVA and above(both new and in-use) shall required to obtain NOC(No Objection Certificate) for consent to established and also consent to operate certificate from the West Bengal Pollution Control Board for such use with effect from 1st January, 2002.

Fireworks:

Firecrackers are widely used in India as merry crackers during festivals, social functions and some religious occasions. In fixing the noise standard of Fireworks WBPCB followed the Hon'ble Court Order wherein the Board was directed to take suitable measures to stop creating sound pollution by means other than the microphones, such as air horn in public vehicles, fireworks and other sources of sound nuisance. The State Board monitored the noise level of noisy fireworks and banned those items which generate more than 90 dB(A) impulse noise from five meter from the source such as Chocolate Bomb, Chain Crackers (Kali Patka), Loose Crackers, Kali Patka, Dhani Phatka, Dodoma, Seven Shorts, Rocket Bombs etc. should not be allowed to be sold or use for any purpose.

Invoking inherent law making process by the Court

Excepting laying down the Ambient Noise Quality Standards in respect of Noise in four different zones, no attempt has yet been made by the Law Making Authority or the Rule Making Authority to lay down any standard for impulsive Noise Level. Unfortunately, in India no such restriction has been made on the user of microphones or loudspeakers for which this Court had occasion to consider the matter not only from the pollution angle but in the context of the rights of the citizens guaranteed under Article 19(1)(a) of the Constitution of India and held that nobody has got any right and/or any fundamental right to suspend the rights of the other citizens of this country. Ordinarily, the duty of the Court is to enforce the law and normally the Court shall leave the matter to the Parliament or the Legislature but the Supreme Court in the case of (a) Union of India v. Raghubir Singh, AIR 1989 SC 1933, held that it is used to be disputed that Judges make law. Today, it is no longer a matter of doubt that the substantial volume of law governing the lives of citizens and regulating the functions of the State flows from the decisions of the Superior Court. In (b) Pamal Kanji Govindji v. Vrajial Karsandas Purchil, AIR 1989 SC 436, it has been held by the Supreme Court that the law must respond and be responsive to the felt and discernible compulsions of circumstances that would be quitable, fair and just and unless there is anything to the contrary in the statute, Court must take cognizance of the fact and act accordingly. In (c) M.C.

Mehta v. Union of India, AIR 1987 SC 1086, it was held that where a law of the past does not fit in the present context. The Court should evolve a new law and in (d) National Workers' Union v. P.R. Ramkrishnan, AIR 1983 SC 75, it was held, if the law fails to respond to the needs of the changing society, then either stifle the growth of the society and choke its progress or if the society is vigorous enough it will cast away the law which stands in the way of its growth. Law must therefore constantly be on the move adopting itself to the fast changing society and not lag behind. It must shake off the inhibiting legacy of its colonial past and assume a dynamic role in the process of social transformation. The short point is that, though the laws of the land do not say anything about the source of noise and talks only about ambient standard which is the result of noises coming from multifarious sources, the Calcutta High Court invoked the inherent law making process, underlined in a Supreme Court judgement, to authorise the West Bengal Pollution Control Board to prescribe the standards for, at least for one source i.e. crackers.

WBPCB has fixed the standards of noise level in fireworks as 90 dB(AI) at 5m distance from the point of bursting in conformity with the Orders of Hon'ble High Court, Calcutta, W.P. No.2725 of 1996 and matter No.C.O.4303 (W) of 1995, which was subsequently upheld by Supreme Court of India in the matter of SLP© No.19469/97. Recently the State Board has decided to stick with this stringent standard under Rule 3(2) of Environment (Protection) Rules, 1986.

Restriction in use of Fire Works
(Re : High Court Order dated 26.09.1997)

- Banned fire works which generate noise level more than 90 dB(Al) at 5 meter distance from the point of bursting such as Chocolate Bomb, Chain Crackers (Kali Patka), Loose Crackers, Kali Patka, Dhani Patka, Dodoma, Seven Shorts, Rocket Bombs etc. should not be allowed to be sold or used for any purpose.

- Forest Department and Airport Authority can use banned fire works for their official purpose with prior permission of the West Bengal Pollution Control Board.

   Noise standards for fire-crackers (MoEF, GOI)
   (G.S.R. 682(E), dated 5th October, 1999.)

Vehicular horn:

Legal Provisions in Controlling of Vehicular Horn Noise:

Restriction in use of Air Horn
(Re : High Court Order dated 19.03.1997 & 07.05.1997)
- Air horn should not be used in the vehicles.
- Air horn should not be sold or stored.

Noise Limits for vehicles with effect from the 1st January, 2003
 (MoEF, GOI - G.S.R. 742(E), dated 25th September, 2000.)

The Motor Vehicle Act 1939 (Amended in 1983)

The Motor Vehicle Act 1988, empowers the Central and the State Governments respectively to frame rules as regards the "reduction of noise emitted by or caused by vehicles" (Section 110) and "prohibiting of restricting the use of audible signals at certain times or in certain places" (Section 111). The rules framed by the Central Government and the State Government under the above sections are as follows.
Rule 119 of the Central Motor Vehicle Rules 1989 reads the following :

1. Every motor vehicle shall be fitted with an electronic horn or other device approved by the Bureau of Indian Standard and approved by the registering authoring for use by the driver of the vehicle and capable of giving audible and sufficient warning of the approach or position of the vehicle.

2. No motor vehicles shall be fitted with any multi-toned horn giving a succession of different notes or with any other sound-producing device giving any unduly harsh, shrill loud or alarming noise.

3. Nothing continued in sub-rule (2) shall prevent the use on vehicle used as ambulance or for fire fighting or salvage purposes or on vehicles used by police officers or officers of Motor Vehicles Department in the course of their duties, of such sound signals as may be approved by the registering authority in whose jurisdiction such vehicles are kept.

Rule 120 of the Bengal Motor Vehicles Rules 1940, is as follows -
1. Every motor vehicles shall be fitted with a device (hereinafter referred to as a silencer) which by means of an expansions chamber or otherwise reduces as far as practicable, the noise that would otherwise by made by the escape of exhaust gases from the engine.

2. Every motor vehicle shall be so constructed and maintained as to conform to noise standards as approved by FIS from time to time.

Rule 114 of the Bengal Motor Vehicles Rules 1940, is as follows -
A. No motor vehicle shall be fitted with any multi-toned horn giving a succession of different notes or with any other sound-producing device giving any unruly harsh, shrill, loud or alarming noise.

B.   Nothing contained in sub-rule (b) shall prevent the use on vehicles, use as ambulances or for fire fighting or salvage purpose or on vehicle used by police officers in the course of their duties, or on other similar vehicles, of such sound signals as may be approved by the Registering Authority.

C.   Every transport vehicle shall be fitted with bulb horn.

In exercise of powers conferred by section 111 of the Motor Vehicles Act 1988 (59 OF 1988) read with Rule 258 (4) (c) of the West Bengal Motor Vehicle Rules 1989, as amended, and in compliance with order of the Hon'ble High Court, Calcutta dated 22.12.1997 in C.O. No. 4303 (W) of 1995, the sale and store of air horns is prohibited in the state of West Benga

Urban Noise Pollution in Residential Areas of the City of Curitiba, Brazil
Objective Analysis

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ABSTRACT

This paper presents a study on noise pollution in residential areas of a large Brazilian city, Curitiba. The equivalent sound level values - L_{eq} - were measured and tabulated for 350 locations spread over residential areas. The results showed that 80.6% of the measured points exceeded 65 dB(A). Only 9.4% of the measured points satisfy the 55 dB(A) limit for residential areas during daytime (7:00am – 7:00pm), according to the environmental legislation in effect in the city.

