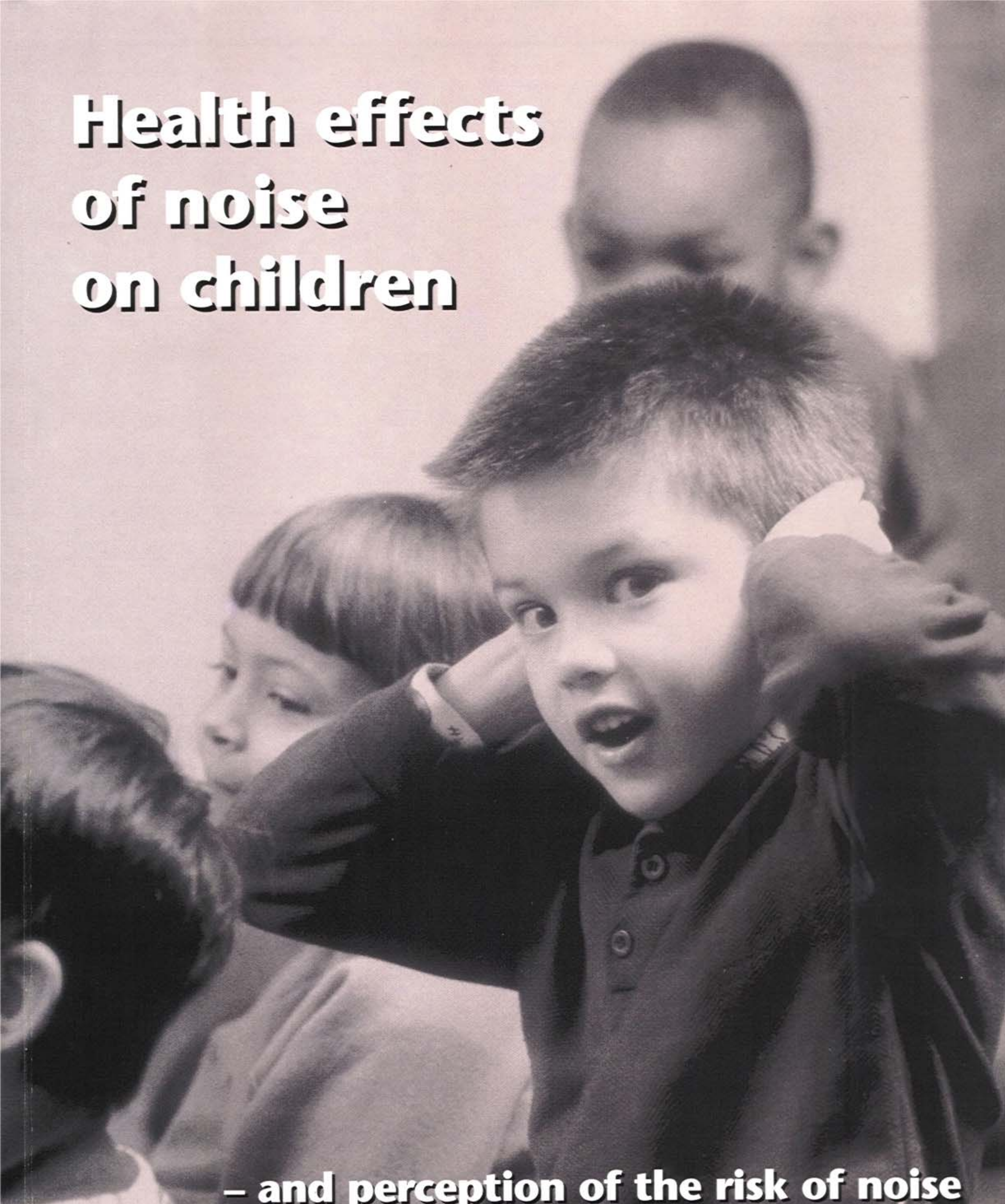
Health effects of noise on children



– and perception of the risk of noise

Edited by
Marie Louise Bistrup

National Institute of Public Health

Report from a project coordinated by the National Institute
of Public Health Denmark

Health effects of noise on children and perception of the risk of noise

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Preface

The National Institute of Public Health has hosted the leadership and project coordination of the project Health Effects of Noise on Children and Perception of the Risk of Noise. The report is a result of the cooperation between a group of European partners that was formed to carry out the project. On behalf of the partners, the Institute hereby publishes the report *Health effects of noise on children and perception of the risk of noise.*

The partners are Willy Passchier-Vermeer and Henk M.E. Miedema, the Netherlands; Staffan Hygge, Sweden; the International Network on Children's Health, Environment and Safety (INCHES) represented by Peter van den Hazel, the Netherlands; Lis Keiding, Project Leader, and Marie Louise Bistrup, Project Coordinator, Denmark; and Mário Cordeiro and Elsa Figueiredo, Portugal. We thank the partners for their interest and cooperation.

A planning meeting among the partners took place on 24–25 February 2000 in Leiden, the Netherlands, and a seminar took place on 19–20 June 2000 in Copenhagen, Denmark. We thank TNO Prevention and Health in Leiden for hosting the planning meeting and we thank the WHO Regional Office for Europe in Copenhagen for hosting the seminar in June. We thank the participants in the seminar for their cooperation and contributions before, during and after the seminar. This report also serves to present the results of the seminar.

Marie Louise Bistrup is the editor of the final report. The chapters have been written by one, two or three partners who are responsible for the scientific content and references for a chapter. The authors are Marie Louise Bistrup, Staffan Hygge, Lis Keiding and Willy Passchier-Vermeer. The partners have had an opportunity to comment on all chapters. For practical reasons, no occasion was established to collectively discuss all chapters. We thank the authors for their good work and commitment.

Carrying out the project has been interesting and rewarding. We are convinced that preventing noise will become an important public health challenge, in part because noise may adversely affect children's health and well-being. We have met goodwill and understanding for the objectives of the project. We hope the report will give the reader an impression of the range of research available and of priorities for future research.

We thank the European Commission for supporting the project under Grant Agreement No. S12.143779 (99CVF2-601) from the programme on Pollution Related Diseases administered by the Health and Consumer Protection Directorate-General. The European Commission has provided 80% of the funding for the project.

We thank Jens Steensberg, Ph.D., Medical Officer Emeritus, Denmark, for encouragement in carrying out this project and for reviewing the first draft of the report. We thank Torben Astrup, Senior Consultant, Ingemansson Acoustics (Denmark) for reviewing Chapter 2 on definitions of noise; we thank Dr Mary Haines, Lecturer in Psychology (United Kingdom) for reviewing the draft of Chapter 5 on perceptions of noise; and we thank Sharon Airey, Research Associate, Heriot-Watt University, Edinburgh (United Kingdom) for reviewing the final draft of the report.

Marie Louise Bistrup has been an enthusiastic and persevering project coordinator, author and editor, and we appreciate the commitment and energy she has devoted to this project.

Lis Keiding
Project Leader

Mette Madsen
Deputy Director

Contents

Executive summary

This project focuses on the effects of noise on children and on perceptions of the risk of noise from a public health perspective. Children have been chosen as the focal point because children may be more vulnerable to noise than adults, because children have less control over their environments and daily situations than adults have and because legislation and policy have not traditionally focused on the special needs of children.

Noise is any sound – independent of loudness – that may produce an undesired physiological or psychological effect in an individual and that may interfere with the social ends of an individual or group.

Children's daily lives are full of noise, and children make noise themselves. It is as if children are being brought up in noise and learn to regard noise as a normal situation. But noise can adversely affect children. The most well-known and most serious consequences of noise are hearing damage and tinnitus. Noise can also provoke a stress response in children that includes increased heart rate and increased hormone response. Noise can disrupt sleep and thus hinder needed restoration of the body and brain. Noise can negatively affect children's learning and language development, can disturb children's motivation and concentration and can result in reduced memory and in reduced ability to carry out more or less complex tasks.

Noise often leads to strenuous use of the vocal cords, which may lead to hoarseness and the development of vocal nodules.

Even before birth, a foetus can be harmed by the pregnant woman's occupational noise. A premature infant may spend time in an incubator in a room with noisy machinery and can be surrounded by noise in hospitals. Homes and institutions are exposed to environmental noise from rail and road traffic and airports, from neighbours and from machinery and equipment inside and outside the buildings.

In day care institutions and schools, the background noise sets the scene for the noise produced by the children themselves. In leisure settings such as discothèques and at rock concerts, loud sound that may be harmful is a desired experience for many adolescents.

Children sometimes accept noise and sometimes they are annoyed by it. Adolescents find that noise in some situations is annoying and interfering with the tasks at hand, and the level of noise can to some extent explain the experienced annoyance of noise.

Many children feel that they were sometimes annoyed by noise during lessons. When more than 50% of students report that there often or sometimes are noise and turbulence in class, noise and turbulence must be regarded as factors impacting negatively on student's learning and well-being.

Children need to be able to find peace and quiet as well as room for being noisy. The adults are responsible for establishing settings that can support children's needs, and protection of children's health by legislation, standards and behaviour modification should be based on knowledge on the harmful effects of noise on children.

In order to help establish a better background for effective interventions, the project has identified a range of research items. The following is a shortlist of future research priorities:

1) effects of noise on cognitive functions in children;
2) effects of noise on children's sleep;
3) the magnitude and significance of noise annoyance among children;
4) intervention programmes and identification of best practices of preventing harmful effects of noise on children; and
5) children's perception and risk perception of noise.

1. Introduction

The inspiration to initiate a project on children and noise stems from a notion that children are more susceptible[1] than adults to a range of environmental factors, that children have less control over the environment than adults and that children have a right to a safe and healthy environment. The International Network on Children's Health, Environment and Safety (INCHES) has initiated projects that focus especially on the effects of the environment on children. Noise is one of the environmental effects of interest that seems to be gaining increasing attention, is increasing in magnitude and is inadequately researched.

A basic position for addressing the relationship between children and noise is that children have a need to be heard, that children during their activities may themselves be noisy and that they also have a need for peace and quiet.

Many parents, educators, health care personnel and adults in general find that children have become noisier and children also complain about noise. It seems that not only children but their environments have become noisier. Noise pollution is increasingly being recognised as an environmental hazard, and children are a high-risk group vulnerable to some adverse effects of noise (2, 3). Children of a certain age and maturity are also competent and active about their own situation, and many children are engaged in preventing harm to the environment, be it globally or locally. Developing preventive strategies requires gaining insight into how children themselves perceive noise and the risk of noise and to assess children's perception alongside adult and professional perceptions of noise.

1.1. Noise as a public health issue

Noise may be characterised as a "transparent" environmental hazard. Noise cannot be seen, smelled, touched, removed or purified as, for example, waste or water. The effects of noise do not pose a stress on the environment *per se* but accumulate in individual people as noise experience with effects on hearing and well-being.

Noise is perceived at an individual level, but when a critical mass of individuals experience noise as a problem that causes hearing problems, disturbs cognitive functions and reduces well-being, noise becomes a public health concern. Noise as a public health issue is relevant to the general public and to politicians and administrations at the local, national and international levels. Acknowledging the scope of noise means including noise in occupational health problems among adults.

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[1] The susceptibility of children is a dimension of child development. Another notion is a culturally determined perception of vulnerability, in which children are seen as passive, receptive and dependent objects (1). Children are complex and competent and actors in their own lives and have independent views as well as being dependent on adult protection and care.

For children, the situation is different as they usually have no influence in which school or institutions they are enrolled, and they are thus forced to stay in environments surrounded by noise, such as kindergartens, schools and leisure settings. This makes it imperative to study and to regulate the noise levels in children's settings and to study and inform about the effects of noise on children.

1.2. Aims of the project

The aims of the project Health Effects of Noise on Children and Perception of the Risk of Noise are:

- to establish an overview of research on the health effects of children's exposure to noise;
- to collect scientific evidence, including dose-response relationships where possible, on the adverse effects of noise on children;
- to identify settings of noise and noise levels to which children are regularly exposed;
- to collect indicators of perceptions of the risk of exposure to noise, with a focus on children; and
- to identify needs for and to suggest more research.

The overall aim is to give a background for preventing the adverse effects of noise on children. The project will attempt to identify the aspects of a definition of noise that could be relevant for preventive purposes.

1.3. Age groups

The study defines "children" as children and adolescents up to 18 years old. The study excludes employed children and adolescents within the age group, because their environments typically are regulated by occupational health standards, which is not addressed in the study. The study includes the foetus and the pregnant mother.

1.4. The role of adults towards children in noise

From a developmental viewpoint, children are naturally noisy sometimes and also need to find peace and be calm. Adults are responsible for fulfilling children's needs while respecting the psychological and physiological rhythms of the child. Adults are responsible for establishing environments and settings that support these needs. Adults make policy and legislation, carry out research and implement policy and legislation. It is up to adults to provide healthy and supportive environments that are designed to care for children and their hearing, health and well-being.

1.5. Process

In summer 1999 the National Institute of Public Health, Denmark and INCHES initiated the project. Partners from three countries in addition to the coordinators were identified and contacted, and the project proposal was developed among the partners. An application was forwarded to the European Commission in August 1999, and the project was approved in December 1999. The partners in the project are listed in Annex 1. The project is supported by the European Commission by Grant Agreement No. S12.143779 (99CVF2-601).

The partners met in February 2000 at the TNO Institute in Leiden, the Netherlands and agreed on a shared format for reviews and developed a plan of work and timetable and a table of contents for the report. A seminar was planned for researchers, practitioners and children's rights experts to assist the partners in identifying proposals for common definitions of noise, identifying how to overcome barriers to achieving common definitions of noise and identifying gaps in the research and proposals for future research. The participants of the seminar are listed in Annex 2.

The seminar took place on 19–20 June 2000 at the World Health Organization Regional Office for Europe in Copenhagen, Denmark. Twenty-five people participated in the seminar, commented on preliminary research results and participated in group work on definitions of noise and on research needed and gave feedback on a draft questionnaire on preventive measures. The reporting of the seminar consists partly of an independent report on preparations prior to the seminar and on results of group work at the seminar, and of the papers delivered at the seminar. The reporting to seminar participants will be completed with the dissemination of the current report to participants.

1.6. Additions to the plan of work

At the planning meeting, an opportunity emerged to develop a questionnaire about perception of risks by various professionals and by children. It was agreed that the Portuguese partners would prepare a questionnaire and distribute and collect it and analyse the responses to the questions. The preliminary results were presented at the seminar in Copenhagen, but no report has been conveyed.

At a later stage an opportunity arose for studying children's perceptions of noise by running a workshop at the United Nations Environment Programme Millennium International Children's Conference on the Environment in Eastbourne, United Kingdom on 22–24 May 2000. INCHES collaborated with the researchers and the conference organisers in including the subject of noise in the theme on "Living in cities". Dr Mary Haines (United Kingdom) organized and carried out a separate workshop on noise and children. The report is contained in Annex 3.

1.7. This report

The report comprises five independent chapters:

- Definitions of noise (Bistrup & Keiding)
- Settings of noise (Bistrup)
- Effects of noise (Passchier-Vermeer, with Hygge for section 4.4.4 and Bistrup for sections 4.5 and 4.7)
- Perceptions of noise (Bistrup)
- Future research (Keiding & Bistrup)

The chapters have been written independently by the partners, and the name of the partner responsible appears in each chapter. Each author has been responsible for retrieving literature and for the quality of references. For some chapters this has led to a dominance of national references if European or general references were not in practice available within the time frame of the project.

The partners have had an opportunity to comment on all chapters. No occasion emerged for discussing collectively the entire report. We thank Jens Steensberg, Ph.D., Medical Officer Emeritus, Denmark, for encouragement in carrying out this project and for reviewing the first draft of the report. We thank Torben Astrup, Senior Consultant, Ingemansson Acoustics (Denmark) for reviewing Chapter 2 on definitions of noise; we thank Dr Mary Haines, Lecturer in Psychology (United Kingdom) for reviewing the draft of Chapter 5 on perceptions of noise; and we thank Sharon Airey, Research Associate, Heriot-Watt University, Edinburgh (United Kingdom) for reviewing the final draft of the report.