1 – INTRODUCTION

This paper presents data on noise emission levels carried out in residential areas of the city of Curitiba, capital of Paraná state, located in the Southern Brazil. The city has 1,619,348 inhabitants and is one of the oldest and one of the most populated cities in Brazil. The economy of Paraná State was until recently agriculture-based. The industrialization is somewhat recent. Along with the economical growth of the State and especially of the capital Curitiba, significant structural changes in the city have been observed. Some examples can be cited:

a) Migration of country people to urban areas in search of more lucrative jobs in automobile construction and other industries;
b) Increasing number of circulating vehicles in urban streets;
c) Increasing activities in civil construction in order to build new homes for the new inhabitants.

The population of Curitiba has been continuously increasing since 1970, as shown in table 1 [1].

Year	1970	1980	1991	1996	2000
Inhabitants	**609 026**	**1 024 975**	**1 315 032**	**1 476 253**	**1 619 348**

Table 1: Populational growth in Curitiba

Together with the increasing number of inhabitants it has been observed an increasing number of circulating vehicles. In 1995 the total number of registered vehicles was 536,641, from which 5,395 were buses and 391,461 were cars; in 1999, the last available information on vehicle number, the total number of vehicles was 684,212, from which 6,983 were buses and 489,420 were cars. The motorcycles and utilitarian vehicles are not included in above numbers. The increasing number of living people and vehicles normally lead to increase in urban noise.

However, in countries with severe economical and social problems such as Brazil, urban noise has not received enough attention. Still, as a general rule for the whole world, the necessity for studies on noise pollution and its influences over the surrounding environment is increasing, especially by the increasing number of noise sources such as machines, markets, factories and the already cited motor vehicles. Many recent noise surveys treating the problem of noise pollution and the noise propagation have been conducted [2, 3, 4, 5, 6].

The objective of the present research was to show noise level measurements carried out during the day in residential areas of the city of Curitiba, and to compare these levels measured in 2000 with levels measured at the same locations and periods of the day in 1992 [7], the only noise survey ever conducted in Curitiba. The results were confronted with the sound emission limits for residential areas according to the municipal law number 8583 of 1995, which legislates about urban noise and public comfort [8]. The measured sites were also classified according to the criterium established by the U.S. Department of Housing and Urban Development – HUD [9].

2. EXPERIMENTAL APPARATUS

Noise levels were measured by using: Brüel and Kjäer Mediator 2238 type 1 to integrate and logg sound level meters, and Brüel and Kjäer Investigator 2260 type 1 to integrate sound level meters [10].

3. EXPERIMENTAL METHOD

The city of Curitiba, according to the municipal law number 8583 of 1995, which legislates about urban noise and public comfort, has limits for residential areas, according Table 2.

Zone	Day – Limit 7:00am – 7:00pm	Rest – Limit 7:00pm – 10:00pm	Night – Limit 10:00pm – 07:00am
Residential	**55**	**50**	**45**

Table 2: Noise emission limits for the residential area – L_{eq} – dB(A)

The current total population in residential areas is 700,000 inhabitants. In the present survey the measurements were carried out during the afternoon in 350 locations spread throughout those areas. This means that the residential areas have been broadly divided at the proportion of one location per 2,000 inhabitants. Similar surveys carried out in two cities in Palestine, similar proportion have been used: one location for each 3,000 inhabitants in the city of Nablus [5], and one location for each 750 inhabitants in the city of Arraba [6].

All measurements were carried out during working days and under ideal meteorological conditions: no wind and no rain. The duration of each measurement in each site was one hour, each site was measured in duplicate. The first measurement was carried out while people were returning home from work between 12:00 and 01:00 pm. Having lunch home is still a characteristic present in many Brazilian cities. The second measurement was carried out when people were returning home after a working day, between 06:00 pm and 07:00 pm. The average values of the measured equivalent sound levels are presented in Table 3.

In order to compare the current data with 1992 data on noise levels in Curitiba [7], the same measurements points had to be used as in [7]. A non-regular grid was used by Barbosa in 1992, with 350 measurements points spread over the main residential area of the city of Curitiba, as shown in Figure 1. Figure 1 shows the measurement points distributed through the residential areas of Curitiba.

L_{eq} - dB(A)	Residential areas			
	1992		2000	
	Locations	Percentage (%)	Locations	Percentage (%)
$L_{eq} \leq 50$	0	0	7	2
$50 < L_{eq} \leq 55$	2	0.6	26	7.4
$55 < L_{eq} \leq 60$	7	2	15	4.3
$60 < L_{eq} \leq 65$	14	4	20	5.7
$65 < L_{eq} \leq 70$	33	9.4	45	13
$70 < L_{eq} \leq 75$	32	9.1	131	37.4
$75 < L_{eq} \leq 80$	133	38	102	29.1
$80 < L_{eq} \leq 85$	129	36.9	4	1.1
$L_{eq} > 85$	0	0	0	0
Total	350	100	350	100

Table 3: Equivalent sound level for residential areas – measured in 1992 and in 2000, in the present study.

4. RESULTS AND DISCUSSION

The measured equivalent sound level (L_{eq}) values of all measurement locations from the Barbosa´s survey in 1992 [7] and the results obtained in the present survey, are directly comparable in Table 3. As already mentioned, the sites and periods of the day the measurements were carried out in the present survey coincide with the ones in Barbosa´s survey [7].

The equivalent sound levels in Table 3 are the mean values of the two measurements carried out for each measurement point as mentioned in the Methods section. In 1992, only two locations, representing 0.6 % out of the total number of locations investigated, the equivalent sound levels - L_{eq} - were at or below 55 dB(A) (Table 3), that is in agreement with the city urban legislation (Table 2). On the other hand, the measurements carried out in 2000 showed 33 locations, representing 9.4% out of the total number of locations, with equivalent sound levels at or below 55 dB(A) (Table 3).

The U.S. Department of Housing and Urban Development (HUD) [9], recommends the following noise levels for residential areas, measured outdoors:

$L_{eq} \leq 49$ dB(A) – clearly acceptable
$49 < L_{eq} \leq 62$ dB(A) – normally acceptable
$62 < L_{eq} \leq 76$ dB(A) – normally unacceptable
$L_{eq} > 76$ dB(A) – clearly unacceptable

Considering the criteria from HUD, only 9 locations in 1992 but 48 locations in 2000, representing respectively 2.6% and 13.7% out of the total 350 locations surveyed, can be classified as *normally acceptable.* But it is important to notice that not all of these locations are in accordance with the local municipal law of the city of Curitiba as stated above.

At this point we can question whether the municipal legislation is not setting a limit for noise emission level that is difficult to be met – 55 dB(A) during the day – facing the local conditions:

1) The bad conditions, in general, of the urban streets;
2) The poor maintenance of the circulating vehicles: cars, buses, motorcycles. It is not rare to find circulating vehicles with damaged exhaust system or even without it.
3) Generally the circulating vehicles are old. The average age of the Brazilian vehicles is 14 years.
4) The bad habits, in general, of the Brazilian drivers:
    a) Using the horn for any purpose, with or without apparent reason to do so.
    b) Accelerating the vehicle during traffic jams or while waiting for green traffic light.
    c) High speed driving inside urban regions. It is not rare to find people driving over 80 km/h.

The present research does not have the objective of analyzing the applicability of the municipal legislation – Law 8583 of 1995. It is clearly noticeable that maybe before the setting of an environmental legislation establishing realistic limit sound emission levels, it would be desirable to conduct an awareness campaign for everybody in general and specifically for drivers to control their bad habits previously discussed, so that maybe this 55 dB(A) limit could be met more often.

A widely accepted scientific fact is that living in black acoustic zones, where the equivalent sound level is higher than 65 dB(A) [11, 12] put an urban population in a high risk status for

numerous subjective effects of noise, including psychological, sleep, and behavioral disorders. Out of the measured locations in the survey conducted in 2000, 80.6% of the locations display measured L_{eq} over 65 dB(A). On the other hand, in the survey carried out by Barbosa in 1992 [7], 93.4% out of the total locations presented L_{eq} values over 65 dB(A) (Table 3).

Figure 2 shows the equivalent sound levels - L_{eq}, and the statistical levels - L_{10} and L_{90} - measured in the main avenues of the city of Curitiba. The reduction in noise pollution between 1992 and 2000 are obvious. Some thoughts can be drawn about what caused the reduction in noise emission in the city along these 8 years, despite population increase and also increase in the number of vehicles circulating in the city. No specific measure was undertaken by the public administration in the sense of seeking for a reduction in environmental noise emissions. However, some measures were taken by the public administration after 1992 seeking for traffic speed control and reduction in the number of car accidents and traffic deaths. As an example, Com. Franco Avenue (see Figure 2) can be cited where after the installation of speed control radars, the number of tramplings has decreased by 85%, and L_{eq} was of 85 dB(A) in 1992 and 78 dB(A) in 2000. The goal of the municipal public administration was to improve the traffic safety conditions but it ended up contributing, without any direct intention, to the reduction in environmental noise emissions. The measures taken to improve the traffic safety conditions were as follows:

1) Installation of vehicle speed control radars. The installation of these radars has also contributed to the reduction of the number of people hit by cars. Installation of electronic speed controllers;

2) Establishment of speed limits for some urban streets and avenues. Nowadays the speed limits are:
   a) 30 km/h – near hospitals,
   b) 40 km/h – residential areas and areas close to schools;
   c) 60 km/h – connecting streets between districts and downtown;
   d) 70 km/h – marginal streets which guides the traffic out of the urban peripheral limit.
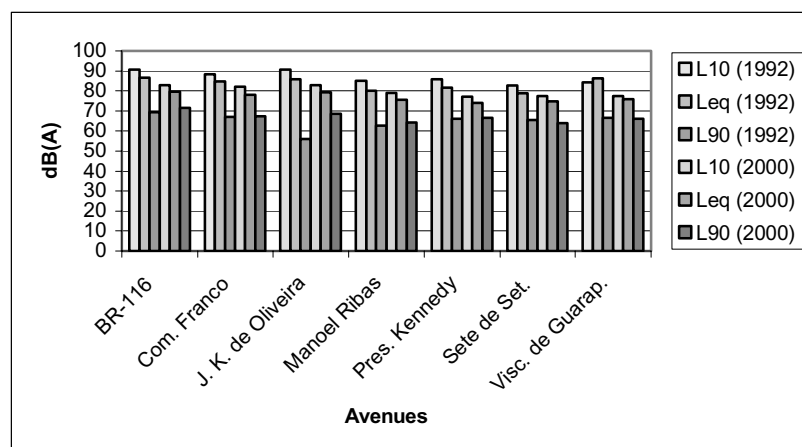

Figure 2: Comparison between emission levels in 1992 and 2000 for the main avenues in the city of Curitiba.

Another possible reason for the reduction in sound emission observed in Table 3 are the better conditions of the new road vehicles circulating in the Brazilian cities and in Curitiba, stimulated by the opening of the Brazilian market to the importation of vehicles, which occurred in the early 1990´s. This fact made the market more competitive, forcing the assemblers established in Brazil to improve their products. The construction of acoustically improved vehicles was certainly one of the improvements.

5 – CONCLUSIONS

We can thus conclude that the residential areas of the city of Curitiba are, during the day, environmentally noise polluted. About 80.6% out of the total locations measured in this study have shown equivalent sound levels over 65 dB(A). The good news for the inhabitants of Curitiba is that in 1992, 93.4% out of the measured locations had equivalent sound levels above 65 dB(A). The explanations for these findings are that the adoption of the law number 8583 of 1995, the installation of radars and electronic speed controllers and the adoption of speed limits for the urban zones of the city have considerably contributed for the reduction of urban noise pollution levels in the city.

There is still much room for improvement. The measures that can be done to relieve even more the environmental noise pollution are:

- Promote awareness of the population about the risks of daily exposure to high noise levels;
- Promote awareness of the population about the existence of a environmental legislation about noise emission;
- Tighter police action toward punishing those who emit sound over the allowable limit or drive over set speed limits.

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Urban Noise Pollution in Residential Areas of the City of Curitiba, Brazil
Community Annoyance Survey

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ABSTRACT

This study describes the reaction to environmental noise of the population of Curitiba (~1,6 Million inhabitants). Out of 1000 distributed forms, 860 were returned. The main isolated noise sources revealed by the survey as disturbing were traffic (73%) and neighbors (38%). As a class, neighborhood noise was pointed out as the most disturbing type of noise as 100% of the surveyed people indicated at least one of the items belonging to this class: neighbors, animals, sirens, civil construction, religions temples, night clubs, toys, domestic electric appliances. The main outcomes of exposure to noise were: irritability (58%), difficulty to concentrate (42%), sleeping disorders (20%) and headaches (20%).

1. INTRODUCTION

This research presents the results obtained from a social survey carried out in the city of Curitiba, Brazil (1,619,348 inhabitants).

The increasing in population and in number of vehicles have led to the appearance of a new component in urban life: the noise. The noise pollution and its consequent influence over the environment and over the life quality of the human bodies have been the center point of several studies conducted in several parts of the world (Kurra et. al., 1999; Sadu et. al., 1998).

All these surveys had a point in common: they had only analyzed the noise under an objective point of view, in other words, the measurements were carried out in various sites, and the urban areas surveyed were classified according to the measured noise levels as acoustically polluted or not.

Regarding the city of Curitiba, which is the scope of this study, Zannin et. al. have made a comparison between the noise levels measured in 1992 (Barbosa, 1992) and the noise levels obtained in 2000 (Diniz, 2000), and they have concluded that such noise levels suffered a reduction. However, none of the surveys conducted in Curitiba had the scope of obtaining information on the citizens' reaction toward this noise.

The main goal of this study is to show the annoyance reactions suffered by the citizens due to the urban noise, and show the main noise sources that cause this annoyance as well.

2 – Methodology

In order to attend the objectives of this research, the authors have developed a questionnaire. These objectives are:

- Identify the main noise sources in the urban environment;
- Identify the reaction of the citizens toward those sources.

The questionnaire contained questions regarding the demographic data of the urban residential environment and the annoyance caused by noise.

The citizens who would participate of the survey were randomly picked up, representing the citizens at the residential areas of the city of Curitiba according to the local Zoning and Area Usage Law (Prefeitura Municipal de Curitiba, 2000).

The participants of the survey have been contacted by telephone and then the forms have been sent to them via post service. After two weeks, fifty collaborators had the incumbency of picking up the questionnaires at the residences of the participants, totaling a return rate of 86% out of the 1000 distributed forms.

3 – Results

Among the respondents, 63% were man and 37% were woman, and they were predominantly between 18 and 24 years of age. Roughly, the age distribution among the respondents among 18 and 59 years of age follow the tendency of the age distribution of the city of Curitiba (IBGE, 1996).

Asked if they felt annoyed by the noise in his/her street, the major part of the respondents (44%) have answered that sometimes they did, and about 32% have answered that they regularly felt annoyed. In another question, the interviewed have classified the noise in his/her street as "little intense" (53%), "intense" (39%), and "very intense" (6%). 2% out of the interviewed people has not answered the question. More than half out of the respondents have affirmed that they had been living at the same location for more than 5 years.

The respondents have been asked if the noise in his/her street had increased or decreased during the period they had been living at their present locations. For this question, 60% out of them answered that the noise had increased.

This conclusion contradicts the results obtained in the study on the noise levels measured at the streets of Curitiba (Zannin et.al., 2001), in which a reduction on the noise levels have been observed when compared to the ones obtained by Barbosa in his survey (1992). In Barbosa's survey, the noise in 93.4% out of the 350 measurement sites were above 65 dB(A), whereas this percentage had dropped to 80.6% in Zannin's survey. The equivalent noise level (L_{eq}) of 65 dB(A) is considered as the threshold of health impairments by the preventive medicine (Belojevic´ G., Jakovlevic´ B, 1997; Maschke, 1999).

It is important to observe that the measurement sites and the time of the day they have been done (Zannin et. al., 2001) exactly match the Barbosa's criteria (1992).