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2. Definitions of noise

by Marie Louise Bistrup and Lis Keiding

"In the modern city, 'noise' became a public health problem, and for some its definition came to be rooted in ideas about the physiological and psychological damage that it was seen to incur. For others, the definition was rooted in the idea of noise as a social problem, and its 'wantedness' or 'unwantedness' was the primary characteristic. At the same time, in the fields of electrical engineering and communication, noise was defined as an electrical signal which interfered with another, information-carrying signal. Acoustical engineers developed new electro-acoustic tools for measuring sound, and a physical unit for measuring sound and noise – the decibel – was created." (1)

2.1. Definition of noise

The introductory quote mentions three elements of historical importance for definitions of noise:

- the physiological and psychological damage noise was seen to incur
- the "wantedness" or "unwantedness" of noise
- the physical properties of noise: noise was defined as an electrical signal.

The aim of this chapter is to describe elements of noise and reflect the relevance of these elements for definitions of noise in relation to children.

Characteristics of noise

Sound is an environmental factor, and it is relevant to look at human exposure to and effects of noise. The exposure depends on:

- the emission of sound
- how the sound is received by the human body
- the setting for the emission and perception of sound.

The effects of noise exposure consist of what is heard or felt, of auditory and non-auditory effects.

A sound wave is a physical disturbance of molecules within a medium – air, water or solid – that can be detected by a listener. Sound waves result from a vibrating object, a sound source. These different waves combine and reach the listener via numerous direct and indirect pathways. The listener's inner ear contains organs that vibrate in response to these molecular disturbances, converting the vibrations into changing electrical potentials that are sensed by the brain – allowing the phenomenon of hearing to occur (2).

The physical qualities of sounds can be described by quantitative values. The characteristics of sound are:

- the sound intensity;
- the frequency of the sound; and
- the periodicity and duration: constant, intermittent, sudden and during day or night, also called time history.

The sound intensity refers to the rate of flow of sound energy per unit area in a specified direction; it therefore measures not only sound pressure but also molecular air particle velocity, including direction. Intensity is a vector quantity. The frequency of the sound is defined in terms of the number of wave cycles that occur during one second; the unit used for describing frequency is the hertz (2).

The physical quantity of sound pressure level is experienced as the loudness of sound and is expressed in decibels (dB) on a logarithmic scale. The A-weighted sound pressure level is used to approximate perception of noise by the human ear. "A-weighting is a standard frequency weighting that de-emphasizes low-frequency sound similar to average human hearing response and approximates loudness and annoyance of noise. A-weighted sound pressure levels are frequently reported as dBA." (2).

Noise exposure is extensively characterised, including the terms used in this report, in Annex 3, prepared by Willy Passchier-Vermeer for the TNO report *Noise and the health of children* (3). Dr Passchier-Vermeer has agreed to include this in this report.

Measuring sound

Acoustical measurement techniques provide a means of quantifying sound levels in an environment. A sound level meter indicates sound pressure levels, but to adjust the measurement to correspond to perception, the averaging of sound pressure levels over time is referred to as time-weighted average measurements. Measuring A-weighted sound levels is common. Different types of frequency weighting are applied to make sound pressure levels better correspond with human perception of loudness. Sound level measurements allow calculations, analysis and prediction of various acoustical factors, such as measurements of background noise, sound insulation or reverberation time and acoustical absorption in a room (2).

Measuring sounds is a science involving the above-mentioned elements and variations thereof, and it falls outside the scope of this report to identify the characteristics of sound measurements. See *Guidelines for community noise*, Chapter 2, Noise sources and their measurement (4).

2.2. Interest-based definitions

Sound can become noise. Noise is often defined as unwanted sound. This definition reflects the subjective dimension of a definition of noise but does not take account of the fact that *wanted* noise can cause adverse effects. If this fact is taken into account, a modified version is:

- Noise is sound with any kind of negative effect on human health and well-being (biological, social, psychological, behavioural and performance outcomes). [proposed at the International Seminar on Children and Noise, Copenhagen, 19–20 June 2000]

Scientists study health, auditory and non-auditory effects of different kinds, and some scientists attempt to establish dose-response relationships. Within the definitions of noise of various professions, noise can be related to different outcomes, so that, for example, physicians use or prefer another definition than people in the acoustics profession or within psychology or among public health, legal and administrative professionals.

A relatively reliable measure of annoyance as a subjective response to noise can be established, but establishing whether noise is causing changes in body physiology is much more difficult. Bernard Berry, head of noise standards at the National Physical Laboratory, United Kingdom, says: "All too often, the measurement and description of the physical exposure is regarded as of secondary importance, and yet it is one of the key components in enabling us to relate and compare different research findings. This points to the need for researchers to make use of internationally standardised measures, such as ISO 1996, but also to retain sufficient flexibility in the measurements of noise exposure to allow us to investigate the possible importance of other measures." (5, 6).

Legislation and regulation

For regulatory purposes in legislation, standards and ordinances, it is imperative to define each word or concept in order to clearly state the goals and methods of the regulation. The following are examples from an ordinance of common concepts (7).

- "A-weighted sound pressure level" means the sound pressure level as measured with a sound level meter using the A-weighted network. The symbol is L_{PA} and the standard notation is dB(A). "Decibel" means the logarithmic and dimensionless unit of measure often used in describing the amplitude of sound. Decibel is denoted as dB.

- "Impulsive noise" means a noise containing excursions usually less than one second, or sound pressure level 20 dB(A) or more over the ambient sound pressure level using the fast meter characteristic.

Legislation and regulation must be based on precise action levels (limit values), including the technical aspects of noise such as frequency, intensity, time of day or night. These action levels are ideally based on solid knowledge on dose–response relationships, but they are determined politically, whether in the realm of government or in the realm of standardisation committees. The knowledge is often scattered with regard to the effects of environmental factors, including noise. Definitions may also include health effects not yet well established by scientific studies but suspected of having adverse effects on children. Further, definitions may include especially sensitive groups, depending on a political decision on the extent to which regulation should or, in practice, can protect these groups. A demanding aspect for establishing regulatory definitions is the fact that regulatory standards and procedures should be distinct enough to be controlled.

Definitions of noise based on physical terms for measuring has a legal and economic impact by specifying how much noise exposure can be tolerated according to legislation and the criteria for noise emissions to which products must adhere. It is also a question of who is responsible for the noise levels at, for example, rock concerts: is it the organizer, the band playing, the sound manager or the people owning and leasing the scene (8)? Some countries either recommend or regulate maximum sound levels at pop and rock concerts, but it needs to be tested who legally is responsible for hearing damage resulting from noise exposure at concerts.

Financial interest can be at stake, such as the toy gun mentioned in the chapter on settings for noise. The toy gun is legal to produce even if some scientists consider the noise emitted by a powdered toy gun (a toy gun that makes noise) to be dangerous for children's hearing (9).

Noise and stress

Noise experts have traditionally emphasised acoustic factors and have used a dose–response model to study the relationship between noise and annoyance. One objective has been to establish acoustic parameters that can best explain annoyance. Ising et al. (10) and Cohen et al. (11) have suggested that noise-induced stress is an annoyance, and Miedema & Vos (12) have described non-auditory effects of noise. The psychological stress model proposed later by Stallen has been suggested used as a theoretical framework for explaining annoyance caused by environmental noise (13). This stress model emphasises the non-acoustic factors such as experienced annoyance and level of control over the noise as being decisive for how annoyed one is by noise. People who regard themselves as being sensitive to noise are more annoyed by noise than those who regard themselves as not so sensitive to noise (13).

Variation in definitions of noise

One kind of definition may be relevant for scientific purposes, such as the science of acoustics and noise or for measuring low-frequency sound and annoyance. Another kind of definition may be more useful in regulating the population's exposure to noise. The definitions of noise used for setting limit values are political, based on technical and financial considerations: for example, when it is decided that noise exposure of 85 dB(A) is the value limit in occupational settings, and above this people in the workforce must use hearing protection. As the introductory quote mentions, each profession tends to develop a specific definition of noise.

The World Health Organization calls non-occupational noise community noise. Community noise (also called environmental noise, residential noise or domestic noise) is defined as noise emitted from all sources except noise at the workplace (4).

The role of terms

Knowledge of the particulars of professional terms, such as acoustic terms or psychological terms, sets boundaries for the extent to which a definition is immediately comprehended and thus becomes useful. Nevertheless, professions and administrative systems need to base work on specific and adequate definitions. This leads to an increase in detail and sophisticated parameters in definitions and often results in exclusiveness. Identifying definitions that serve scientific, political and popular needs simultaneously appears to be difficult.

Barriers to achieving general definitions

Differing interests in professional and interest communities influence the potential for reaching common understanding and definitions. Terms comprise an aspect of differences in interests in the professional communities. Differences between countries and cultures in how they describe noise and the effects of noise can also be a barrier to achieving common definitions of noise. It may, for example, be difficult is to reach agreement on whether a definition should be common across effects or across countries or both. An example could be whether noise levels at pop and rock concerts should be regulated by national legislation only or by European Union regulation, as mentioned by Almstedt et al. (8).

2.3. Noise as environmental pollution

Noise, commonly defined as unwanted sound, is an environmental phenomenon to which humans are exposed before birth and throughout life. Noise can also be considered an environmental pollutant, a waste product generated in conjunction with various human activities. Under this definition, noise is any sound – independent of loudness – that may produce an undesired physiological or psychological effect in an individual and that may interfere with the social ends of an individual or group. These ends include all human activities – communication, work, rest, recreation and sleep (14).

An important difference between sound or noise and other classic environmental pollutants is the fact that sound is not harmful to the environment *per se* but is being stored as sometimes harmful impressions in individual people. Noise cannot be diluted, cleansed, collected or reused, but a precautionary principle can be applied, so that no human being should involuntarily be exposed to noise that could be harmful to their hearing, health and well-being.

Noise and the quality of life

The stress model of noise is mentioned in section 2.2. The stress model is related to emotions and the quality of life. Many noise-related health effects appear to be mediated through people's emotional response to the noise, which in turn is influenced by such factors as social status. People of lower social status may perceive themselves to be trapped in an overcrowded, low-rent neighbourhood, perhaps forced to keep their windows open for ventilation and thereby exposed to all the city's noise. The frets of the noise itself might then be heightened by the tenants' belief that they are powerless, by dint of finances, to control their circumstances (5).

Noise is not simply an annoyance but a hazard to one's physical and mental well-being. For example, when people are constantly thinking about noise it assumes a dominant place in their lives at the expense of other activities. It boils down to hatred of noise and the feeling of losing control, and in the end of hating oneself for allowing the noise to "win out" (15). One becomes a victim to noise. If children in noisy circumstances find that they cannot control or even influence the level of noise, they get into a pattern of learned helplessness.

Other aspects of noise

Noise is almost always defined as a variation of sound, but noise can also be looked upon as a foreign or intruding factor, for example when a noisy helicopter flies low over a silent snow-clad landscape. The relationship between noise, annoyance and noise sensitivity and stress, or the effect of combined exposure such as air quality and noise (11), ototoxic effects (12) and effects on the vocal chords, are also important mechanisms to consider when defining noise and the effects of noise.

2.4. Factors to consider in defining noise in relation to children

Many elements must be taken into account when discussing public health definitions of noise in relation to children. Definitions may be considered in relation to the purpose of the definition, such as who and what are being addressed by the definition and what background knowledge is necessary to sustain the definition. When definitions include children, additional aspects, such as children's rhythm during day and night, their exploratory behaviour or children's susceptibility may have to be taken into account. Regional differences may also play a role, such as the organisation of day care and academic schooling and perception of children's social competence.

How children behave

Definitions are perceived as something strict, predictable, useful and reliable that does not change overnight. Children are extraordinary: they are curious, spontaneous and do not behave according to a manual; children explore and shift focus instantly. Children are more vulnerable than adults to some types of noise exposure and suffer a range of effects of noise (as described in Chapter 4). When children are included in a definition of noise, it should be acknowledged that children represent an unpredictable dimension.

Characteristics of children in relation to noise

The following situations are relevant to the health of children in relation to noise:

- Some sounds may be noise to sensitive groups such as foetuses and the youngest children, although whether they find them unwanted cannot be measured directly.
- The circadian rhythm of children may influence children's susceptibility to noise.
- The threshold of what is perceived as noise varies greatly for healthy children and for healthy adults.
- Certain diseases or handicaps in children may lead to thresholds for the adverse effects of sounds that differ from those for healthy children.
- Special methods may have to be used to measure some adverse effects of noise in the developing child. New, perhaps less invasive, measurement methods could be applied. The methods should not interfere with the child's development. Measurements over time may be important for comprehending how noise affects a child's development.
- Children are forced to stay at locations defined by adults for much of their everyday life, such as homes, day care institutions and schools. Thus, children cannot generally avoid noisy environments in such settings.
- Children may be in environments that are not regulated at all or are not regulated to reflect children's susceptibility to noise, such as schools or day care institutions.
- Children can sometimes enjoy and be stimulated by sounds that some adults and some other children perceive as noise, such as toys with loud or special sounds or some types of music.
- Children depend on adults to advise them on protecting their hearing or prohibiting them from being exposed to hearing-damaging sounds, such as some fireworks and some loud music.

- Children depend on adults providing them with surroundings that support healthy development and learning and living, including conditions in day care institutions and in classrooms during teaching at schools.

Definitions of noise for preventive purposes

For preventive purposes, it may be useful to consider children's exposure to noise in different settings with different opportunities for prevention and specific regulations. There are, for example, quite different ways of preventing the adverse effects of noise from products such as toys and household devices, from traffic near dwellings and institutions, from other inhabitants of dwellings and in overcrowded day care institutions. In addition to considering how to prevent noise exposure it could also be useful to examine opportunities for children to be in environments with low noise or with pleasant and/or stimulating sounds.

Straightforward criteria for setting limit values for exposure to noise may imply that nobody should be adversely affected by sounds or that nobody should be exposed to noise. This is not realistic for the following reasons.

- Some people are particularly sensitive to sounds from common, unavoidable everyday activities that may affect them adversely.
- Society has conflicting interests in performing activities that cannot avoid being noisy to some degree, although the noise is a side effect of the activity: for example, many types of transport.
- Another potential conflict relates to actively producing sounds that will be a pleasure to some but will be noise to others, such as pop concerts.
- There is a special problem of sounds that may be perceived as noise produced by people themselves, for example screaming babies, shouting children and quarrelling parents.

2.5. Conclusion

Current scientific knowledge is inadequate to predict that any particular individuals, including children, can safely be exposed to a certain level of sound. Strategies to prevent damage from sound exposure should include limiting loud and potentially hazardous sound emissions, using individual hearing protection devices, education programmes beginning with school-age children, consumer guidance, increased noise labelling of products and hearing conservation programmes for occupational settings (16).

The scientific evidence on the dose–response relationships of noise does not include all age groups of children or vulnerable groups (see Chapter 4). Nevertheless, various adverse effects are indicated and suspected, and the task is therefore to identify aspects of a definition that will be relevant in addition to the dose–response knowledge. The effects on children's cognitive capacity and the role of noise on stress and on sleep as well as awareness of children's circadian rhythms, psychologically as well as physiologically, need to be considered when the public health of children is assessed with regard to noise.

The definition that includes most considerations related to children, noise and public health is the following.

Noise is any sound – independent of loudness – that may produce an undesired physiological or psychological effect in an individual and that may interfere with the social ends of an individual or group (14).

2.6. Summary

Many elements must be taken into account in discussing public health definitions of noise in relation to children. Definitions may be examined in relation to the purpose of the definition, such as who and what are being addressed by the definition and what background knowledge is necessary to sustain the definition. When definitions include children, additional aspects, such as children's rhythm during day and night, their exploratory behaviour or children's susceptibility may have to be taken into account. Regional differences may also play a role, such as the organisation of day care and academic schooling and perception of children's social competence.

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Noise is any sound – independent of loudness – that may produce an undesired physiological or psychological effect in an individual and that may interfere with the social ends of an individual or group.

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3. Settings of noise

by Marie Louise Bistrup

3.1. Introduction

This chapter describes the settings in which children are exposed to noise and presents noise exposure levels in these settings. The selection of settings is chosen as it reflects children's daily lives and activities and also because it may serve operational purposes for example with regard to legislation, standards and preventive actions. The settings are: the home, toys, health care settings, day care institutions, schools, after-school and leisure activities, transport and regional differences. The examples come from various sources, and many references are from settings and thus studies in Denmark.

Noise can be measured in different ways: by measuring the ambient noise level, the noise level in rooms with activities, the noise level in the middle of a room, or as when road traffic noise is measured, often in front of a residential building. Noise can also be measured using dosimeters carried by an individual or groups of individuals.