Asked about what noise sources caused the biggest annoyance, the majority of the respondents have point the traffic, followed by the neighbors. No doubt is the traffic a continuous noise source, as well as the neighbors in many cases. However, several possibilities of answer for this question were related to non-continuous sources such as: sirens, fireworks, temples, night clubs and civil construction.

The majority of the respondents have answered that they sometimes felt annoyed by the noise in his/her street and have pointed out at least one of these non-continuous sources as the cause of annoyance.

The coexistence of continuous and non-continuous noise sources is a possible explanation for the fact that, despite several respondents have classified the noise as "little intense", the majority felt annoyed by this noise.

By considering this new focus it is possible to construct a new point of view in this analysis. For example, by putting together in a single group the respondents who always felt annoyed by the noise (32%) and the respondents who sometimes felt annoyed (44%), a new group is formed, denominated "Annoyed by the Urban Noise", which is represented by 76% out of the

respondents. The respondents who somehow felt annoyed by the urban noise belong to this group.

Among the respondents of the first group (related to those who always felt annoyed), 14% found the noise they are exposed to very intense, 58% found it intense and 25% found it little intense. By combining the above information it is possible to conclude that it is not absolutely necessary for the noise to be intense or very intense to cause annoyance on somebody since 25% out of the annoyed people found it little intense.

By putting together the respondents who classified the noise in his/her street as little intense and those ones who classified it as intense, a new group will be formed, represented by 93% out of the annoyed people. On the other hand, 5% out of the respondents who classified the noise as very intense did not feel annoyed at all.

Now, by considering the 24% who did not feel annoyed by the noise in his/her street, it is noticeable that 83% out of them classified the noise as little intense. These indicators show that those people do not feel annoyed simply by the fact they are not exposed to significant noise levels. Interesting results has also been obtained regarding the annoyance level and the nature of the noise sources. If the sources are analyzed separately, it is noticeable that among the respondents who felt annoyed by the noise in his/her street, 73% pointed out the traffic as the main source of annoyance and 38% pointed out the neighbors, conform shown in figure 1.
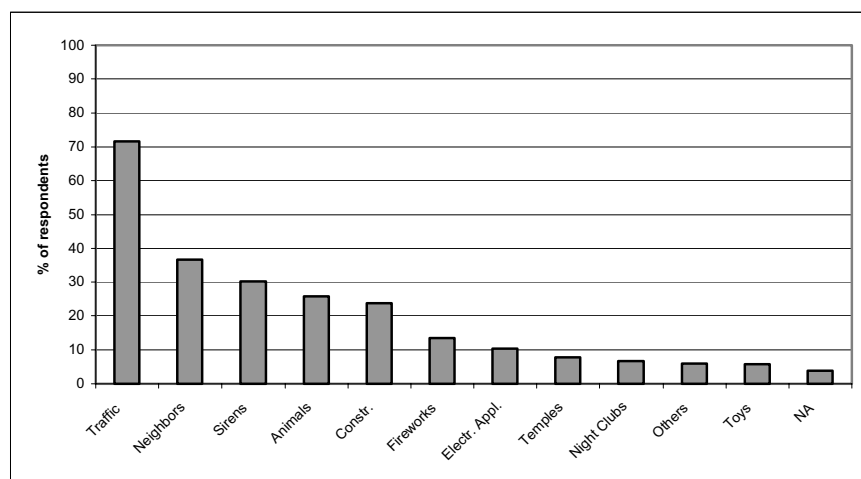
NA = No answer
Figure 1: Answers to the question: "What noise sources annoy you?"

Furthermore, it has been noticed that 52% out of the respondents had been living at the same location for more than 5 years. Among these respondents, 73% have perceived an increase in the noise in his/her street during this period, and 54% out of them pointed out the traffic noise as the main source of annoyance and 28% out of them pointed out the neighbors. As this question could accept multiple answers, there was still 18% who pointed out other sources of annoyance.

Surely the traffic highly contributes to the increase in the environmental noise pollution in Curitiba. However, it is not the only important factor. Other factors, like noise generated in the neighborhood of the respondents, can also be a significant factor in the subjective urban noise perception. Still among the respondents living at the same location for more then 5 years, 27% out of those who felt annoyed by the noise in his/her street also pointed out the civil construction,

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which is a type of neighborhood noise. With all this, it is possible to conclude that the rapid expansion of the city of Curitiba is a significant factor in the urban noise pollution increase.

At this stage it is possible to analyze how the urban noise analysis would be presented if the noise sources were grouped into two main groups, as follows:

1) Traffic noise: automobiles, buses, motorcycles, trains.
2) Neighborhood noise: neighbors, animals, sirens, religious temples, night clubs, civil constructions, toys and electrical appliances.

By considering this new approach of grouping the noise sources, it is noticeable that within the group "Annoyed by the Urban Noise" (76% out of the respondents), everybody has pointed out at least one of the sources grouped within "Neighborhood Noise" as a source of annoyance. Furthermore, 76% out of them also felt annoyed by the traffic noise. This information is illustrated in table 1.

Noise source	Percentage of annoyed (%)
Neighborhood	100
Traffic	76

Table 1: Noise sources of annoyance – grouped sources

Departing from these results it is possible to understand the apparent contradiction between the conclusion obtained from the urban noise in Curitiba (Zannin et. al. 2001) and the answers for the question "In your opinion, do you think the noise in your street has increased?". In the methodology adopted for the former study (Zannin et. al., 2001), the main source of annoyance considered was the traffic noise. However, it is noticeable in this analysis that the noise sources grouped within "Neighborhood Noise" are more significant for the community than the traffic noise, even if the latter is the most important one when non-grouped sources are considered. So, it is comprehensible that the subjective perception of the citizens has pointed out to an increase in the urban noise. The population has increased, consequently the neighborhood noise has also increased.

Belojevic and Jakovlevic (1997) pointed out some effects of the noise over the urban inhabitants: irritability, difficulty to concentrate, insomnia and headaches. It has been observed that everybody within the group "Annoyed by the Urban Noise" had declared that they felt at least one of the effects related above, predominantly irritability and difficulty to concentrate, conform figure 2.

4 – Conclusion

This survey has showed that the main isolated cause of noise annoyance perceived by the citizens of Curitiba is the noise generated by the traffic of automobiles, followed by the noise caused by the neighbors. Other studies on urban noise pollution had already detected the traffic noise as the main noise source.
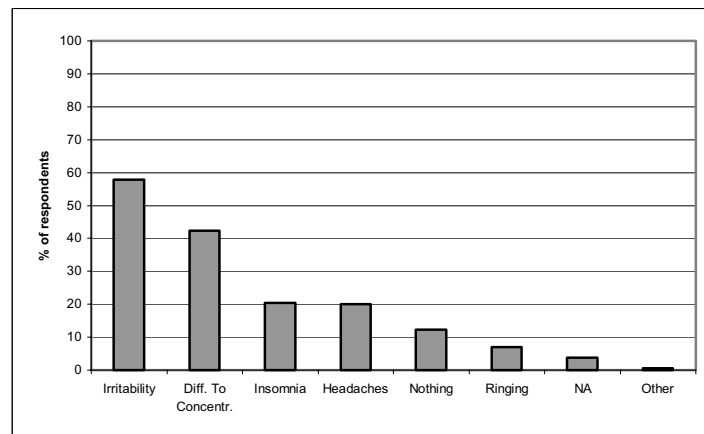
NR = No answer
Figure 2: Answers to the question: "What does the noise cause on you?"

The comparison between the noise levels measured by Barbosa (1992) and Zannin et. al. (2001) has pointed out a reduction on the emission levels. However, if two classes of noise sources are considered as follows: 1. Traffic Noise (automobiles, buses, motorcycles, trains) and 2. Neighborhood Noise (neighbors, animals, sirens, religious temples, night clubs, civil construction, toys and electrical appliances), it is noticeable that the neighborhood noise if the main source of annoyance, since 100% out of the respondents have declared that they felt annoyed by at least one of the sources grouped within this class. This survey contradicts the findings of Barbosa (1992) and Zannin et. al. (2001), which pointed to a decrease in the noise levels and did not care for the subjective reaction of the population, whereas this analysis have pointed to an increase in the noise levels according to the subjective response of the citizens. The respondents have pointed out the following effects of the urban noise: irritability (58%), difficulty to concentrate (42%), insomnia (20%) and headaches (20%).

5. Acknowledgements

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Summary record of the presentation on
the EU environmental noise policy

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The Green Paper on Future noise policy published by the European Commission in 1996 identified scope for improvement in 3 key areas:

- Firstly, gaps in our knowledge should be filled to better assess the noise exposure situation in Europe – in particular the lack of comparability between different Member States and between different sources of noise should be addressed.
- Secondly, the public should be more informed and involved.
- And thirdly, noise abatement should be part of an integrated strategy towards a better quality of life.

The Environmental Noise Directive

In that context, further to a proposal made by the European Commission in July 2000, the European Parliament and Council adopted on 25 June 2002 Directive 2002/49/EC relating to the assessment and management of environmental noise (END)[i]. The aim of this Directive is to provide a common approach to tackle noise issues across the EU. Its underlying principles are similar to those for other overarching environment policy directives:

- **Monitoring the environmental problem:** by requiring member states to produce strategic noise maps for major roads, railways, airports and agglomerations, using harmonised noise indicators namely L_{den} (day-evening-night level) and L_{night} (night level). These common indicators will enable strategic noise maps to be used to show respectively the number of people annoyed and sleep-disturbed. The first maps have to be produced in 2007.
- **Producing local noise action plans to address noise issues:** these are for competent authorities to draw up and publish with close public participation and consultation. The measures in the plans are entirely at the discretion of the competent authorities and they must be made available to the public. The first action plans have to be produced in 2008.
- **Informing and consulting the public:** in line with the principles of the Aarhus Convention on public participation in decision-making.
- **Developing a long-term EU strategy:** Article 10 of the directive requires the Commission to produce a report establishing a review of existing Community measures relating to sources of noise, no later that 18 January 2004. Furthermore, the revision clause under article 11 requires the Commission to submit in 2009 a report on the application of the directive, report to consider notably the need for further Community measures to address environmental noise.

The 6th Environment Action Programme

Further to a European Commission proposal of 2001, the European Parliament and Council adopted on 22 July 2002[ii] a decision laying down the Sixth Community Environment Action Programme that outlines the priorities for action on the environment for the next five to ten years. Under the key priority "*environment and health and quality of life*", one objective of the 6th EAP will be "*to substantially reduce the number of people regularly affected by long-term average levels of noise, in particular from traffic which, according to scientific studies, cause detrimental effects on human health, and preparing the next step in the work with the Noise Directive*".

This objective shall be pursued by means of the following actions:

- Supplementing and further improving measures, including appropriate type-approval procedures, on noise emissions from services and products, in particular motor vehicles

including measures to reduce noise from the interaction between tyre and road surface that do not compromise road safety, from railway vehicles, aircraft and stationary machinery;
- Developing and implementing instruments to mitigate traffic noise where appropriate, for example by means of transport demand reduction, shifts to less noisy modes of transport, the promotion of technical measures and of sustainable transport planning.

EU legislation relating to sources of noise
Regarding the reduction of noise emitted by specific sources, the European Union adopted legislation as early as 1970, with a Directive introducing noise provisions for road vehicles. Indeed, it appeared that for the purpose of building a single market and protecting the environment, EU wide legislation for noise sources should be implemented.

Since then, many other initiatives were taken and today the European noise legislation covers a wide range of sources, from tower cranes to aircraft:

Road traffic noise
- Motor Vehicles – Directive 70/157/EEC
- Motor Cycles - Directive 97/24/EC
- Tyres for motor vehicles and their trailers and their fitting - Directive 2001/43/EC

Aircraft noise
- Subsonic Aircraft - Directive 80/51/EEC
- Subsonic Jet Aeroplanes - Directive 89/629/EEC
- Limitation of the Operations of Aeroplanes - Directive 92/14/EEC
- Operating restrictions at Community airports - Directive 2002/30/EC
- Noise classification of civil subsonic aircraft (negotiations on Commission proposal COM(2001)74 in progress)

Railway noise
- Interoperability of the Trans-European high-speed rail system – Directive 96/48/EC
  - Technical specification for interoperability (TSI) relating to high-speed rolling stock – Commission Decision 2002/735/EC
  - Technical specification for interoperability (TSI) relating to high-speed railway infrastructures – Commission Decision 2002/732/EC
- Interoperability of the conventional Trans-European rail system – Directive 2001/16/EC

Miscellaneous
- Household Appliances - Directive 86/594/EEC
- Recreational craft (negotiations of Commission proposal COM(2000)639 in progress)

Next steps
The growing pressure from citizens to address noise, and in particular to tackle sources of noise, makes the case for a global assessment of noise exposure and its effects. Regarding exposure, the implementation of the environmental noise directive will provide comparable data across Europe, based on common indicators. But there is also a need to better assess the effects of noise on populations, and thus the potential benefits of addressing noise issues.

In that context, Annex III of the environmental noise directive states that "*dose-effect relations should be used to assess the effects of noise on populations*". The European Commission working group 2 on dose-effect relations already provided a position paper[iii] giving relations between noise expressed in Lden and percentage of people annoyed or highly annoyed. Besides, work is going on in order to develop dose effect relations for noise and sleep disturbance. If necessary, additional relations may need to be developed for vulnerable groups of population (e.g. children), different climates or cultures, or in the case of a reinforced sound-proofing or the presence of a quiet façade.

Additionally, it is a Treaty obligation to assess the costs and benefits of environmental legislation. This is why work has started in order to value noise and to introduce more cost & benefit analysis (CBA) in noise policies. CBA can bring together policy makers, engineers and noise experts by providing an analytical framework, or a checklist of questions that need to be answered, when working on noise management.

In order to develop the application of this helpful tool in noise work, the European Commission services organised a workshop during the Internoise 2001 conference: A Billion Euro Question: "How Much Should We Pay for Noise Control, and How Much is it Worth?".

This was followed-up by another workshop in December 2001 on the "State-of-the-art in noise valuation". The main objectives of the workshop were to discuss the best current valuation techniques and estimates for monetary value of noise exposure, and to identify research needs in that field. In order to support the work and discussions of the experts during the workshop itself, DG Environment had commissioned a review of the state-of-the-art in noise valuation. Documents relating to these recent initiatives can be found on the DG Environment noise website[iv]

Finally, an overview of the EU noise expert network was presented. This network was established in order to ensure exchange of information between stakeholders and to bring together expertise in the field of noise. Working groups have been established dealing on the one hand with noise emission (from roads, railways, airports and outdoor equipment) and on the other hand with noise perception (Wgs "Assessment of exposure to noise" and "Health and socio-economic aspects"). Furthermore, the CALM network is dedicated to the definition of the research needs in the field of environmental noise. The coordination of these groups is ensured by the European Commission, in co-operation with the noise steering group, which is a consultative body comprising representatives of Member States, candidate countries, NGOs, industry and noise experts.

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[i] Directive 2002/49/EC of the European Parliament and Council of 25 June 2002 relating to the assessment and management of environmental noise, OJ L 189 of 18 July 2002
[ii] Decision n°1600/2002/EC of the European Parliament and Council of 22 July 2002 laying down the Sixth Community Environment Action Programme, OJ L 242, 10.9.2002
[iii] Position paper available at: http://www.europa.eu.int/comm/environment/noise/noise_expert_network.pdf
[iv] DG Environment noise website: http://www.europa.eu.int/comm/environment/noise/home.htm

Urban Environmental Noise Pollution And Control Criteria

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Introduction

Urban environmental pollution of noise and control criteria have become a contemporary world problem. Noise pollution possesses local and disperse characteristics in the time and space, i.e. limitation in the range of environmental noise influence and dispersity in the distribution of noise source. Noise pollution is a kind of physical pollution. It is not fatal but it can directly influence sense organs. When the noise source produces noise, the people within the certain range would feel it. The urban noise source exists everywhere in the urban area.