There are two basic elements for understanding the role of noise for children in different settings:

- the difference between the level of background noise (ambient noise level) and the level of sound or speech necessary to be understood or heard (masking effect); and
- the acoustic quality of a room, specified by the reverberation time.

Acoustic quality

The acoustic quality of a room depends on the building material and absorbency of surfaces in the room and the characteristics of the furniture and installations and the size and design of the room. Uninhibited reflection of noise results in a room with poor acoustics. A room with poor acoustics is not pleasant to be in, and sound signals such as speech are difficult to comprehend (1).

Masking of speech

Some portions of the speech waveform, generally those associated with consonant sounds, are substantially lower in amplitude than other parts associated with vowel sounds. Because of this, noise masks the consonant sounds of speech more effectively than it masks the vowel sounds. To protect these more fragile speech components from masking, the amplitude peaks of the speech waveform can be clipped, with the remaining signal reamplified to normal levels. This increases the intensity level of the consonants relative to the vowels and reduces the masking effects of noise (2).

Signal-to-noise ratio

A learning environment requires at least a +15 dB signal-to-noise ratio. Children with special needs, such as children being taught in their second language, require a +25 dB signal-to-noise ratio to have reasonable speech understanding. The ambient noise level should be at least 25 dB(A) below the comfortable speech level in a given situation. The level depends on the situation. In a smaller room and with one speaker and one listener, the level is lower than in a large classroom.

A speech signal for classroom situations must be at least 15–25 dB above the ambient noise level and noise sources, such as coughing, throat clearing, paper rustling, foot shuffling, noise from tables and chairs etc. (3).

A method of describing intelligibility is to measure the percentage of consonants that will be misunderstood or lost in conventional speech, called percentage articulation loss of consonants (%ALCons). In public spaces such as airports an acceptable loss is 10%, whereas in educational situations 5% is considered acceptable (3).

"Quite surprisingly, poor classroom acoustics seem to be the prevailing condition for both normal-hearing and hearing-impaired students. In particular, reported ambient A–weighted noise levels are approximately 5–35 dB above values currently agreed upon for optimal understanding by normal-hearing children and 17–32 dB too high for hearing-impaired children." (4).

One could talk about "comfort levels", and noise levels of 30–35 dB(A) would be experienced as an acceptable and comfortable background noise.

Reverberation time

Reverberation is the combined effect of multiple sound reflections within a room. After the source sound stops, reverberation in a room causes the perceived sound to decay at a smooth and gradual rate.

The reverberation time at a particular frequency is defined as the time taken for sound to decay by 60 dB. A constant noise source is used and then shut off. If the overall reverberation time is short (less than 0.3 seconds), the room is acoustically "dead" as for example in a heavily furnished room with thick carpets, curtains and upholstered furniture. If the overall reverberation time is long (more than 1.5 seconds) the room acoustics seem "lively" and echoed, such as in a large empty room with painted plaster walls and a tiled floor.

Room size also has a bearing on reverberation time. In a small room the reverberant sound level is quite high compared to the source sound level, and the reverberant level builds faster.

3.2. The home

The European Commission (5) estimates that 20% of the population in the European Union experiences noise levels that scientists and health experts consider to be unacceptable: where most people become annoyed, where sleep is disturbed and where adverse health effects are feared. About 45% of the residents of the European Union live in “grey areas” where noise levels can cause serious annoyance during daytime. In 1998, people younger than 19 years of age comprised 24.2% of the European Union’s population, and one could assume that children are exposed to at least as much noise as adults are (5).

The population of the Netherlands seems to experience the lowest peak noise levels, since only 3.6% were exposed to more than 65 dB(A), followed by the Danes with 5.9%. The highest levels were found in Germany (12.5%) and Belgium (9.6%); no data for southern Europe were available (6).

Industry, raw material extraction, trains, aircraft and road traffic create noise. There is noise in busy harbours and inside and outside factories, and positive human activities such as play and recreation often produce considerable sound (7).

“My home is my castle” implies that the home is a protected area within one’s control. Many of today’s homes do not protect sufficiently against intrusive ambient noise.

Homes in the countryside

Most rural homes are less burdened by noise than are urban homes. Machines related to agriculture, such as motorised ploughs, harvesters, tractors, silos, grain-drying installations and ventilators, do make noise, but not as regularly as road traffic noise in cities.

The sound of bicycle wheels spinning in a background of natural sounds from birds and bees in the countryside is a stark contrast to the noise encountered in urban traffic. Finding restorative areas totally free of human-made noise is difficult, and noise can be a nuisance for children and adults during transport in the countryside as well as in urban areas.

Noise and vibration in buildings

Building service noise can affect people both inside and outside the building. Noise and vibration from ventilation and air-conditioning plants and ducts, heat pumps, plumbing systems and lifts influence the internal acoustic environment. Vibration from road traffic affects people and buildings. The effects of small steady vibration on health are little known, but substantial vibration can disturb cardiac rhythm and sleep and produce stress and uneasiness. The health effects depend on the frequency of the vibration, because resonance occurs in various parts of the body (7). Low-frequency sounds are emitted by such sources as vehicle engines, air conditioners and elevators (8). Ultrasound disturbs some people, but research is scarce.

Noise in the community environment

Noise from neighbours and their social and recreational activities is a common annoyance, especially in high-rise buildings and densely populated areas. Music and loud voices from restaurants, bars and community centres and activities related to the home and to recreational areas such as plazas and parks also generate noise.

Outdoor sources of noise other than traffic include motorised and non-motorised tools and garden equipment. Some children operate these, but they more often play next to these sources of noise (9) (Table 3.1).

Table 3.1. Noise level of various tools and equipment

Type of machine	Noise level (dB(A))
Electric lawnmower	78
Non-motorised lawnmower	80
Motorised lawnmower	85
Electric hedge trimmer	84
Electric saw	92
Compost shredder	99
Power drill	100
Motorised saw	102

Source: Ministry of the Environment, Denmark (9)

Noise is occasionally radiated into public space, such as recorded background music in shopping centres, swimming pools and advertisements on beaches.

Noise inside the home

Sources of noise in the home include electric installations and appliances such as dishwashers, washers and dryers, hair dryers, electric ventilators, kitchen fans, blenders, mixers, vacuum cleaners, the fan in personal computers, television, videos and computer games (Table 3.2).

Table 3.2. Noise exposure of 140 housewives is used to illustrate the noise exposure to children inside and outside the home

Circumstance of exposure	L_{Aeq} in dB(A)	Standard deviation	Number of measurements
On the street	75	5.5	52
Leisure and hobby	74	7.4	29
Child care	73	7.0	38
Eating	69	5.5	135
Domestic activities	69	6.3	79
Watching TV	66	5.8	118
Reading	61	8.1	78
Exposure over 24 hours	70	4.7	140

Source: Passchier-Vermeer (10) adapted from Sone & Kono (11)

3.3. Noise from traffic

Noise from traffic is the most significant source of noise in the home. People experience noise inside and outside their homes: in rooms facing traffic and more distant rooms, on balconies, in playgrounds and in gardens and courtyards. According to measurements in 1993 in Denmark, 485,000 homes are exposed to road traffic noise above 55 dB(A), amounting to 18–20% of all dwellings (Table 3.3).

According to Transport 2005 (12), Denmark's 1993 environmental action plan for transport, dwellings exposed to noise over 55 dB(A) from road traffic and airplanes are considered to have a high level of noise pollution, and homes with noise from these sources above 65 dB(A) have very high levels of noise pollution.

Table 3.3. Number of dwellings exposed to noise in Denmark in 1993 according to source

Noise level (dB(A))	Road traffic		Train traffic		Air traffic	
55–59	175,000*	(36%)	**		25,000	(62.5%)
60–64	165,000	(34%)	25,000	(64%)	12,000	(30.0%)
65–69	110,000	(23%)	10,000	(26%)	3,000	(7.5%)
> 70	35,000	(7%)	4,000	(10%)	0	
Total	485,000*		39,000		40,000	

Source: Ministry of Transport, Denmark (12)
*These figures are probably underestimated
**Train noise is included only at ≥ 60 dB(A)

Noise from trains is usually perceived as less burdensome than noise from road traffic and airplanes. The standards for train noise are 5 dB(A) higher than those for road traffic noise. Thus, dwellings with a train noise level exceeding 60 dB(A) have a high level of noise pollution, and dwellings exceeding 70 dB(A) have a very high level of noise pollution (13).

Trends in the rest of Europe are similar to Denmark. According to the European Commission (5), data over a 15-year period do not show significant improvement in exposure to environmental noise, especially from road traffic. The proportion of the population exposed to levels above 65 dB(A) remained high, and many western European countries experienced increases by the end of the 1980s at 55 to 65 dB(A), the grey zone, apparently as the result of rapidly growing road traffic (14).

Urban dwellings

Road traffic noise is predominantly an urban phenomenon. In Denmark, 70% of the dwellings exposed to noise levels over 55 dB(A) are in towns with more than 20,000 inhabitants, whereas only 55% of all dwellings are located in towns of that size. More than half the dwellings exposed to very high noise levels are located in Greater Copenhagen, whereas just 10% of those noise-burdened dwellings are in towns with a population less than 20,000 inhabitants.

The level of noise from traffic in Denmark's towns may not have increased, but the period during which traffic is noisy has increased. Whereas the period from 8:00 to 18:00 was previously the most noisy, currently people can also feel burdened by noise during the evenings and nights. Although technological development has resulted in vehicles producing less noise, the increase in traffic has outweighed the reduction from individual vehicles.

The proportion of single-family houses burdened by high or very high noise levels is about the same as the proportion of this kind of dwelling in relation to all dwellings in Denmark. Twenty-five percent of dwellings burdened by high or very high levels of external noise are in high-rise buildings, whereas these account for 14% of all dwellings. Since the 1980s, the number and percentage of dwellings burdened by high or very high noise levels have been reduced, although road traffic has increased. The reduction in the number of homes with high noise levels probably resulted from regulation of traffic and urban planning, reduction of speed limits from 60 to 50 km/h in towns and from 90 to 80 km/h on highways and the fact that new houses are better insulated.

3.4. Noise from toys

Children play and want to play with toys. Toys are usually manufactured by adults and are often purchased by adults. Many toys produce noise, and children with toys produce noise. The sound of a toy is designed to illustrate or accentuate the function of the toy, as is also the case with many household appliances.

Noise levels of toys

In 1999 the National Consumer Agency of Denmark (15) tested 17 toys. Table 3.4 shows the average and peak sound levels for a selection of toys.

Table 3.4. Average and average peak sound levels for selected toys

Toy	Average noise level (dB(A))	Peak noise level (dB(A))
Music box	81	79
Toy mobile phone	75	85
Robot soldier	No data	94
Pull turtle	No data	95
Musical telephone	No data	89
Sit-on fire truck	No data	87
Vacuum cleaner	No data	83
Laser pistol	No data	87
Police machine gun	No data	110
Cap gun fired with caps	No data	134
Cap gun fired without caps	No data	114
007 cap pistol with caps	No data	127
007 cap pistol without caps	No data	118

Source: National Consumer Agency of Denmark (15)

The A-weighted single-event sound pressure level, L_{pa}, is measured at a distance of 3 cm for close-to-the-ears toys. The C-weighted average peak emission sound pressure level, L_{pc}, is measured at a distance of 50 cm. A study in Germany (16) compared the acoustic impact of toy pistols on the ear with the acoustic impact of the standard rifle of the German military (G 3) on the ear of the soldier. The study concludes that "all of the five randomly selected types of toy pistols (revolvers) are much louder than the rifle, if they are fired close to the ear. There is a standard of the European Union related to safety of toys (EN 71-1) and it tolerates peaks of impulsive noise from toy pistols that are illegal for workplaces without auditory protection".

A study in Finland (17) measured noise from 40 toys and rated the harm of the noise. The study concludes that "According to the developed harm rating the noise produced by all toys that gave a single impulse reached a peak level that was so high that exposure to one single impulse could cause a child a hearing defect."

Directives and standardisation in the European Union

The European Union has two processes for developing standards and definitions on environmental factors or pollutants.

Directives are processed in the European Council and in the European Parliament and are thus accessible for public scrutiny. Technical annexes are adopted at closed meetings of the European Commission, called the committee procedure. Deliberations and decisions on technical definitions and classifications are often transferred to standardisation organisations (18).
Toys that are intended for the European market must be produced according to Council Directive 88/378/EEC of 3 May 1988 on the approximation of the laws of the Member States concerning the safety of toys (the Toys Directive) (19). A Member State cannot prevent the marketing of a product if the product complies with the requirements of the Toys Directive.

The European Council has mandated the European standardisation organisations, the European Committee for Standardization (CEN) and European Committee for Electrotechnical Standardization (CENELEC), to prepare technical declarations and test methods. European Standard EN 71-1:1998 replaces EN 71-1:1988. It was prepared by Technical Committee CEN/TC 52, Safety of Toys, but opinions differed between producers of toys and consumers' organisations about acceptable levels of noise from percussion caps (cap guns). The main changes in the new standard are requirements for percussion caps specifically designed for use in toys. After a grace period of 3 years ending in 2001, acoustical requirements that are stricter than in the previous standard apply.

The European Commission is considering to implementing acoustical requirements in the Toys Directive. As of March 2001, it is therefore difficult to establish what will be the future requirements for the maximum acceptable level of noise in toys within the European Union.

Groups of toys

Standard EN 71-1:1998 divides toys into five main categories:

1. close-to-the-ear toys;
2. hand-held toys;
3. rattle;
4. squeeze; and
5. table-top and floor toys.

Hand-held toys are toys manifestly designed to emit sound and intended to be held in the hand. Examples include clicking toys, toy tools and cap-firing toys.

Typical baby and toddler's toys are rattles, various music boxes, cars and children's versions of household equipment. Infants and children's toys are typically toy cars and toy guns.

Levels of sound

In European Standard EN 71-1:1998, Section 4.19 on percussion caps specifically designed for use in toys (described in Annex A) and Section 4.20 on acoustics determine the emission sound pressure levels permitted for toys manifestly designed to emit sound when tested according to Section 8.31 of the standard. The requirements mention the A-weighted emission sound pressure levels produced by close-to-the-ear toys measured in a free field or measured using an ear coupler. The most interesting requirement regards the C-weighted peak emission sound pressure level, L_{pcpeak}, produced by toys using percussion caps, which must not exceed 140 dB.

A note states that 140 dB at the measurement position corresponds to 150 to 160 dB at a distance of approximately 2.5 cm.

Standard EN 71-1:1998 (C.26 Acoustics) says on child vulnerability to noise from toys: "... there are scientists who hold the opinion that, since the auditory canal in children is smaller that in adults, there is a different amplification which makes children more sensitive to high frequency sounds". Some countries and consumer consider the Toys Directive to be outdated, because it allows production of toys up to 140 dB(A), which may be harmful to children's hearing.

If noise from toys exceeds 110 dB(A), the toy must have a warning label that says that the toy may not be used close to the ear and the toy is not supposed to be used by children below 3 years. Any child or adolescent can fire a powdered gun. It is questionable whether the adult will notice the warning labels, and children cannot be expected to read or to take an interest in warning labels.

ISO standards

The International Organization for Standardization (ISO) promotes the development of standardisation and related activities in the world with a view to facilitating the international exchange of goods and services. ISO's work results in international agreements, which are published as voluntary international standards. The Technical Committee 181, Safety of Toys, has not been able to agree on acoustic standards for toys. Instead the requirements and test methods of European Standard EN 71-1:1998 are enclosed in Annex F to the standard for toys, ISO 8124-1:2000, as an informative, not normative, annex.

3.5. Health care settings

Incubators, neonatal intensive care units and paediatric wards are all components of a health care system set in motion to help children fight disease and recover. Most children in health care need a peaceful environment to support their development and recovery. But peace and quiet may be hard to find in a hospital. Not much research has been done on children and noise in hospitals, but the noise levels that affect adults probably affect children at least as much.

Noise in incubators and in neonatal intensive care units

Premature babies often spend their first months in incubators or in neonatal intensive care units, which are often noisy. Measurements in neonatal intensive care units have shown equivalent sound levels from 60 to 90 dB(A), with peak levels of very loud events up to 120 dB(A). The equivalent sound levels in the incubator are 60 to 75 dB(A), and when the ports of the incubator are closed, the maximum sound level is up to 100 dB(A) (see also Chapter 4).