The urban environmental noise exerts influence on people's living, learning and working. The clamorous noise makes person feel disagreeable. People can not concentrate their attention on work. The rest and sleep were also disturbed. Exposed to the high intense noise, people are difficult to hear risk alarm signal and communicate with each other, resulting in injurious accidents. With the development of modernization in China, civil cases about the noise disturbing people happen incessantly. According to the statistics of ten cities in China including Beijing, Shanghai, Tientsin and Fuzhou, the proportion of lawsuits of noise disturbance to the total pollution cases has been on annual increase, 29.7% in 1979, 34.6% in 1980, 44.8% in 1981, and 50% in 1990. It is one of imminent issues of noise which need to be brought under control

Today, more and more people are noticing the hearing damage and physiological nonauditory effects. Urban environmental noise has become a common concern of all members of society, so it is an impending necessity that we develop a guideline for community noise.

The noise pollution is complicated. The key to its settlement lies in effective control of urban environmental noise source, soundproof, noise abatement, cutoff of the noise transmission pathway, and individual hearing protection. To combine prevention with management, to give priority to prevention and to employ comprehensive management will be the executive principle for effective control of urban noise pollution.

1. ## Urban environmental noise source and classification.

Urban environmental noise source can roughly be divided into industrial noise, traffic noise, architectural noise and community noise. In line with the principle of noise source, it can also be divided into machine noise, aerodynamic noise and electromagnetic noise, and so on. There are two types of noise : stationary noise and non-stationary noise.

1.1 Industrial noise source

At present in China, there are the source of heavy industry noise such as the machinery, metallurgical, power, automobile, shipbuilding, chemical, petroleum, building industry and timber and the source of light industry noise such as the textile, paper making, glass, printing, food and electronic. The investigation on the noise from state- owned industrial enterprise have shown that the noise exposure level is less than 90 dB(A) in the electron industry and light industry, the noise of textile factories is 90-105 dB(A), the noise of machine-building industry is 80-120 dB(A), the noise of rock drill and ball grinder is 120 dB (A), the noise of pneumatic drill, pneumatic pick and air exhausting device is more than 120 dB(A), the noise of the gas-turbine

power station, air exhausting device and air stamping is 110-150 dB(A). When transmitted into neighboring residential area, the noise is often over 30 dB(A).

We have investigated noise sources of 121 factories in eight different trades in Fujian province and detected noise exposure level at 2255 points. The noise exposure level was less than national standard [90 dB(A)] at 1089 points, accounting for 48.29 of the total and the noise exposure level exceeded national standard [90 dB(A)] at 1166 points, accounting for 51.70 of the total, which revealed that the noise from half of the factories in Fujian province exceeded medical standard of the national law and regulation (Table 1).

Especially, there are not acoustics protection in residence area or the noise came from factories with defenceness prdcedure which will disturb the living of their residents. Table 1 Distribution of the Noise Exposure Intensity in the Prominent Trades in Fujian Province, China

point's SPL number dB(A) Trade	Centeral sound pressure level									
	80	85	90	95	100	105	110	115	120	Total
Textile	49	95	73	44	39	23				320
Machine	205	278	149	103	70	51	11	9		876
Iron and steel	11	24	17	11	10	2		1		76
Architecture	13	24	40	54	29	10				170
Chemical	20	33	28	16	11	5	4			117
Electron	29	15	5	4	2					55
Light industry	100	194	161	106	45	21	2		2	633
Ship-building		1	3		2	1				7
Total	425	664	473	343	206	114	18	9	3	2255
	18.85	29.45	20.98	15.21	9.14	5.06	0.80	0.40	0.13	100

1.2 Traffic noise

There are four kinds of transport including of highway transport such as cars, public transport, lorries, heavy-duty trucks; railway transport such as passenger and freight trains; civil aviation such as passenger planes, cargo aircrafts, helicopters; and water transport such as passenger ships, river steamers, merchantmen, dredged and yachts.

Traffic contributes to the main components of noise sources in cities. Investigations have revealed that the noise of the moving heavy-duty vehicle is about 89-92 dB, the noise of electric horn is about 90-100 dB and the noise of air horn is about 105-110 dB. General; when a big jet passenger plane is taking off, speech communication is interfered within l km both sides of the runway and people within 4 Km can not go to sleep and rest; when a supersonic passenger plane is flying at the attitude of 1500 M in the sky, it's pressure reaches the ground in a range of 30-50 km., where quite a lot of people are affected.

1.3 Noise at construction sites.

Following the development of urban modernization in China, the noise of civil constructions in cities is getting more and more serious. About 80% of buildings in Fuzhou city were build in recent twenty years, with sharp increase in urban noise pollution. The statistics made by departments concerned show that 10 meters away from the location with the constructing machines, a pile-driving machine generated 88 dB and a bulldozer and excavator 91 dB, which not only caused direct damage to civil workers but also exerted serious influence on the living and rest of the residents.

1.4 Noise in community

The community noise refers to the noise generated by the public activities, such as noise in the street, noise from the electronic equipment (air conditioner, refrigerator, washing machine, television set), musical noise (in the bar, hotel and club sound where pressure level of pop music exceeds about 120 dB), and the sound of clock, gong and drum by musicians or monks. More serious are high-pitch speakers, gong and drum, bursting firecracker, and the noise from parades and public activities in the street, seriously disturbing people's normal life and making people annoyed.

In short, the urban noise pollution in China is complicated, 20% comes from industrial production and 27% from traffic and transportation. About 98.67% industrially produced noise is concentrated on within the range of 80-105 dB (Table 1) while most of the urban traffic noise is concentrated on between 70-75 dB. Although the range influenced by industrial noise was less than that of traffic noise, the position of industrial noise source is basically fixed, lasting for a long time and the surrounding environment is affected seriously. Because of historic causes, some urban planning in China is unreasonable and residential areas is mingled with industry in cities. The civil disputes due to noise thus happen from time to time.

In general, the deteriorating tendency of the urban noise in China has brought under control to a certain extent in recent years; however, the range of noise pollution continues to enlarge. The statistical data of National Environmental Protection Bureau have shown that the overproof rate of noise in urban areas crowded with industry was 38.5 in 1990. So it badly needs the introduction of legal administration.

2. Negative impacts of the noise on hearing system of human body

Long duration of exposure to urban environmental noise, the inner ear of people will suffer pathological damage, temporary threshold shift (hearing fatigue), permanent threshold shift and deafness and so on . Today, the evaluation method of noise induced deafness is still the same as that of common deafness, i.e., damage threshold is fixed at where the mean hearing threshold level at the speech frequencies 0.5, 1 and 2 K HZ is equal to or greater than 25 dB. But the noise induced hearing damage has an effect on high frequency at first, so we must advocate taking some high frequency hearing loss into consideration when the noise induced deafness is evaluated. Investigation has proved that hearing damage threshold at high frequency and speech frequency is greater than or equal to 30 dB ($\geq$30 dB). The hearing loss at speech frequency increases with the enlargement in degree of hearing loss damage at high frequency. The major hearing loss notches at high frequency occurs at 4 K HZ and 6 K HZ. The proportion of "v" shaped notch is 70.68 . The proportion of "v" shaped notches at 4 K HZ, 6 K HZ and 4 - 6 K HZ is 92.60%.

Diagnostic criteria of the noise induced hearing damage

1. Objects to be observed are those urban residents who have been under the long influence of the environmental noise with bilateral high-tone tinnitus and whose auditory curve presents high-frequency descent, declining ≥20dB at the frequency of 4000 Hz or 6000 Hz.

2. Noise-induced hearing damage. The threshold of high frequency hearing damage will be set where the hearing loss is ≥30 dB at the frequency of 3000 Hz, 4000 Hz or 6000 Hz.