A study on noise recorded inside the incubators had two components. The first was the background noise from the incubator motors, which varied from 74.2 to 79.9 dB(A). The second source was impulsive events beyond 80 dB(A). These events were the result of voluntary and involuntary contact with the incubators' Plexiglas surface or the abrupt opening and closing of the access ports. Considering the noise level and frequency, this latter component is undoubtedly an important source of stress to newborns (20).

Noise in hospitals

A study on noise levels in hospitals in Scotland shows that noise is adversely affecting patient recovery times. Patients have great difficulty in falling asleep in noisy hospitals, and this delays their recovery. It also ends up costing more because hospital stays are longer and more sedative medication is dispensed. These findings probably also apply to children (21).

Another study (22) shows a very strong relationship between the number of loud sounds (≥ 80 dB(A)) and the wakening of elderly patients in a hospital's intermediate respiratory care unit. The loud sounds came from various sources, such as loud voices, televisions, equipment alarms, intercoms and beepers. A loud beeper produced 80 dB(A). Loud noises from 22:00 to 6:00 markedly disrupted patients' sleep. Other studies show that at least one third of sleep-deprived hospital patients have what is called intensive care unit psychosis, marked by symptoms of night-time disorientation and delusion. Sleep deprivation may also adversely affect respiratory muscle function, possibly hindering weaning from mechanical ventilators. Some previous research showed that peak sound levels in a hospital during a 24-hour period were consistently above 70 dB(A).

The internal readings in 1991 in a medical practice hospital in Brazil between 9:00 and 11:00, outside the peak road traffic period, showed L_{eq} varying from 63.2 to 68.4 dB(A) (Table 3.5) (23). Measurements were taken in the absence of patients and health care activities and reflect the ambient noise at that particular hospital.

Table 3.5. Levels of noise in dB(A) measured in the new interior part of the medical practice hospital of Universidade Federal de Minas Gerais, Belo Horizonte, Brazil when it was not occupied by patients

Place	L_{max}	L_{min}	$L_{eq(30\ min)}$
Pediatrics II (8th floor, extremity of block)	78	59	68
Pediatrics I (8th floor, middle of block)	77	59	68
Pediatrics III (8th floor, centre of block)	77	57	67
Infirmary I (4th floor)	79	58	65
CTI I (2nd floor, extremity of block)	80	55	66
CTI (2nd floor, centre of block)	78	54	63

Source: Alvarez & Pimentel-Souza (23)

When the hospital rooms are busy with staff activities, the noise from equipment and from other patients noise rises above these levels. A comfortable level for patients would be below 50 dB(A), maybe even less for traumatised patients or patients in critical condition. The study indicates that the patients almost always remain in an advanced condition of noise stress (23).

3.6. Day care institutions

Little research is available on the noise exposure of children in day care institutions. Instead proxy measurements for adult exposure to noise in day care institutions are often used. It is fair to assume that children do not experience less noise than adults. Children probably experience more noise, as they are usually closer to the noise sources than adults do and often contribute to the noise.

Room design

A study in Canada examined seven child care centres to test a hypothesis associating noise problems with the openness of the interior layout. Noise exposure levels above 75 dB(A) (L_{eq}, 8 h) were measured in four of the seven settings. Variation in noise level was related to the influence of a few variables, the most potent being the number of people that could be heard simultaneously. The workers at the centres with a more open design reported significantly more health problems and disadvantages (Trouchon-Gagnon C, Hétu R. Extra-auditory effects and noise control in educational settings: a study in day-care centres for children, submitted).

Noise directly and indirectly interfered with activities in day care centres more where the interior design was an open plan than in enclosed centres (24). An open plan means a room in which every person present, child or adult, can be heard by all others, and a closed plan has subdivided rooms inside which the grouped children and educators are acoustically isolated from the other groups.

Sone & Kono (11) (cited in Passchier-Vermeer (10)) found the mean noise exposure during working hours in child care institutions with infants to be 86 dB(A).

Crowding and noise

Due to the climate, Scandinavian children spend about 80% of their time indoors. More than 12% of Denmark's population, the children, spend a large part of their everyday life in nurseries, kindergartens or after-school programmes.

In 1998, the Danish Federation of Early Childhood Teachers and Youth Educators and the National Union of Nursery and Child-care Assistants reported on a project (25) that could provide a basis for their future effort to improve the noise and indoor climate conditions in Denmark's child care institutions. The project aimed at demonstrating whether regulations and guidelines governing noise and indoor climate are being observed in Danish child care institutions.

In the late 1990s, the preschool day care institutions were forced to accommodate approximately 50% more children than in 1990. About 24% of these children have been enrolled within the already existing capacity of the institutions. According to the project, this is an important factor in increasing noise levels.

According to the report of the project (25), never before have so many children been taken care of by so few adults in so little space for such a long time.

The project found that at least 47% of Denmark's day nurseries (0–3 years of age) have average room noise levels exceeding 80 dB(A), and up to 14% exceed 85 dB(A). At least 44% of Denmark's kindergartens (3–6 years of age) have average room noise levels exceeding 80 dB(A), and up to 5% exceed 85 dB(A). Noise thus appears to be a major problem for all types of day care institutions. The study also showed that, with a few exceptions, the reverberation time at the institutions is below 0.6 seconds, a limit specified by the Danish Building Code. This implies that the noise problem at most of the institutions cannot be explained solely by poor acoustics.

Children play with toys, and the circumstances of play determine the noise levels: the acoustics of the rooms in the day care institution, the sound absorbency of interior decorations and the rustling of chairs and furniture. Soft surfaces such as carpets on the floor could protect hard toys from falling directly on a hard floor but may become a hygienic problem, especially for children with allergies. Tablecloths can diminish sounds from utensils and toys.

Overcrowding

When many children are close together, the risk of spreading infectious disease increases. Children in day care experience bouts of eye and ear infections, rhinitis and lice. If the middle ear is filled with extra liquid because of inflammation, this causes considerable temporary hearing loss (up to 50 dB). A study in Denmark found a relationship between overcrowding and middle ear infections: one additional square metre per child could reduce infections by 11% (26).

Maxwell (27) found that pre-school children from crowded homes were more negatively affected by day care crowding than their peers from uncrowded homes. Children from two crowded settings were rated by day care teachers as more behaviourally disturbed than children who experienced crowding in only one setting, either at home or in day care.

Vicious circles

A child with a middle-ear infection experiences hearing loss, including hearing his or her own voice; to compensate for this, the child speaks more loudly which, in turn, may cause other children and adults to speak more loudly, resulting in noise. If a child is given antibiotics, this may lead to a slight ototoxic effect and decreased hearing and, as described above, the child may raise his or her voice. Hearing may also be impaired if the membrane erupts or is punctured, again resulting in increased voice levels and noise, and the membrane may get a scar that will potentially reduce hearing, with consequences for life, for example reduction in access to certain jobs (28).

3.7. Schools

"Because children's listening skills are not yet fully developed, they are more easily distracted by background noise than adults." (29)

Noise in the classroom stems from the acoustics of the room, the material and furniture, the children and adults communicating and moving around, from other classes and functions, slamming doors, corridors, halls, ventilation systems and computers. Added to this is external noise from industry, road traffic, trains and airplanes.

Children listen and speak up to 75% of their time in school. Researchers in the United Kingdom (29) measured noise in classrooms under realistic conditions, with activities in classrooms (Table 3.6). The background noise was measured in classrooms in primary schools around the United Kingdom. The classrooms were divided into three categories according to their design. Open-plan and cellular classrooms have been considered independently, and a separate group included only classrooms, with specific acoustic treatment. A wide variety of schools were studied, including urban and rural schools and old and modern buildings. The levels stated are the means of a number of noise samples taken in approximately 60 classrooms under two different conditions: the children silent and the children working and talking under normal conditions. Acoustic treatment of classrooms usually consists of acoustic suspended ceilings, with a higher level of absorbency, which lowers the reverberation time and to some extent protects the rooms from intruding noise.

Table 3.6. Average (range) background noise levels in dB(A) measured in 60 classrooms in the United Kingdom

	Open-plan classrooms		Cellular classrooms		Acoustically treated classrooms	
Pupils silent	56	(49.1–70.3)	56	(31.4–67.8)	47	(33.9–55.0)
Pupils working	72	(59.8–84.3)	77	(51.9–101.1)	70	(58.9–79.0)

Source: Airey et al. (29)

Thus, open-plan classrooms have slightly higher levels of background noise when the pupils in the tested classrooms are silent, caused by noise from surrounding areas, but are quieter during active lessons. This is usually due to higher reverberation times in cellular classrooms and because teachers in open-plan rooms tend to restrict their lessons to quieter activities to avoid disturbing other classes. The acoustically treated classrooms showed, as would be expected, lower noise levels than the not acoustically treated classrooms.

A study in Copenhagen, Denmark (30) found high levels of background noise in classrooms with natural ventilation as well as in classrooms with mechanical ventilation. Noise levels were measured in 80 classrooms when the classrooms and the adjacent rooms and corridors were not in use. The highest measurement result was used for each room. The schools with natural ventilation are the older schools in the city centres, and the mechanically ventilated schools are more recent schools outside the city centres.

With closed windows in the naturally ventilated rooms, noise levels above 35 dB(A) were reached in 57% of the measurements and, in the mechanically ventilated rooms, in 8% of the measurements. With windows open, 45 dB(A) was reached in 65% of the naturally ventilated and 30% of the mechanically ventilated rooms. In the naturally ventilated rooms the noise level is above 58 dB(A) in 18% of the classrooms (30). Background noise was measured, prior to children and teachers entering the room. Children's activities will add to the noise levels, and a teacher has to use a voice 15–25 dB above the total background noise to be heard.

Learning environments

Speech is clearer in quieter rooms because the signal-to-noise ratio, where the signal is usually the teachers' voice, is much higher. The average teacher's voice level is about 57 dB(A) (31). The United Kingdom Department for Education and Employment (32) recommends a signal-to-noise ratio of +15–20 dB for children to perceive speech clearly. Table 3.6 shows that, although the teacher could make herself or himself heard when the children are quiet, it would be virtually impossible for the teacher's voice to be clearly perceived once the children begin talking and working.

The design and use of learning environments should take into account the circadian rhythm of the child, and should be aware of the fact that new ways of teaching, for example by working in groups, may add to noise. Flexible curricula can also pose problems if, for example, some classes have recess while other classes are working hard, maybe with windows open to let in fresh air, and at the same time letting in the noise of the peers in the schoolyard.

Children's perception of noise in schools

A survey of the physical environment in schools in Denmark (33) reports that 19% of the responding children were frequently annoyed by noise during school lessons, 19% were not annoyed by noise during lessons and 62% were annoyed sometimes by noise. The annoying noise could be either self-generated noise from laughing, chatting or bullying during lessons or related to the physical environment such as noise from chairs and tables or external noise, such as from other classrooms.

Some of the girls responded that they did not want to go outside during breaks to play in the schoolyard "because there is so much noise". The students were asked about home activities in relation to school, and a small group of children responded that leisure time was considered positive because then one gets out of the noise (33).

3.8. After-school and leisure noise

According to one study (25), in at least 64% of Denmark's after-school centres the average room noise exceeds 80 dB(A), and up to 25% of exceed 85 dB(A). Thus, the after-school centres are seriously affected, since the limit value of 80 dB(A) considered to protect adults from "hearing impairment" is probably exceeded in almost one quarter of these.

Noise levels in evening clubs and sports facilities such as basketball courts and football fields are high, and in indoor swimming pools children's cheerful voices are reflected by hard, tiled surfaces.

Portable sound systems presumably induce some hearing loss in a small group of people. Compared with discothèques and concerts, music from headphones seems to be less of a problem, especially since the maximum output levels of such devices can be controlled. However, it should not be neglected. Maybe 10–15% of teenagers use headphones at a sound level that can cause problems. In discothèques and concerts, very high sound pressure levels that impose the potential risk of hearing loss have been measured frequently. The noise level in a discothèque is about 100–110 dB, a rock concert is probably 120 dB; 138 dB was measured at a concert with the rock group Kiss (34). Noise at rock concerts not only potentially harms the hearing of the audience, but many stage employees and musicians from classical orchestras as well as rhythmic bands are experiencing hearing problems, especially tinnitus.

The desired experience for adolescents at discothèques and rock concerts is not just the music; the tactile stimulation and the pulse and vibrations from musical instruments are also perceived as stimulating and are important for concert visitors.

Children at ever-younger ages use portable sound systems and headphones while playing video games, and they watch movies and videos at high sound levels. The use of headphones may be good for people in the vicinity, as they are not supposed to hear the sound, but the sound emitted is too often too close to the ear of the person with the headphones. A rule of thumb is that if someone 1 metre away has to shout for the person using the headphones to hear their voice, then the sound is too loud and may damage hearing.

Noise from outdoor equipment, motorised leisure vehicles and shooting gear are potentially harmful activities. The noise levels are shown in the section on the home.

3.9. Noise during transport

Transport noise stems from trains, from engines in motor vehicles and the friction between the vehicle and the ground. Road contact noise exceeds engine noise at speeds higher than 60 km/h. Railway noise depends primarily on the speed of the train but also varies according to the type of engine, cars and rails. Trains exceeding 250 km/h can make noise similar to that of overflying jet aircraft (35).

Aircraft takeoffs are known to produce intense noise, including vibrations and rattle, but also landing can cause noise, especially when reverse thrust is applied. Larger and heavier aircraft produce more noise than smaller aircraft, but they may operate from smaller airports closer to residential areas. Airports hosting many helicopters often create especially severe noise problems (35).

Noise from road transport is emitted in a background of noise from activities such as industry, construction, hammering, public works, air traffic and sonic booms. The noise increases with the amount of traffic, the number of large vehicles and their speed, and from stop-and-start driving on uneven surfaces or inclines, such as road bumps. The dissemination of the noise depends on the location and height of buildings and other sound barriers. The quality of the surface of roads and the character of tyres also play a role in the amount of noise emitted by traffic (7).

Children experience noise from a variety of sources during transport. Young children are transported by public transport or individually in prams, strollers, on parent's bicycles or in cars or they walk or bicycle. Schoolchildren walk, roller-skate, use skateboards or scooters and bicycles. As young children are smaller than adults, they are often closer to the source of noise.

Passchier-Vermeer (10) concludes, based on comparing data with measurements from transport by Sone & Kono (11), that the measurements of noise levels in traffic in Japanese cities are comparable with those in traffic in European cities (Table 3.7).

Table 3.7. Noise levels in transport in cities in Japan according to the mode of transport

Mode of transport	L_{Aeq} (dB(A))	Number of measurements
Walking and bicycling	74	48
Private car	74	135
Motorcycle	82	17
Bus	77	52
Train and tram	77	93
Underground railway	80	63

Source: Passchier-Vermeer (10) adapted from Sone & Kono (11)

Noise inside means of transport varies according to the insulating capacities of the vehicle and the noise in and around the vehicle. It can be difficult to conduct a conversation in a rumbling car, in a tram with piercing stops and turns, in a bus with penetrating noise from friction, during the shrills of a train stopping and the high-pitched sounds of cars and trucks breaking and starting.

Boom cars

Youths may turn up their car sound systems to extreme levels while driving. A boom car is one whose stereo system has been modified by the addition of powerful bass speakers capable of broadcasting loud booming bass notes. An advertisement for boom cars reads "a place where sound and emotion become one – a big ear-drum-crushing, kidney-punching torture chamber" (http://www.phoenixgold.com).

3.10. Regional differences

Some differences across Europe in experience with and settings for noise are different climates that allow a variety of uses of the outdoors and the natural environment, different lifestyles and various ways of organizing public life. In southern Europe, more daily activities may be carried out outside the home, such as eating out and dining late in warmer seasons. Northern Europe has a colder climate and a tradition for having young children take a nap outdoors in baby carriages, even if the temperature is below freezing. Noise may be a factor considered when choosing whether to put the child outside or not, but fresh air is rated high, and certain levels of noise will be regarded as not affecting the sleep of the child.

Other differences in exposure to noise stem from different ways of structuring public life. In many countries children start academic schooling at age 4–5 years, whereas in other countries formal schooling starts at age 6–7 years. The children that start later in formal schooling may experience more noise in kindergarten than the children of the same age who have already started school. Enrolment in school affects expectations towards children's ability to learn, sit still, understand instructions etc., and this may, in turn, influence the levels of noise that are acceptable in different cultures.