3. Occupational deafness and noise induced deafness. The mean of hearing loss ≥30 dB of the speech frequency 1000 Hz, high frequencies 4000 Hz and 6000 Hz is regarded as the diagnostic criterion of occupational deafness and noise induced deafness. The formula see the following: (HL1khz+HL4khz+HL6khz)/3 ≥ 30dB

4. Calculating method of hearing threshold in bilateral ears for the noise induced hearing damage and deafness (when the mean of the hearing threshold is calculated, take the round number in line with rounding-off method)

● First step
The hearing threshold value at all frequencies should be undergone an age correction.

● Second step
Calculate average value of hearing threshold of the monoear.
Average value of hearing threshold of the monoear

$$= \frac{HL\ 1khz + HL\ 4khz + HL\ 6khz}{3} \geq 30dB$$

● Third step
Calculate average value of hearing threshold of bilateral ears.
Average value of hearing threshold of bilateral ears

$$= \frac{\text{average value of hearing threshold in better ear(dB)}\times4 + \text{average value of hearing threshold in worse ear(dB)}\times1}{5}$$

5. Classification of Hearing Damage Standard:

Hearing loss of Communication noise (dB HL)	Degree of hearing loss	Difficulty in hearing speech in the common environment 1 meter away
< 25	Normal	Able to hear murmur/ whisper clearly
26 -- 40	slight degree of hearing loss (Mild hearing loss)	Unable to hear murmur, yet able to hear light sound
41 --55	Middle degree of hearing loss (Intermediate hearing loss)	Unable to hear light sound , but able to hear common speech
56 --70	Middle severe degree of hearing loss (light severe hearing loss)	Able to hear common speech , but able to hear high sound
71 --90	Severe degree of hearing loss (Severe hearing loss)	Unable to hear high sound, but able to hear shouting
>90	extreme degree of hearing loss (Extremely severe hearing loss)	Unable to hear shouting at the ear clearly

Classification of deafness

As people would feel their severity of deafness different from the result of audiometry, it is difficult for us to make classification of deafness in line with a certain standard. At the moment, the classification standard is mainly on the average value of thresholds at speech frequencies of HL 500 HZ. HL 1000 HZ and HL 2000HZ. The deafness is categorized into 4 grades;

Grade 1   Mild deafness   Difficulty only in hearing the low sound conversation.
          The average hearing threshold is 10-30 dB
                    .
Grade 2   Intermediate deafness   Difficulty in hearing conversation in short range
          The average hearing threshold is 60 dB

Grade 3   Severe deafness   Only able to hear a shouting at the ear.
          The average hearing threshold is 60 - 90 dB.

Grade 4   Complete deafness   Unable to hear shouting at the ear.
                              The average hearing threshold is more than 90 dB

Influence of noise on non-hearing systems of human body

The influence of urban noise pollution not only will be localized on hearing damage but also on human body as a whole. Its affected degree not only relies on the noise exposure intensity but is also related with the psychological and physiological status.

3.1 Influence of noise on neural system.

With long exposure to environmental noise, the majority of urban residents suffer from notable neurasthenia syndrome. Its clinical findings include annoying, headache, insomnia, dreams, decreased memory, which is generally worsened with intensified noise exposure.

3.1.1 Noise disturbes sleep and makes one restless. The degree of noise influence on human sleep diversifies to different people and is also related to its quality and intensity. It is studied that 52% of people will wake up from their sleep when environmental noise intensity reaches 52 dB(A), among whom some will only be awakened on 35 dB(A). The old and labor workers are usually easier to be awakened (Feng Gen Quan 1978).

3.1.2 Neurasthenia of restless type. Long stimulation of environmental noise may induce changes in human characters. This is notably manifested as fatigue and easy angry feeling and sometimes irritatation by trivial matters, owing to noise stimulation causing irregular excito-inhibition of cerebral cortex and abnormal conditional reflex. It is investigated that fatigue accounts for 38.4-58.3 , while easy angry feeling for 45.5-50 .

Beijing Health and Epidemic Prevention Station carried out a subjective survey of 16,943 workers with neurasthenia syndromein who were exposed to different sound pressure levels of 80-85, 90-95 and 100-105 dB(A) in1982. It revealed a neurasthenia positive rate of 24.55% in the noise contact group, compared with 6.70% in the control group (P<0.01). The difference was marked. The positive rate of neurasthenia symptom increased with the rise of noise sound pressure level (A SPL). It also showed an elevated tendency with the increase of working ages of noise contact. The examination result of electroencephalogram illustrated that the alpha rhythm in the noise contact group decreased to 71.2 , compared with 96.9 in the control group (P<0.001), and that the wave amplitude, regularity and stability of symmetry/symmetric basis line of the separate opposite areas of the two cerebral hemisphere in the noise contact group was not so good as those in the control group, showing that the degree of ECG rhythmical loss was higher than that in the control group. The result also showed that the presence of background slow and abnormal waves and the change evoked by excessive ventilation in the noise contact group were higher than those in the control group. The abnormal rate of electroencephalogram accounted for 25.2   in the noise contact group, which was notably higher that 5   in the control group (p<0.001) . It may well be that it is bear a relationship with active action decrement of the rhythm in the reticular structure of brain cortex and the impairment of the balance ability of the hypothalamic active process. The tests of the content of vanillylmandelie acid (VMA) in the twenty-four hours urine of 111 noise contact people found that the average VMA value accounted for 11.91±0.423 mg (the normal value is 8.22±4.7 mg) in the noise contact group,

which, after statistic treatment, was proved notably higher than that in the control group. The difference was objectively significant (P<0.01) to show the change of sympathetic nerve functions and the influence of noise on the neural system.

3.2 Influence of noise on the cardiovascular system.

Noise may keep man's sympathetic nerve in tension and therefore induces rapid heart beat, elevated "T" wave of electrocardiogram, arrhythmia, conductive block, cramp of blood vessels, change of blood pressure and so on. It is learned that the artery pressure is unsteady, and some people have increased blood pressure, while others have decreased one.

Influence of noise on pulse. It is investigated that if one is long exposed to noise his pulse will tend to increase. Among 1,450 people in long noise exposure, 1.72% have rapid pulse (>100 times/minute), while 156 people in the control group are not found with rapid pulse. There's notable difference (P<0.05) between two groups. Rapid pulse phenomenon is not found in the 80-85 dB(A) noise contact group. Only when the noise exposure level reaches 90-105 dB(A) can we find rapid pulse phenomenon. It is reputed that only when noise exposure level is above 90 dB may we find rapid pulse phenomenon.

Influence of noise on heart. It is manifested in electrocardiogram that ST-T segment is mostly characterized by blood deficiency change, showing that noise may affect the function of heart's coronary circulation and cause abnormal blood supply to the heart. Another characteristics of electrocardiogram is apparent increase of sinus arrhythmia, which shows that noise may induce vegetative nerve functional disturbance, bringing forth functional changes of the heart, the nerve and especially the rhythm and the conducting systems. Among 1,450 people in the noise exposure group, 15.16% are found with sinus arrhythmia, compared with a positive rate of 6.25% among 156 people in the control group. There is apparent difference (P<0.05) between two groups.

3.3 Influence of noise on blood.

Literature at home and abroad reported that long exposure to intensified noise may result in abnormal functions of the autonomic nerve and the blood vessel, decreased tension of the blood vessel wall, leukocytosis, lymphocytosis, anemia and so on. We investigated 1,450 people in the noise exposure group for total white blood cells and their classification and hemoglobin determination with the comparative result of 156 people in the control group as follows.

Table 3 **positive rate of total white blood cells, classification and hemoglobin**

Group	Cases No.	Leukocytosis No.		Eosinoplilia No.		Lymphocytosis		Hemoglobin descent	
Noise exposure	1450	0	0.14	100	6.89	655	45.17	505	34.83
control	156	0	0	10	6.41	57	36.50	27	17.33
P value		P>0.05		P>0.05		P<0.05		P<0.01	

It is found in this investigation that lymphocytosis and hemoglobin descent phenomena in the noise exposure group, compared with that in the control group, are of apparent significance ($p<0.05$, $P<0.01$). Hemoglobin decent is to some extent related to the change of sound pressure level ($p<0.01$), showing that long environmental noise exposure would result in hemoglobin descent.

4. Standard values of environmental noise in different urban area of China
4.1 Standard values of environmental noise in different urban areas. (see Table 4):

Table 4   equal effect
              unite: sound pressure level
                 Leg dB(A)
_____

Applied Area	Day	Night
special residential quarter	45	35
residential, cultural & educational area	50	40
mixed area of first class	55	45
mixed area of second class & commercial center	60	50
Industrial area	65	55
two sides of traffic artery	70	55

_____

The definition of applied areas:

• "Special residential quarter" is the residential area in need of quietness.

• "Residential, cultural & educational area" means the separate area for residence, culture, education and government.

• "Mixed area of first class" means the area mixed with commerce and residence.

• "Mixed area of second class" means the area mixed with industry, commerce, residence and traffics.

• "Commercial center" means the commercially dense and prosperous area.

• "Industrial area" means the definitely planned area for industry in a city or a district.

• "Traffic artery" means the road with a traffic volume over 100 vehicles per hour.

• The range limit of the applied area in this standard is specified by local governments.

• The peak value of noise frequently and suddenly produced at night is not allowed to exceed the standard value of 10 dB(A), eg. pneumatic drill, pumping air noise. The peak value of noise

accidentally and suddenly produced at night is not allowed to exceed the standard value of 15 dB(A), eg. short hoot sound.

• Noise standards for the day and the night are specified by local government according to the local convention and seasonal change.

4.2 Method of noise detection

4.2.1 This standard value is the tolerant outdoor noise level. The detecting spot is located in one meter distance away from the residential or the working building. The propagation device is placed over one meter above the groud, where noice influence is sensitive, eg one meter out of the window.

4.2.2 In this standard, the statistical method of noise level detection and equivalent sound pressure , is done at the designated location under clause 1.2 accoding to the regulation of environmental noise detection.

4.2.3 Noise source assessment see "Guidelines for Community Noise" chapter 4.

5. Overall control of urban noise

There are three main factors in urban noise transmission, i.e. noise source, transmission approach and noise contacter. Only when these three factors are simultaneously present can noise result in disturbance and harm to human beings. Therefore, these three factors must be considered to bring urban noise under effective control.

5.1 Noise source control and technical reduction of noise.

Environmental noise mainly come from eletrical machinery products. In order to weaken the noise intensity of any noise source, products must be restructured, and component processing precision and whole machine assembly be improved. Technical noise reduction is mandatory through legistration to bring a remarkable reduction of the intensity of noise generators to the national standard__ Industrial Enterprises Hygiene Standard and Different Urban Areas Environmental Noise Standard. The state regulates that new factories to be built must control the noise exposure level below 85 dB(A), the built factories below 90 dB(A), and urban environment in the day-time below 45-70 dB(A) and in the night-time below 35-55 dB(A). We adopted an epidemiological investigation method in an statistical analysis of 12,286 cases from a total of 42,396 workers in 1,034 factories in nine provinces and cities.

The analysis proves that 90% workers may be protected for 20-30 years from hearing loss in a noise exposure level below 90 dB(A) when medium and high frequency hearing damage threshold is taken as the standard, and 90% people may be protected for 20-30 years from deafness in a noise exposure level below 90 dB(A) when the average hearing value of vocal frequency above 25 dB is taken as the standard. Technical noise reduction is one of most effective and radical method. It may be carried out in different areas such as machinery equipment, engineering construction and production technology to eliminate noise source, reduce noise intensity and control noise transmission. An assessment of different noise sources must first be considered in noise reduction of industrial machines and facilities.

Only when we have a good understanding of the intensity order of noise sources can we make a proper choice among different possible measures of noise reduction. These measures include machine noise control, air flow noise control, electromagnetic noise control and vibration isolation techniques. Noise producing mechanism from different sources is usually not simple, for example, when a pneumatic drill is working, noise produced may be mechanical, pneumatic and electromagnetic.

5.2 Noise transmission control

5.2.1 Sound absorption and noise reduction. It is an effective method to control noise intensity in the noise transmission. A same machine produces stronger noise when working indoors than outdoors because not only sound transmitted by air medium can be heard but also the mixed sound reflected from the surfaces of different indoor objects. The intensity of mixed sound depends on the sound absorption ability of the surfaces of different indoor objects. Smooth, stiff object surfaces reflect more sound waves and intensify the mixed sound. Good sound absorption materials can absorb some sound energy projected on their surfaces, and therefore reduce the intensity of the mixed sound effectively. Good sound absorption materials require porousness on the surface and the interior. Pores should be tiny, interconnected with one and another, and open to the exterior so that sound waves are easy to transmit to the interior of materials. There are three common types of sound absorption materials, ie. fibre, foam and granulation.

• Porous sound absorption materials of fibrous type are glass fibre, mine woos cotton, woolen blanket, sugarcane fibre, wood silken board and so on.

• Sound absorption materials of foam type are polyamino-methylester foam plastics.

• Sound absorption materials of granulation type are expansive pearl rocks, tiny pore sound absorption bricks. Porous sound absorption materials have a good ability to aborb high frequency sound, but a poor ability to aborb low frequency sound. To solve this problem, common vibration sound absorption structure is designed by the principle of common vibration sound absorption, which achieve a good effect of sound insulatin

5.2.2 Application of silencer

The silencer is a device which allows air flow pass and at the same time reduces noise effectively. It can be generally used for all kinds of pneumatic equipment to reduce the noise produced at the entrance and exit or transmitted along the pipeline, such as ventilators, compressors, air pumping machines, internal combustion engines and gas turbine engines. It is also widely used to control noise upon high pressure air discharge. Various measures are taken for silencers including resistance sound silencing, reactance sound silencing, consumption sound silencing, and diffuse sound silencing.

5.2.3 Sound insulation techniques

Sound insulation is also a common technique to control noise in engineerings. Some common components are sound insulation walls, masks, rooms and screens.

5.3 Individual hearing protection

Individual protection is necessary when noise control in its sources and transmission is difficult to meet the standard. In fact, it is effective and the most economical in many occasions. It is also one of effective measures to lessen noise impairment. Some alternatives used for this purpose include sound preventive ear plugs and masks, and sound insulation caps and cotton, which may reduce 10-40 dB noise exposure level.

5.4 Countermeasures for overall control of urban environmental noise.

5.4.1 Scientific, rational planning should be made for a city and its urban environment. Special industrial parks are consolidated to construct. Forces are organized to help factories and enterprises with high noise pollution carry out regional noise control plan. Residential areas should be protected with necessary noise isolating belts or green belts to lessen the noise impact from industrial areas. Residential and cultural areas should be located far from high noise sources such as industrial areas and airports. More urban trees and grasses should be planted to reduce traffic noise pollution. When necessary, noise preventive screens are to be built along two sides of the road.

5.4.2 Enterprises of medium and large size with serious noise disturbance to people should be restructured or removed if they are difficult to be reformed on the site. It should be closely carried out to assess the influence of noise on environment and follow the formality of noise prevention approval to avoid new noise pollution.

5.4.3 "The Rules for Prevention and Control of Environmental Noise Pollution of the People's Repubic of China" and relevant environmental noise standards should be followed strickly. Supervision and tests must be strengthened and noise control techniques be widely applied. Those unqualilfied are given a limited period to tackle noise pollution.

5.4.4 Noise limiting and grading standards are necessary to be applied to mechanical facilities with different noise sources, and noise vibration control level to electromechanical products. Advanced guilt type products with low noise are developed to replace or discard those with high noise.

The properties of special materials including sound absorption and silencing, and sound and vibration insulation are to be improved. The techniques of sound silencing and noise reduction must also be enhanced.

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