In French schools, for example, the structure the school day has been changed. A specific concern of French psychological research and educational policy has been the circadian or daily psychological and physiological rhythms of the child. A government circular issued in 1998 by the Minstére de l'Education National de la Jeunesse et des Sports explains that children are more lethargic in the early afternoon, so that intellectual activities or intense physical efforts are not appropriate. Schools are therefore permitted to arrange their hours and activities accordingly, so that class time is concentrated in the morning and some late afternoons while the early afternoons are devoted to extracurricular activities, creative activities and free play. This reorganisation may influence the level of noise. An evaluation did not mention noise, but pointed to improved behaviour, greater tolerance in dealing with others, an improvement in the general climate of the schools, less violence and greater participation and concentration in class, which would probably be indicators of less noise in class (36).

3.11. Conclusions

A setting is a system for characterising the sources and circumstances of noise exposure. Physical and psychological processes cause the effects of noise regardless of how the setting is labelled. For example, differences between occupational noise and environmental noise are differences in human labelling of the situations in which people are exposed to noise. One person's occupational environment, for example a hospital, is a setting of care and healing for the patient.

The decisive factor in describing the effects of noise is not the setting *per se* but the circumstances for the person experiencing noise. A critical factor is to establish the effects of noise by identifying the character and level of noise and the duration of noise exposure in relation to effects.

The results of the review of noise in this chapter on settings have identified the following ranges of sound levels and some peak sound levels, noting that noise is measured in many different ways (Table 3.8).

Table 3.8. Sound levels reported in this chapter

Location or source	Noise level (dB(A))	
The home	range:	61–75 dB(A)
Tools and equipment	range:	78–102 dB(A)
Neonatal intensive care units	range:	60–90 dB(A)
	peak events:	120 dB(A)
Incubators	range:	60–75 dB(A)
	peak events:	100 dB(A)
Hospitals	often exceeding	70 dB(A)
Day care institutions	up to:	75–81 dB(A)
Toys	range	79–134 dB(A)
Schools		47–77 dB(A)
After-school clubs		85 dB(A)
Discothèques		110–138 dB(A)
Transport in cities		74–82 dB(A)

Children are exposed to high noise levels in the home, in day care, in schools and clubs and during leisure activities and from toys. Children are exposed to high sounds from going to discothèques and listening to loud music through headphones. Few studies are available, but the available ones show that children during an average day spend half their time in noise levels so high that hearing and voices are strained and teaching and learning are difficult. Some toys emit sounds that instantly destroy hair cells and may permanently damage hearing.

3.12. Summary

Some sounds are so loud that an individual or groups of people call it noise. The levels and character of sound in our environment, the acoustic conditions in our surroundings, and the number of people present and their activities contribute to the sense of peace or sensation of pleasant sounds from human activities or an impression of noise or even unbearable noise.

The review of settings for children discloses daily lives full of noise. It is as if children being brought up in noise learn to accept noise and perceive noise as the normal condition. Products such as home appliances and toys are developed with a sound designed to stimulate a sense of efficiency or emotion. The industry of sound design is one setting that determines the levels of exposure to noise.

Noise can be measured in different ways: by measuring the ambient noise level, the noise level in rooms with activities, the noise level in the middle of a room, or as when road traffic noise is measured, often in front of a residential building. Noise can also be measured using dosimeters carried by an individual or groups of individuals. The noise levels referred to in this chapter stem from various sources and measurement types.

Some ranges of sound levels and some peak sound levels have been identified. The noise levels in incubators range from 60 to 75 dB(A) with a peak at 100 dB(A); noise from toys ranges up to 80 dB(A), and a toy gun can have a peak level of 140 dB(A). In day care institutions and schools noise regularly reaches levels of about 80 dB(A); in discothèques and at concerts the noise is up to 138 dB(A).

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4. Effects of noise

by Willy Passchier-Vermeer

Staffan Hygge wrote the subsection on cognitive effects in section 4.4 and Marie Louise Bistrup wrote sections 4.5 and 4.7

4.1. Introduction

The world of the child is becoming noisier and noisier (1). Compared with the mid-1950s, environmental noise levels (sources such as road traffic and aircraft) have increased substantially, causing higher noise levels during day- and night-time at home, at school and during outdoor and indoor leisure activities. In addition, children spend increasingly more time in situations with (many) other children, such as in day care institutions and kindergartens, with high noise levels caused by a combination of loud voices, loud toys and poor acoustics. In an unknown percentage of households, television or audio equipment is turned on for the whole day, thus creating a continuously noisy environment for the child. Children may be more annoyed or otherwise adversely affected by noise than adults, in part because they have less well-developed coping responses and are often less able to control their environments. It is unknown to what extent aggressive behaviour, helplessness and hyperactivity result from the continuous noise exposure of younger and older children.

In contrast to the extent of noise exposure of children is the extent of research into the effects of noise exposure on their health. It is largely unknown which adverse noise-induced effects occur in children and at which age levels these effects start to occur. Environmental noise regulations based on exposure–effect relationships for adults are usually assumed to apply to children as well.

This chapter gives an overview of the adverse effects of noise exposure on the health of children. The overview is based on data obtained from the literature. General information on the effects of noise exposure on children was obtained from Mills (2), De Joy (3), Passchier-Vermeer (4–6), Horne (7), Evans & Lepore (8) and Evans & Maxwell (9). The possible effects of noise on children's health are presented in sections classified according to the age of children. Health is assumed to include biological (physiological and somatic), psychological, social and emotional aspects.

In considering the effects of noise on children, the following methodological aspects are of importance.

- Have effects been "proven" in the real-life situations of children or have they "only" been observed under experimental test conditions?
- Is there a plausible model for the underlying mechanism into which an observed effect of noise on children and the observed direction of the effect fits?

- Do specific functions of children adapt to noise exposure in the course of time or not? What are the possible long-term consequences of noise exposure, irrespective of the adaptation of the functions studied?

It is an important question whether prolonged noise exposure results in increasingly adverse effects on children or whether those exposed for longer periods adapt to the situation with effects disappearing after a while. Evidently, the relevance for health and development should be taken into account if the effect or effects studied are permanent. On the other hand, if a survey shows that adaptation of the measured effect variables occurs, it is unsure what the price of these temporary effects is on other variables that were not measured. For instance, if a real-life study of the effect of noise exposure on variables related to mental and physiological stress (blood pressure and cognitive performance) shows that the child adapts to the noise situation at school, it is uncertain whether the child adapts to other functions such as aggressive behaviour, unless that variable was measured as well.

4.2. The foetus

Three types of possible effect on the foetus from high noise levels during gestation of the mother are relevant:

- hearing impairment, assessed in epidemiological surveys in which the noise exposure of the pregnant mother was the decisive factor with respect to noise load; audiometry was performed when the children reached school age;
- effects associated with birth outcomes: low birth weight, gestational age and growth retardation; and
- abnormalities of the baby originating during pregnancy (teratogenesis).

The information available on noise-induced effects on the foetus shows hearing impairment associated with exposure to high occupational noise levels during gestation (10, 11). Ongoing research indicates that growth retardation of the child is associated with extensive occupational noise exposure of the pregnant mother (12). It cannot be excluded, but seems unlikely, that environmental noise causes foetal abnormalities (13, 14). Overall, the studies on the effect of environmental noise on the foetus have been hampered by serious methodological limitations, both in the assessment of noise exposure and effect and failure to control for known determinants of the effects under investigation.

4.3. Pre-term and full-term babies

Pre-term and full-term babies differ substantially. Pre-term babies must cope with their environment with immature organ systems. The auditory, visual and central nervous systems are the last systems to mature. These last stages occur, in part, during the time the pre-term child is in an incubator or neonatal intensive care unit (NICU). In addition, the sleep–wake patterns among pre-term and full-term infants differ markedly (15).

It has long been recognized that high noise levels exist in the NICU and incubators, the environment in which the premature baby usually lives for shorter or longer periods up to months. Measurements in the NICU have shown equivalent sound levels from 60 to 90 dB(A), with peak levels of very loud events up to 120 dB(A). The equivalent sound levels in the incubator are 60 to 75 dB(A) and, when the ports of the incubator are closed, peak sound levels up to 100 dB(A) occur (16–24).

Four types of adverse noise-induced effects on the pre-term baby have been considered:

- impaired hearing;
- disturbed sleep;
- somatic effects; and
- effects on auditory perception and emotional development.

Impaired hearing

In premature babies, the hearing organ is still developing after birth. Taking into account the extra vulnerability to hearing impairment during development of the hearing organ, higher levels of NICU and incubator noise seems to be able to impair hearing in pre-term babies (4). However, no research has been carried out that could support this statement (25, 26).

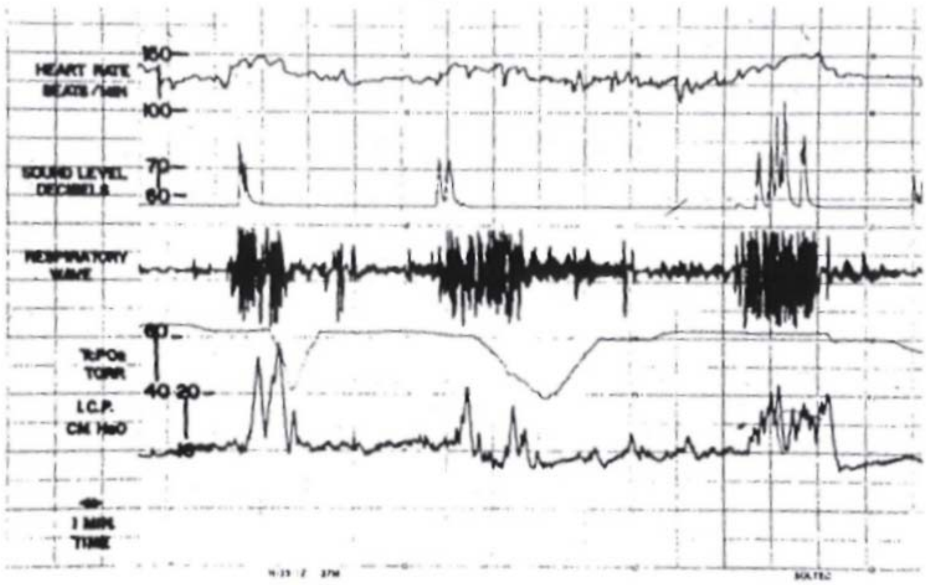
Disturbed sleep

Noise events in the NICU and incubators are sufficiently loud to affect sleep, either by awakening the infant or by changing the state of sleep. Pre-term infants who have difficulty maintaining stable behavioural states experience the same or greater sleep disruption from similar stimuli as do full-term infants (27).

Somatic effects

Figure 4.1 shows a recording of heart rate, respiratory wave, transcutaneous oxygen tension and intracranial pressure from a 1-week-old pre-term male infant in an incubator. Sudden loud noises cause agitation and crying, which usually increase heart rate and respiratory wave, decrease oxygen tension and increase intracranial pressure. Through the increased number of awakening events and associated crying, noise in the incubator and the NICU is a potential cause of hypoxaemia and a source of neonatal morbidity. Fluctuations in arterial oxygen tension, blood pressure and intracranial pressure may contribute to hypoxic brain damage and intracranial haemorrhage. The decrease in oxygen saturation of blood can affect all the vital organs. The infant residing in the NICU or incubator can experience many such acute effects in the period of rapid brain growth (24).

Figure 4.1. Physiological effects of noise on a preterm baby



Source: Long et al. (24)

Auditory perception and emotional development

Current knowledge strongly suggests that stimulation provided by the auditory environment plays a role in emotional development and in the development of the auditory perception of the baby. The sound quality in the NICU and incubator is reduced, since speech and other relevant sounds are masked. Infants in an incubator also find localizing the origin of airborne sounds to be difficult, and these sounds contain fewer higher-frequency components. This impaired sound quality implies that the pre-term infant may have difficulties in subtly discriminating (the intonation of) the voice of the mother and caretakers. The possible emotional implications for the pre-term baby at a later stage are unknown (4).

4.4. Preschool children and schoolchildren

The following effects on preschool children and schoolchildren have been considered:

- hearing impairment
- effects on sleep
- stress-related somatic effects
- cognitive effects
- vocal nodules.

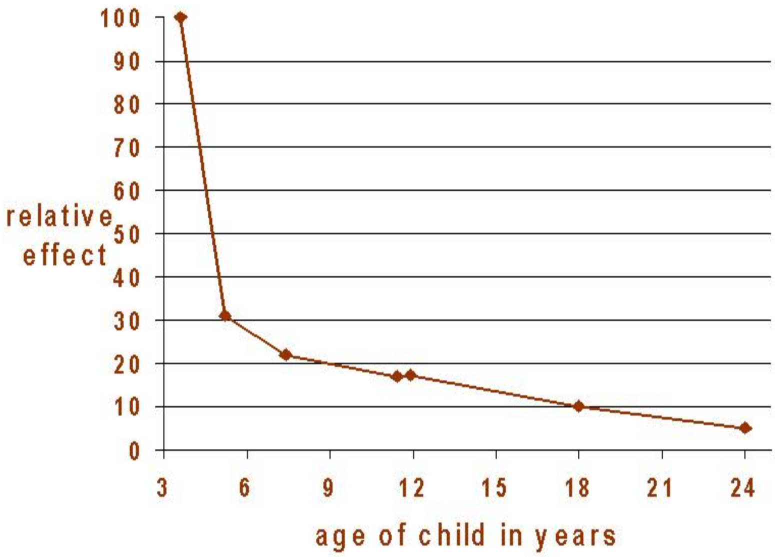
Noise-induced somatic effects (such as on blood pressure and hormone levels) can best be considered as part of a stress response of children to their noisy environment. Psychological and cognitive processes also play a role in this stress response of children. Somatic (physiological) results should therefore be considered together with psychological outcomes to give an overall insight in the problem (4).

Hearing impairment

The investigations undertaken so far show that environmental noise exposure does not affect the hearing threshold levels of children, except for exposure to noise from extremely low flying military aircraft. However, taking into account the very high noise levels present 24 hours a day in megacities, research in this area might show hearing impairment in children associated with these very high levels of noise exposure (28). Given the high noise emissions of specific toys and equipment, some noisy activities may impair the hearing of children. Potential sources of hearing impairment in children are: toddlers' noisy toys, firecrackers, tractors and other agricultural machines, snowmobiles, shooting equipment, power tools, musical instruments and personal audio equipment. Although hearing impairment has been reported in isolated cases, the results of large-scale hearing surveys among schoolchildren fail to show increases in hearing impairment attributable to noise exposure.

Young children may be more susceptible to noise-induced hearing impairment than adults (5, 6). This is made plausible in Figure 4.2. The upper figure gives the results of experiments with mice, an animal with the same physiology of the hearing organ as humans. It gives the effect of exposure to very high noise levels as a function of the age of the mouse. The effect has been assessed by counting hair cell loss in exposed mice killed after noise exposure or by measuring cochlear microphonics in living mice. The effect is presented relative to the effect at the age of 4 days. If developmental stage of mice is converted to that of human children (the lower figure), susceptibility to hearing impairment in preschool and school children is greater than that of adults, at least for very high levels of noise exposure. Whether this also applies to the real-life noise exposure of children is unknown. It is plausible that exposure to environmental and leisure noise, even lifetime exposure with equivalent sound levels over 24 hours below 70 dB(A), does not cause hearing impairment in a large majority of adults (over 95%). If younger children are more vulnerable to acquiring noise-induced hearing impairment at the lower exposure levels than are older children, the observation threshold will be below 70 dB(A). Regarding noise exposure relevant for children, this implies that many young children are regularly exposed to noise levels above this observation threshold.

Figure 4.2. **Susceptibility to hearing impairment as a function of age, birth = 100 on a relative scale. *Upper*. Mice. *Lower.* Humans.**



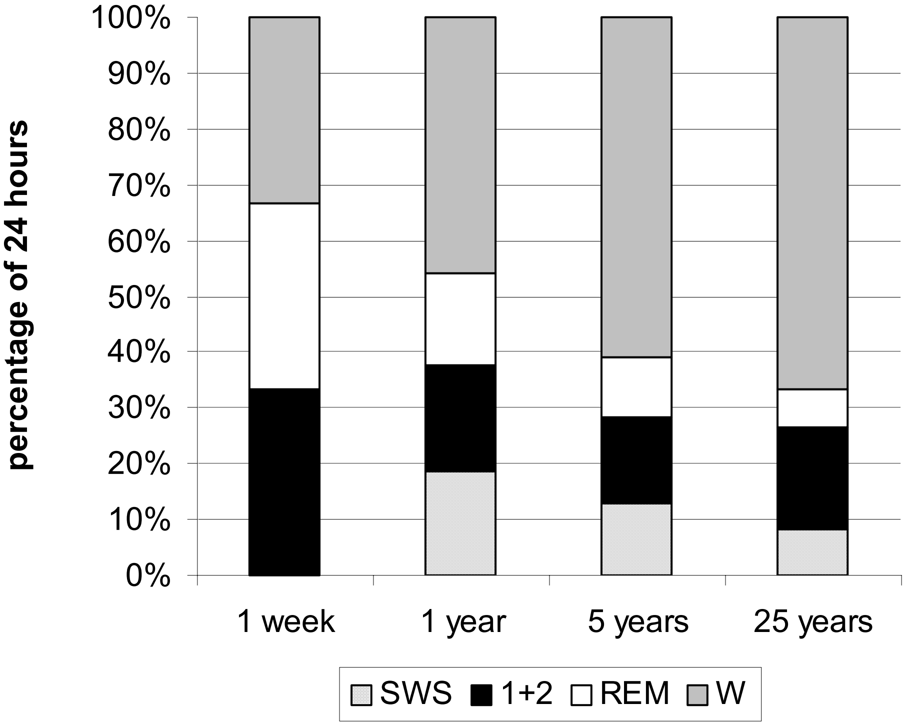
Source: Passchier-Vermeer (5)

Effects on sleep

There are only a few observations on the effects of noise during sleep on the sleep parameters of children. The few test results do not contradict the hypothesis that – analogous to physiological reactions in the waking state – physiological responses occur in children at lower levels of noise exposure than in adults (29). On the other hand, even if the child is awake as assessed by electroencephalography (EEG), this usually does not produce a behavioural response, such as pressing a button (30). In particular, during rapid eye movement (REM) sleep, noise events of sufficient intensity can cause EEG awakening in children. During the last third of the night, in which REM sleep is predominant, children under experimental conditions show 50% EEG awakenings from noise signals with maximal levels of up to 95 dB above the threshold (31). Although children exposed at home may show fewer incidents of awakening (32), this is an important finding, because REM sleep is necessary to consolidate memory. The few test results obtained so far indicate that noise events in the first part of sleep (evening) affect children's sleep less than so noise events in the early morning. Since sleep is very important to the health and development of children, much more research is needed to obtain more detailed insight into possible adverse noise-induced effects.

Sleep is a recovery process that is essential for humans to function properly. Sleep EEG shows two distinct phases of sleep: non–rapid eye movement (NREM) sleep and REM sleep, also called dream sleep. NREM sleep covers four stages: stages 3 and 4 are called deep sleep (slow-wave sleep: SWS) and stages 1 and 2 light sleep (in these stages, the transition from SWS sleep to REM sleep or awakening occurs). In general, body restoration was assumed to occur mainly during NREM sleep and brain restoration mainly during REM sleep. However, it was recently shown that memory consolidation, as part of brain restoration, not only takes place during REM sleep but also that SWS in the first part of the night contributes significantly to memory consolidation. There are essential physiological differences between NREM and REM sleep. Figure 4.3 shows the time spent in the various sleep-wake stages for humans of various ages (4).

Figure 4.3. Sleep–wake stages for humans at various ages as percentages of the 24 hours spent in a given stage



Symbols: SWS = slow-wave sleep; 1+2 = sleep stages 1 and 2; REM = rapid eye movement; W = wake.

Stress-related somatic effects

Table 4.1 gives an overview of surveys on stress-related somatic effects in schoolchildren, including the blood pressure and neuroendocrine indices of chronic stress of these children. In most instances, measures of cognitive performance were also assessed (see subsection on cognitive effects, p. 57). In each survey, schools and children from specific school classes were selected. Children were then classified according to the exposure to a specific noise source (road traffic and aircraft) outside and inside the classroom. Most young children attend schools close to home, and noise exposure during class and exposure at home and while playing outside are probably highly correlated. The question therefore remains whether noise-induced effects should be exclusively attributed to noise exposure during class or whether exposure in other situations (at home) also influenced the effects observed. This reasoning also seems valid for the cognitive effects of noise exposure on children. This is even more so, since sleep disturbance caused by night-time noise can impair memory reprocessing during sleep.

Table 4.1. Surveys on blood pressure and neuroendocrine indices of chronic stress in preschool children and schoolchildren (discussed afterwards)

Reference and number of children tested	Noise source and type of study	Time of measurements	Mean values or mean differences between noisy and quiet classes or level of significance
Karsdorf & Klappach (33) *n* = 263	Road traffic noise Cross-sectional study	During class hours	Difference in systolic/diastolic blood pressure (mmHg) at ages 13–16 years **Age (years)** **Difference (mmHg)** 13 9/12 14 9.5/12 15 11.5/14.5 16 14.5/15
Cohen et al. (34) *n* = 262	Aircraft noise Cross-sectional, first part of longitudinal study	Before start of school	Difference in systolic/diastolic blood pressure (mmHg) between children exposed to noise versus unexposed according to the number of years of exposure **Exposure (years)** **Difference (mmHg)** < 2 4.5/7.5 2–3.5 4/3 3.5–4 2/3 > 4 2/2
Cohen et al. (35) *n* = 163	Aircraft noise Longitudinal study: for first part, see Cohen et al. (34)	Before start of school	No statistically significant effects (tested one-sided at a significance level of 0.05)
Lercher (36) *n* = 796	Highway noise Cross-sectional study of various environmental factors	During class hours	Percentage of children far from or close to a highway with blood pressure > 120/80 mmHg (respectively) or serum cholesterol > 176 mg/dl **Far away** **Close** Systolic 26 21 Diastolic 6 5 Cholesterol 62 52
Regecova & Kellerova (37) *n* = 1542	Road traffic noise Cross-sectional study	During class hours	Systolic/diastolic blood pressure in mmHg among four groups (see text for details) **Group** **Value (mmHg)** 1 96/60 2 97/61 3 101/63 4 102/64
Evans et al. (38) *n* = 217	Aircraft noise Cross-sectional, first part of longitudinal study	Before start of school (resting blood pressure) and during class hours (difference between these measures is a measure of the reactivity of blood circulation)	**Parameter** ***P*** Resting diastolic NS Resting systolic 0.08 Reactivity diastolic NS Lower reactivity systolic < 0.05 Epinephrine (+43%) < 0.05 Norepinephrine (+45%) < 0.05 Cortisol (+4%) NS NS: not statistically significant
Evans et al. (39) *n* = 135	Aircraft noise Longitudinal study: for first part, see Evans et al. (38)	Before start of school (resting blood pressure)	Difference in systolic/diastolic blood pressure (mmHg) between children exposed to noise versus unexposed according to the number of years of exposure **Exposure (years)** **Difference (mmHg)** less than 0.5 3/2 0.5–1.5 0.5/0

Two early cross-sectional studies showed higher systolic and diastolic blood pressure in schoolchildren exposed to very high levels of road traffic noise (33) or very high levels of aircraft noise at school (34) than children not exposed or with minor exposure to these noise sources. Karsdorf & Klappach (33) measured the blood pressure of 13- to 16-year-old secondary school children in the first 5 hours after the beginning of class. The results show an increase with age in the statistically significant differences in systolic and diastolic blood pressure between noise-exposed children and children not exposed to loud noise from road traffic at school. Unfortunately, factors known to modify the effects of noise (body weight, smoking, social class, diet and alcohol use) were not taken into account. It is therefore largely unknown whether the actual noise exposure caused all the effect reported.

Cohen et al. (34) measured resting blood pressure before school started. Their study shows unambiguously that resting blood pressure and noise exposure at school are associated. Cohen et al. (35) re-examined children from the first investigation again 1 year later. Of the 262 children from the first investigation, only 163 took part in the second investigation. It turned out that a large proportion of the children exposed to aircraft noise with higher blood pressure did not participate in the second investigation. The analysis of the sample that took part in both investigations of the longitudinal study did not show any effect of noise exposure, testing session or interactions between noise exposure and testing session on either systolic or diastolic blood pressure.

Lercher (36) examined 796 schoolchildren living close to or far from highways. The study considered not only noise exposure but also other environmental factors, such as exposure to lead. The results are presented as the percentages of children with a systolic blood pressure over 120 mmHg, with a diastolic blood pressure over 80 mmHg or with serum cholesterol levels exceeding 176 mg/dl. Blood pressure was mostly measured in the morning from 0900 to 1200. The results observed contradict the hypothesis of higher values in the children exposed to higher levels of noise, and this contradiction remains if effect-modifying factors are taken into account.

Slovakian researchers studied 1542 children 3–7 years old from child care centres (37). They estimated the exposure from road traffic noise at the child care centres and at the homes of the children. The children were classified according to these two types of noise exposure into four groups (road traffic noise with equivalent sound levels below or above 60 dB(A)): 1) quiet child care centre and quiet home, 2) quiet child care centre and noisy home, 3) noisy child care centre and quiet home and 4) noisy child care centre and noisy home. Blood pressure and heart rate were measured in the morning (0830 to 1200). Systolic and diastolic blood pressure were significantly higher and heart rate lower in groups 3 and 4 compared with groups 1 and 2 after controlling for age, weight and height. The differences in mean systolic and diastolic blood pressure of the various groups were lower in the youngest age group and increased with age. Although the study was carefully designed, social class might explain part of the difference observed (see also Lercher et al. (40)).

In the Munich airport study, schoolchildren were examined in the years Munich airport moved to another location (39, 41). One location was close to the old airport and the other close to the new airport. The cross-sectional part of the study showed non-significantly ($P = 0.08$) higher systolic blood pressure in children highly exposed to noise at school (38). Children were matched on socioeconomic characteristics. The study also examined neuro-endocrine indices of chronic stress: urinary cortisol levels and levels of epinephrine and norepinephrine. Overnight resting levels of epinephrine and norepinephrine levels were significantly higher in the children exposed to aircraft noise at the old Munich airport compared with the control group. There were no differences in cortisol levels. After the airport moved, overnight resting levels of epinephrine and norepinephrine levels rose significantly among children living under the flight paths of the new airport. There was, again, no effect on cortisol levels.

Conclusion

Only the cross-sectional study of Cohen et al. (34) shows that aircraft noise exposure (specifically at school) is statistically significantly associated with increases in systolic and diastolic blood pressure. In the Munich study, noise induced an increase in epinephrine and norepinephrine levels. These results can best be considered as part of a stress response of children to their noisy (school) environment. Psychological and cognitive processes also play a role in this stress response of children. Somatic (physiological) results should therefore be considered together with psychological outcomes to provide overall insight into the problem (see the next subsection on cognitive effects). Amazingly, the surveys in which physiological as well as psychological variables have been studied never reported about the correlation between both sets of effect measures. Concerning adaptation, the data presented by Karsdorf & Klappach (33) and by Regecova & Kellerova (37) on road traffic noise show an increase with age in the differences in blood pressure between noise-exposed and unexposed children (no adaptation), whereas all data on aircraft noise exposure show decreasing differences with duration of exposure (adaptation). If the potential effect-modifying factors had no role, this would imply that children physiologically adapt to a certain degree to aircraft noise but not to road traffic noise. As pointed out earlier, this does not imply that the child also adapts to aircraft noise exposure in all other aspects nor that long-term consequences or other effects are therefore absent.

Cognitive effects

Reading

The best documented effects of noise on children's cognition have been found through research showing negative effects on acquiring reading skills. About 20 studies have found indications of negative relationships between chronic noise exposure and delayed acquisition of reading skills in young children (Evans & Lepore (8); in this text only the central references are given; see those for further references). There are no contradictory findings, and the few null results are probably caused by methodological problems, such as comparing children across school districts that have different reading curricula (42). In addition to the near unanimity of the findings, several other aspects of the research on noise and reading render definitive conclusions. The data include prospective, longitudinal effects (41), evidence of a dose-response function and results showing that sound attenuation interventions in three different situations reduced or eliminated the negative effects of noise on reading (42, 43). Several of the studies have pretested children for hearing damage, showing none, as would be expected given the levels of ambient exposure. Further, most of these studies had controlled well for socioeconomic status. Finally, some of the studies have carefully assessed children under quiet conditions, indicating that the effects of noise are caused by chronic exposure rather than acute conditions during the testing phase.

Studies of acute noise on reading performance are much more mixed, which can be attributed to the shorter duration of exposure. No effects have been found in several studies along with a pattern of interactions suggesting that girls and children with less ability may be at some modest risk. Acute noise has not been found to affect math performance.

Memory

There are fewer studies of noise and other cognitive processes among children than reading. The most ubiquitous memory effects occur in chronic noise, especially when complex, semantic materials are probed (44). Several studies of both chronic (38, 41, 45) and acute noise (44) have found adverse effects of aircraft noise exposure on long-term memory for complex, difficult material. Hygge's (44) study replicated the adverse effects of simulated aircraft noise at both 66 and 55 dB(A) L_{eq} (measured during the 15 minutes of exposure in the classroom). He also showed that the adverse effects of aircraft noise and road traffic noise exceed those caused by train noise or irrelevant speech at comparable intensity levels. Chronic noise exposure does not impair long-term recall of visual materials and recognition memory. No memory effects of acute noise exposure on long-term memory have been reported, but that was not probed for complex, difficult material.

Children's incidental memory for visual material may be adversely affected by chronic noise exposure, although this effect has not always been replicated. Short-term memory does not appear to be sensitive to chronic noise unless it is sufficiently loud to mask the encoding of stimuli.

Attention

Several studies have examined possible links between noise exposure and attentional deficits among young children, with a mixed set of results. Studies in schools exposed to airport or train noise reveal that noise levels are sufficiently loud and intrusive to distract children as indexed by observers (46). Several investigators have uncovered relationships between chronic noise exposure and poorer visual search performance under controlled, quiet testing conditions. Haines et al. (45) found results with an auditory sustained attention task analogous to those found with a series of clerical tasks, including proofreading. No adverse effects of chronic noise on visual search tasks have been reported. Further, although adverse noise effects have been found on memory, attention was unaffected as indexed by the number of text pages read.

Other variables may moderate the relationships between chronic noise and visual attention or concentration. Cohen et al. (42) found that the duration of exposure to chronic noise may play some role. Fourth- and fifth-grade children performed better on a visual search task during acute noise exposure if they had been exposed to chronic noise for 2 years or less; whereas the opposite pattern occurred for children chronically exposed to noise for more than 4 years. Young children from noisy homes were less negatively distracted by an auditory distracter during a visual matching task, and children attending noisy schools performed a visual coding task better under acute noise conditions whereas they did worse, relative to well-matched quiet counterparts, when performing the task under quiet conditions. These data are difficult to compare with other studies because Cohen et al. assessed stimuli presented for a very short duration, whereas other investigators examined sustained attention in visual search tasks.

The findings suggesting differential resistance to auditory distraction as a function of personal history with ambient noise match well, indicating that children chronically exposed to noise have poorer auditory discrimination: ability to detect differences between words that sound similar. Noise-related deficits in auditory discrimination might be caused by children learning to ignore auditory stimuli (gate out distraction) as a way to cope with chronic noise. It is also interesting that two studies have found that young children chronically exposed to noise are less adept at picking out the most optimum signal-to-noise ratio when meaningful stimuli are presented among a background of broadband continuous noise.

Motivation

Laboratory studies and several field studies have found that children chronically exposed to noise are less motivated when placed in achievement situations in which task performance is contingent on persistence (8, 42). Chronic noise has also been associated with deficits on a standardized index of frustration tolerance, and infants reared in noisier homes manifest lower mastery scores on a standardized developmental paradigm. A second index of motivation, refraining from making a choice, is also affected by chronic noise exposure. Following a set of experimental procedures in quiet conditions, children chronically exposed to noise were more likely to relinquish choice over a reward to an experimenter, compared with their well-matched quiet counterparts.

Mechanisms and underlying processes

Several studies suggest that noise can interfere in important ways with speech perception or language acquisition, which may, in turn, account for some of the harmful impacts of chronic noise on reading and other higher level processes, such as long-term memory for complex, semantic material. For children with no auditory damage, levels of road traffic noise were significantly correlated with auditory discrimination of speech. Airport noise exposure is correlated with poorer speech perception. Of potential importance, they also showed that sound perception (such as the ability to recognize common, ambient sounds such as a church bell or a piano) was not related to ambient noise exposure. Both these studies tested children under well-controlled, quiet conditions and ruled out auditory damage as an explanation. Studies have also shown that children who attend schools in noisy areas are less adept at discriminating the optimum signal-to-noise ratio in an auditory task (38, 42). It has been suggested that children chronically exposed to noise develop a cognitive strategy of tuning out or ignoring noise as way to deal with it. Unfortunately, this tuning-out process may overgeneralize so that children learn to tune out not only ambient, background sound but also focal material such as speech.

Conclusion
Reading, long-term memory and learning in children are particularly sensitive to noise. The effects of noise on children's cognitive functions are not wholly mediated by attention but seem to depend on the way information is stored and reorganized in memory and learning.

4.5. Vocal nodules

A 1982 study in Norway (47) related the strain and wear and tear on children’s voices as a result of noise exposure in child care centres. The factors contributing to noise are:

- the number of children
- the length of stay in day care
- pedagogical initiatives
- the acoustical standard of the building
- lack of space (crowding).

Children raise their voices and risk developing hoarseness and vocal nodules because of noise and relative overcrowding. Voice strain and nodules are caused by stress to the larynx, within which are the delicate vocal cords. Vocal cords can develop into open bleeding wounds and scars, and this requires an operation to heal.

The number of children screaming so much and so loudly that their voices are damaged and require treatment increased in Denmark during the 1990s. Noise in schools and day care institutions results in boys’ voices getting hoarse and girls’ voices squeaky. The noise level in schools and day care institutions is so high that children scream to make themselves heard above the other children (48).

Children with vocal nodules can be difficult to understand and risk losing their voices altogether. Other children become so tired of screaming or of trying to make themselves heard that they give up saying anything at all and, for example, do not raise their hands in class. If children give up speaking, their voices do not develop properly and language learning is not reinforced.

Classic vocal abuse may occur when children are talking too long, too loudly and using too much effort. Usually children develop vocal nodules or vocal strain from the excessive interaction of two or more of the following:

- talking and singing, for example: excessive and over-enthusiastic rehearsal of school plays or concerts;
- excessive choir or solo-singing practice;
- overusing the voice on school camps or excursions
- shouting in the playground;
- talking and shouting against background noise, such as in a swimming pool;
- overusing the voice during an infection such as a head cold; and
- overusing the voice when tired or emotionally upset.

Lengthy talking, even at a normal rate and volume but without a quiet recovery time, can also contribute to vocal strain and nodule formation (49).

4.6. Teenagers

There is a nearly complete lack of research into the somatic, mental, physiological and behavioural effects of noise on teenagers, nor are there studies on noise-induced sleep disturbance of subjects of this age group. The only noise effect in teenagers to which many studies have been devoted is noise-induced hearing impairment and accompanying tinnitus (ringing in the ear).

Hearing impairment

The potential sources of hearing impairment mentioned for schoolchildren (noisy toys, firecrackers, tractors and other agricultural machines, snowmobiles, hunting equipment, power tools, musical instruments and personal audio equipment) may also impair the hearing of teenagers. In addition, it is not unlikely that noise levels in boom-cars and (under helmets) of motorcycles cause noise-induced hearing impairment in teenagers (4).

Some older teenagers are employed. The relationships presented in International Standard 1999 (50) about noise-induced hearing impairment and noise exposure show that, during the first 10 years of exposure, hearing impairment at the most affected frequency (4000 Hz) is only somewhat less than after lifetime exposure. Preserving good hearing and preventing noise-induced tinnitus if technical noise abatement measures are not taken therefore requires that teenagers be instructed to use personal hearing protection as soon as they start being exposed to high noise levels, not only at work but already at technical schools and polytechnics. The extent of hearing impairment in teenagers caused by occupational noise exposure and exposure at technical schools and polytechnics is unknown (51).

Many studies on hearing impairment among teenagers have been aiming at assessing the degree of hearing impairment in teenagers without trying to specify the relationships between exposure and effect (52). Specifying relationships is difficult indeed, since there are many types of variation in exposure parameters. It is usually very difficult to obtain sufficient quantitative data about exposure in the past and present (53, 54). For example, the actual noise levels at pop music concerts and discotheques vary between and within concert halls and discotheques. Also, the number of exposures per year or the annual hours of exposure usually varies in the course of years. In a study of the relationship of hearing threshold levels and exposure to pop music through headphones (55), a study population was selected that was – as assessed from a national inventory of pop music habits in the Netherlands – assumed to have no or minor exposure to pop music at concerts and discotheques. The study comprised over 400 subjects aged 14 to 20 years, and the exposure of each subject to music through headphones (and during other activities) was assessed in detail. It was made plausible that the model given in International Standard 1999 (50) for occupational exposure also applies, albeit with a slight adaptation, to this type of exposure (56). Whether the model also applies to the much more irregular exposure of teenagers to pop music at pop concerts, discotheques and dance halls is unknown.

Based on the results of epidemiological surveys on hearing threshold levels of a random sample of the general population or parts of the general population (such as 18-year-old military recruits), Passchier-Vermeer (6) concluded that by far the largest part of the cumulative distribution of hearing threshold levels of the general population has not changed in the last 25 years or so. Given the data on children in secondary school in the Netherlands, this conclusion has been confirmed for the Netherlands. However, the results, based on screening audiometry of two large populations of young people in Austria and Norway at the end of the 1980s, showed serious deterioration in the hearing of young males and females (17–18 years old), which was attributed to pop music activities. This observation is not supported by studies in the Netherlands, Sweden and Germany, based on threshold audiometry of smaller groups of young people. Procedures related to mass screening techniques probably caused a systematic increase in hearing threshold levels in Austria and Norway.

Although noise-induced hearing impairment among teenagers has been reported in isolated cases, a comparison of the present distributions of hearing threshold levels of young populations with those distributions 30 years ago fails to show increases in this distribution (57).

4.7. Combined and ototoxic effects

Exposure to chemicals may result in reversible and permanent ototoxic effects on children, and the combination of noise and metals and organic solvents to a lesser degree than adults in occupational settings, but children are exposed to chemicals, for example, in play environments. Children can receive ototoxic exposure from ambient air, exhaust from cars, volatilization from furniture and surfaces, cleaning products, dirt in playgrounds and emissions from the chemical surface of toys. Adolescents may seek deliberate chemical exposure while sniffing glue or gas from lighters. A potential risk from sniffing in addition to brain damage is the effect on hearing (58, 59). High exposure to lead has been reported to affect the hearing of children (60), and toluene and xylene are reported to reduce hearing.

Children risk ototoxicity from chemicals used in therapeutic medicine. According to Robert A. Hendrix (personal communication), premature babies risk damaged or reduced hearing resulting from noise exposure in the incubator, in which the noise effects are potentiated by the ototoxicity of aminoglycoside antibiotics such as gentamicin. Medical treatment for example chemotherapy and radiotherapy, cisplatin or aminoglycoside antibiotics, carry a risk of ototoxicity. Children with otitis media (middle-ear infection) are often treated with paracetamol, which can result in reduced hearing during treatment. Some medicines have reversible effects, such as salicylic acid, whereas other compounds may permanently affect hearing.

A vicious circle thus develops when a child with reduced hearing because of middle-ear infection is treated and the medicine reduces his or her hearing even more. The child may react by speaking more loudly, thus raising the noise level and also risking the development of hoarseness and vocal nodules.

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5. Perceptions of noise

by Marie Louise Bistrup

5.1. Introduction

This chapter illustrates various perceptions of noise among professions involved with noise research and among children and adolescents. Part of the chapter is based on the results of a seminar held on 19–20 June 2000 in Copenhagen, Denmark on children and noise: health effects, perceptions of risk and definitions of noise.

Another part is based on the Noise and Children workshop. An opportunity arose to involve a group of children in an assessment and discussion of noise at the Millennium International Children's Conference on the Environment on 22–24 May 2000 in Eastbourne, United Kingdom. The study was conducted and the report written by Mary Haines and her colleagues (1).

Finally, a small number of recent reports have been identified that have addressed children's perception of noise.

Impressions of perceptions of noise

Before the seminar on children and noise: health effects, perceptions of risk and definitions of noise, seminar participants were asked to answer a set of questions; one set of questions was related to the participants' perception of how noise is perceived among the general public and among themselves. The questionnaire is enclosed as Annex 4.

"What is your impression of what is in your country perceived as noise *by the general public*?":

- Sounds from busy traffic in residential areas are mostly perceived as noise.
- Sounds from heavy traffic outside schools are often or mostly perceived as noise.
- Sounds from neighbours in apartments (shouting, loud music etc.) are sometimes, often or mostly perceived as noise.
- Sounds from children shouting in day-care institutions are either mostly perceived as tolerable sounds, sometimes perceived as noise, or are often perceived as noise, but are never mostly perceived as noise.
- Sounds with high peaks from children's toys are either mostly perceived as tolerable sounds, sometimes perceived as noise, or are often perceived as noise, but are never mostly perceived as noise.

"What is your impression of what is perceived as noise *by your profession*?" Sounds from busy traffic in residential areas are often or mostly perceived as noise.

- Sounds from heavy traffic outside schools are exclusively mostly perceived as noise.
- Sounds from children shouting in day-care institutions are mostly perceived as tolerable sounds and sometimes perceived as noise, but are never mostly perceived as noise.
- Sounds with high peaks from children's toys are perceived in all possible manners: perceived as tolerable sounds, sometimes perceived as noise, or often or mostly perceived as noise.

Summary of public and professional perceptions of noise

By answering these questions, the participants assessed their personal and professional perception of noise and their impression of the general public's perception of noise in a number of situations from daily life. The participants, predominantly researchers, attending the seminar, for example, regard sounds from heavy traffic outside schools and sounds with high peaks from children's toys as more noisy than does the general population. Overall, the seminar participants rate the daily activities as more noisy than what they think is perception by the general public.

5.2. The Noise and Children workshop

The aim of the Noise and Children workshop was to further understanding about children's experience with noise and their perceived risk of noise pollution. Quantitative and qualitative techniques were used with a sample of 36 self-selected children aged 10–12 years from 12 countries attending the workshop at the Millennium International Children's Conference on the Environment (1) identified some indications of children's perception of noise.

5.2.1. Perception of chronic noise and environmental satisfaction at home

Neighbours' noise and road traffic were the most frequent sources of noise perceived at home. Aircraft noise was perceived by 42% of the sample. Very few children perceived industrial and rail noise exposure at home. Almost all the children (92%) felt that their home environment was safe or very safe, that their home environments were clean or very clean (89%) and that their home environment was friendly or very friendly (89%). This high level of satisfaction with the home environment suggests that the children's perceived noise was not confounded by other environmental stressors.

Noise annoyance from chronic noise exposure at home

In a focus group the children reported that noises from people were the sort of noise affecting them most in their everyday lives. The children were most annoyed by neighbours' noise at home, although the level of annoyance reported was fairly low, with most reporting being "a little annoyed". The children attending the workshop reported very low levels of noise annoyance for road traffic, rail, aircraft and industrial noise at home, but this may be due to actual noise exposure levels at home. The annoyance reaction is known to be associated with actual exposure levels.

Annoyance and emotional response to acute noise

From a list of options, the response from the children was that the most annoying sounds were: traffic noise, a creaking door and a man snoring. The least annoying sounds were giggling girls and an office clock. A mobile phone was rated as moderately annoying, and the ringing tone induced a mixed emotional response of tension and happiness.

Tension was the emotion that was most strongly associated with the most annoying sounds (traffic noise, a creaking door and a man snoring). Chalk on the blackboard was the only sound for which irritation was rated more highly than tension. Compared with "tension" and "irritation", "sadness" was not as frequently reported as an emotional response to the sounds.

Summary of the Noise and Children workshop

The response pattern for perceived noise at home mirrors community noise surveys of adults with neighbours' noise and road traffic noise also being the most frequently reported. This indicates consistent and reliable responses from this sample of children.

The most striking result was that children report the highest annoyance for neighbours' noise at home. Neighbour noise has been neglected in previous research examining the non-auditory health effects of noise exposure on children.

In contrast to the noises from people, the children felt they had little control over noise emitted from transport. This result is consistent with the quantitative results in which children report neighbours' noise and road traffic as the most frequent sources of noise in their home environments. The qualitative results suggesting how noise affects children are also consistent with their emotional reactions to acute noises. For example, a man snoring and road traffic were rated as most annoying, irritating and tense and a girl's giggling not very annoying at all. Thus, there is an indication that the children gave consistent and reliable answers across quantitative and qualitative measures. The report on the Noise and Children workshop is contained in Annex 5.

5.3. Youth's perception of noise

Adolescents' opinion of the effects of noise reflect the fact that children in some situations find noise annoying and interfering with the tasks at hand. Lundquist (2) examined how annoying high-school students found noise and studied the relationship between the experienced and rated annoyance and the noise level. The relative correlation between L_{eqA} and students' assessment of annoyance shows that the experienced annoyance of noise can only somewhat be explained by the level of noise. On verbal definitions ranging from not annoying to almost unbearably annoying, students in seventh grade rated the average assessment of annoyance as somewhat or relatively annoying, and students in eighth grade rated the average annoyance as somewhat annoying. The ratings by girls and boys did not differ.

Another article (3) reports on the noise that young people make at school and concludes that young people need to be heard as well as seen. When the level of noise tolerated in the average school is looked at closely, it is hardly surprising that young people become baffled as to why normal social intercourse, normal chatter, is allowed in the home, the street, the youth club and the workplace and yet is forbidden at school during teaching.

A recent Danish survey initiated by the National Council for Children in 2000 found that, among students in sixth grade (12–13 years), 19% felt annoyed by noise during lessons, 19% did not feel annoyed and 62% felt that they were sometimes annoyed by noise during lessons (4). Some of the children described why they did not want to play in the schoolyard: "because there is so much noise", and others looked forward to coming home after school in order to "get rid of the noise" (4, 5).

Another study (6) asked children about noise and turbulence during lessons:

- 52% reported that frequently they experienced noise and turbulence;
- 44% reported that during the first 5 minutes of lesson time is spent unproductively;
- 24% reported that most students in class do not listen to what the teacher says; and
- 20% reported that most students in class start working long after the lesson starts.

When more than 50% of students report that there often or sometimes is noise and turbulence in class, noise and turbulence must be regarded as factors negatively affecting student well-being and learning. Students in classes with little or rare noise reported that they find the learning situation better than did the children in noisy classes (4, 6). More girls than boys reported belonging to a noisy class, and only a slightly larger percentage, 21%, of children in larger classes (more than 20 pupils) reported having a very noisy class, whereas only 20% in smaller classes (less than 20 pupils) reported being in very noisy classes. The grade level was also important for the assessment of noise, as 28% of eighth and ninth graders reported being in very turbulent learning situations versus only 13% of pupils in grades 5–7. Children in very noisy classes reported having headaches more often than did children in not so noisy classes, but the use of painkillers did not differ by grade level for children experiencing no or little noise and children experiencing very much noise. This is probably explained by the fact that the use of painkillers is generally more common in higher grades, and children's use of painkillers is similar in noisy and not so noisy classes.

5.4. Conclusion and summary

People in professions involved in noise research seem to regard the public as being better able to tolerate noise than they themselves can. This may be influenced by the assumed greater knowledge among professionals of the potential harmful effects of noise on children.

We have not found reviews of children's perception of the risk of noise but some studies on children's perception of noise. Children seem to give consistent responses to observations with noise and reliable observations and responses to perception of noise. Children feel annoyed by noise to a degree that would interfere with their tasks, and children attempt to avoid noise. Adolescents report annoyance levels that are related to noise levels, but other adolescents find it paradoxical that noise is allowed in all other places than in schools. Attempts should be made to more routinely include the views of children on noise in the assessment of noise and preventive action. Especially important would be developing methods to collect the views of small children and their perception of noise, because this dimension is lacking.

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6. Future research

by Lis Keiding and Marie Louise Bistrup

6.1. Introduction

We believe that this review of settings of noise for children, effects of noise on children and on perceptions of noise reveals gaps in the research. There may be some existing resources of which we have not been aware, but we believe that there is a real lack of knowledge and research and that many countries have not given priority to studying this subject or to alleviating or preventing the harmful effects of noise.

The gaps in the research mean that more research is needed. A list of priority areas is presented at the end of this chapter.

In connection with definitions of noise, it has been stated that “noise” implicitly means sounds with some sort of harmful effect. In this chapter, the word “noise” is however, for practical purposes, used in general, including research in which some results may also show no harmful effects of the sounds studied.

Research seems to be lacking in almost all areas related to children and noise. Systematic research is lacking on the effects on hearing, health, well-being and cognition and the role of noise on children’s sleep for different age groups of children.

Research into the somatic, psychosomatic and behavioural effects of noise on teenagers is nearly completely lacking, nor are there studies on noise-induced sleep disturbance of subjects in this age group.

Knowledge on the effects of noise in different children’s neighbourhoods is lacking, as is knowledge on the indirect or secondary effects of noise on children when children’s parents, caretakers or teachers are annoyed by noise.

Systematic assessment is lacking at the regional or national as well as European level on how many children are exposed to what kind of noise and where and how, and knowledge is lacking on the levels of exposure, which is needed as a background for establishing new policy.

Qualitative methods to supplement quantitative investigation of children’s perception of noise have not been well developed, and there are no studies on the role children themselves can play in handling noise.

Reviews and research looking into the mechanisms and deliberations with regard to the possible health significance of different types of sound design are lacking, and especially with the susceptibility to noise of the child population in mind.

Investigations to explore the beneficial impact of relaxing environments free from noise in providing psychological restoration for children are missing.

There are few studies on preventing the harmful effects of noise on children.

6.2. Future general research

At a seminar on 19–20 June 2000 in Copenhagen, Denmark on children and noise: health effects, perceptions of risk and definitions of noise, the working groups dealt with three questions related to research:

- What are the gaps in research?
- What knowledge is needed to prevent adverse effects of noise on children?
- What are the future research priorities?

The following section is based on the recommendations from the seminar, with gaps in the research identified leading to a list of future research topics.

The proposal for future research topics related to children and noise is divided into some general comments, some examples of recommended research within methodology and a list organised according to the settings in which children are exposed to noise.

General comments

The review of research reveals differences in the precision of measurements and difficulties in comparing measurements and in assessing and confirming existing findings. Outcome measures vary. In some studies it could be an advantage to look at noise together with some biomarkers of, for example, stress.

General research themes

- How many children are affected by noise?
- Noise exposure in childhood as a predictor of adult exposure
- Standardised measure or assessment of exposure
- Define settings in terms of time–activity patterns and identify activities
- Study room acoustics
- Selection and standardisation of outcome measures
- Annoyance as a predictor of social behaviour
- Dose–response relationships
- Studies of long-term health effects
- Research related to preventing adverse effects, thus identifying best practices on how to prevent adverse effects of noise on children
- Research as a background for recommendations related to educating architects, designers and planners on how noise affects children and on the best ways to prevent noise

Examples of recommended research within methodology

- Improving retrospective assessment of noise exposure
- Longitudinal studies, such as multicentre studies
- Twin studies
- Intervention studies
- Taking advantage of the research opportunities in relation to natural experiments

6.3. Research topics according to setting

The home

- Influence on the inhabitants of noisy environments close to the home
- More studies on intervention into the physical construction of buildings and the interior planning of the rooms to prevent noise effects
- Hearing impairment from music and toys
- Focus on the effects of noise on children's sleep and on the after-effects of noise, with the restoration of the brain and body being important:

  - Effects of noise on "normal" children
  - Effects of noise on sick children
  - Effects of noise on preterm babies
  - Effects of noise on pregnant women's sleep and noise exposure on the foetus
  - Effects of nighttime noise
  - Effects of daytime noise on sleep quality and quantity
  - Effects of sleep on the immune system and hormone levels
  - Psychological effects of noise such as on daytime performance and behaviour
  - Studying individual differences between children at various ages and in cultures in different parts of Europe

Hospitals and health care institutions

- What type of noise disturbs sleep?

  - Measurement techniques (less invasive than EEG)
  - Ill babies and children
  - Daytime sleep patterns
  - Effects of various interventions to protect against hazardous noise

Day care institutions and schools

- Crowding in kindergartens and schools and its effects on learning
- Intervention programmes in schools: before and after evaluation studies
- The role of noise on cognitive functions for all relevant age groups
- Children's sleeping environments in day care settings
- What are the characteristics of good learning environments?

Clubs and leisure activities

- Studying the effects of loud music and noise on teenagers

Nature

- Study tranquil areas and the role of silence and sounds in nature for children's health

Combined sources

- Noise is not experienced in isolation, so studying the effects of combinations of noise exposures and effect-modifying factors:
    - Noise, social disadvantage, poor housing, poor schools and poor teaching
    - Noise and other environmental stressors, such as air quality indoors and outdoors

Regional differences

- Terminology within Europe
- Schools versus kindergartens
- Day nurseries versus preschools
- Different lifestyles
- Different perceptions of noise
- Different perceptions of children's day and night rhythms

6.4. Future research priorities related to children and noise

As shown above, research efforts should be directed towards many research areas and settings of importance to children. However, making a short list of research priorities is not solely a matter of importance and relevance but also a matter of what can be researched given the current theoretical and methodological knowledge and a sense of where the frontiers are opening up. Adding these latter criteria to the tools for choosing research areas has led us to the following short list of priorities for future research on children and noise:

1. Effects of noise on cognitive functions in children
2. Effects of noise on children's sleep
3. The magnitude and significance of noise annoyance among children
4. Intervention programmes and identification of best practices of preventing harmful effects of noise on children
5. Children's perception and risk perception of noise.

1. Effects of noise on cognitive functions in children. Including special awareness that children are developing and learning, and research into the link between psychological and somatic effects

2. Effects of noise on children's sleep. The consequences of sleep disturbed by noise, including:

- effects on a "normal" child
- effects on an ill child
- effects on preterm babies.

3. The magnitude and significance of noise annoyance among children. Including the effects of noisy or tranquil environments on children's social behaviour.

4. Intervention programmes and identification of best practices of preventing harmful effects of noise on children. Including a focus on schools, kindergartens and after-school clubs: before and after evaluation studies.

5. Children's perception and risk perception of noise. Both among the youngest of the children who can express their perception and among older children, including children doing noisy work jobs at school (similar to noise exposure in the occupational health of adults).

All these themes require overviews of the magnitude of the noise problem for children, such as the sources of exposure, combined exposure and time pattern of exposure. In addition, the groups of children most commonly exposed to hazardous noise and especially vulnerable groups of children should be identified. This will allow a better background for setting priorities for intervention to be established.

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Annex 3. Characterisation of noise exposure

by Willy Passchier-Vermeer

Sound pressure level and sound level

Sound is a physical phenomenon with alternating compression and expansion of air, which propagates from a source in all directions. These alternating compressions and expansions can be described as small changes in pressure around the atmospheric pressure. The frequency of the alternations determines the pitch of a sound: a high pitched tone (e.g. 4000 Hz) has a squeaking sound, a low pitched tone (e.g. 200 Hz) a humming sound. Sound pressures, relative to the atmospheric pressure, range from less than 20 micropascal up to more than 200 pascal, a range of 1 to 10 million. Therefore, in acoustics, the logarithm of the sound pressure relative to a reference sound pressure is taken as a basis for a sound exposure measure: the physical quantity sound pressure level expressed in decibel (dB).
The human hearing organ is not equally sensitive to sounds at different frequencies. Therefore, a spectral sensitivity factor is used which rates the sound pressure levels at the different frequencies in a comparable way as the adult human hearing organ does: the so-called A-weighting. The biophysical quantity A-weighted sound pressure level (symbol L) is expressed in dB(A) and is referred to as sound level.

Long term noise exposure

Equivalent sound level

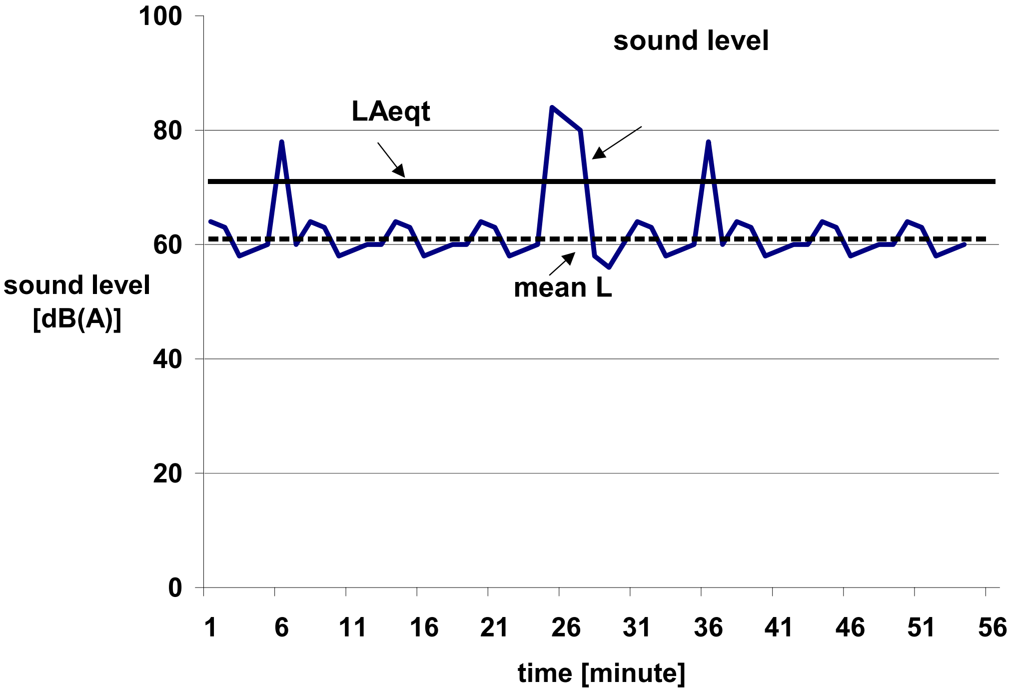
The sound level is the basic metric from which other biophysical metrics to specify long-term exposure to noise are derived. In environmental and occupational situations the sound level fluctuates with time. From these fluctuating sound levels, the equivalent sound level (symbol $L_{Aeq,T}$) over a period of time T is determined from:

$$L_{Aeq,T} = 10 \lg 1/T \circ 10^{L(t)/10}\, \mathrm{d}t$$

In the equivalent sound level over a period T, the highest sound levels occurring during this period are counted more heavily than in the ‘normal’ average sound level over period T. This is demonstrated by the example given in Figure A1. It shows the typical situation in an incubator. The average sound level over the period shown in the figure is 60 dB(A), the equivalent sound level over that period is 70 dB(A).
Common exposure periods T to assess environmental or occupational noise exposure are 24 hours (full day) and 8 hours (working day).
For environmental health assessment purposes, usually a noise metric is assessed on an annual basis. In various countries, the so-called *day-night level* *(L_{dn})* is in use. This metric is the equivalent sound level over 24 hours, with the sound levels during the night (period of 23:00 - 07:00 h) increased by 10 dB(A). Also a ‘day-evening-night level’ (L_{den}) is used, which is constructed similarly, be it that the sound levels during the evening (19:00-23:00 h) are

increased by 5 dB(A), and those during the night (23:00-07:00 h) by 10 dB(A). Commonly L_{dn} or L_{den} are measured in front of the facade of residential buildings.

Figure A1. Characterisation of long term noise exposure. As an example,the sound level (in dB(A)) is given as a function of time (in minutes). The average sound level over the time registered is 60 dB(A), the equivalent sound level over that time 70 dB(A)



Single noise event

Specification of the noise of a single noise event
In Figure A2 the sound levels of an isolated noise event are given as a function of time. The noise comes from a single shot of a toy pistol and is measured at a distance of 20 cm from the toy in the direction of the barrel. The noise from such an event can be specified by its maximal level, sound exposure level, or peak sound pressure level.

Maximal level
To assess the so-called maximal level, several time-averaging networks of a noise level meter may be used, such as S (averaging time 1 s) and F (averaging time 125 ms).

Sound exposure level
If a noise event is of a short duration, less than one second, the sound exposure level or SEL of the event is equal to the equivalent sound level measured over 1 s. If the event is of a longer duration, the sound exposure level

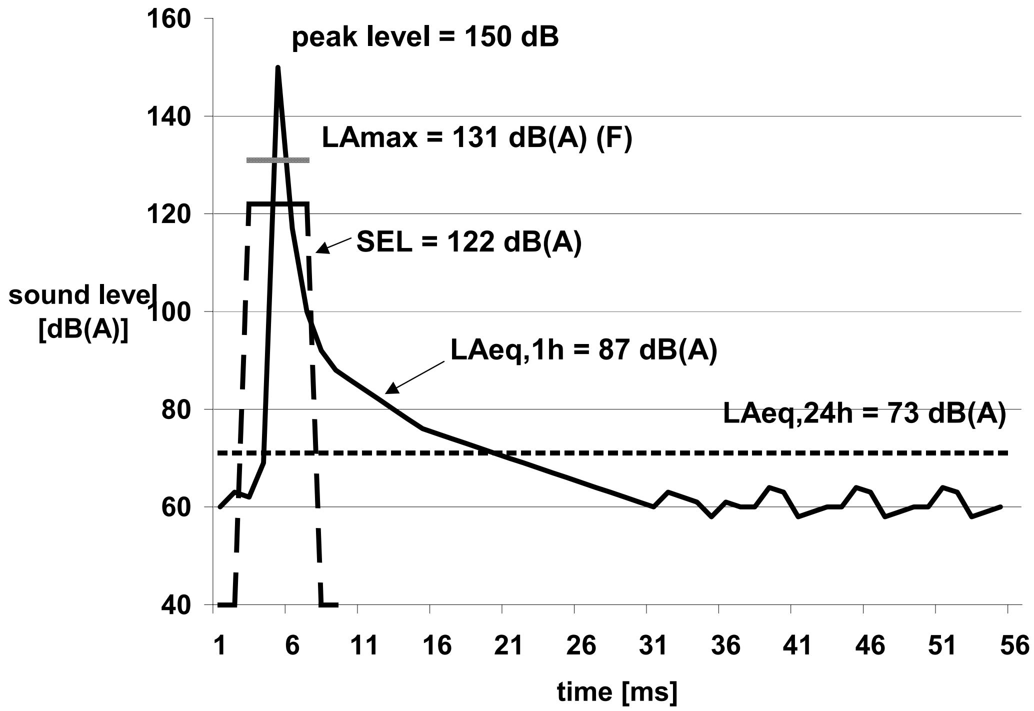
or SEL is the equivalent sound level during the event normalised to a period of one second.

Peak sound pressure level
A single noise event of very short duration, such as the noise impulse from a toy pistol, may also be specified by its peak sound pressure level. To assess this peak value, the measurement time is in the order of about 50 to 100 microseconds. Usually no frequency weighting system is used if the peak sound pressure level is measured.

The example
In Figure A2 the noise measures of the noise impulse accompanying a shot with a toy pistol are given. The peak sound pressure level is 150 dB at a distance of 20 cm (this is a typical value, see Passchier-Vermeer, 1991). Given a typical duration in the order of milliseconds, the maximal level on F is equal to 131 dB(A), SEL is 122 dB(A), $L_{Aeq,1h}$ is 87 dB(A) and $L_{Aeq,24h}$ 73 dB(A).

For 100 of these pistol shots $L_{Aeq,24h}$ is equal to 73 + 20 = 93 dB(A) (73 + 10*lg 100 = 93).

Figure A2. Characterisation of a noise event. As an example the noise of a pistol when fired once is given. The sound level is given as a function of time (in milliseconds).



Annex 4

Perceptions of noise

Your name……………………………………………………………..

Profession………………………………………………………

Area of research or activity……………………………………….

Country…………………………………………………………

Question no. 1

We want to get an impression of cultural differences among European countries and among different professions on the perceptions of noise. Please fill in the simple tables below. You are welcome to add comments.

1. **a. What is your impression of what is in your country perceived as noise *by the general public*?**

Please put one x in each row in the table

	mostly perceived as tolerable sounds	sometimes perceived as noise	often perceived as noise	mostly perceived as noise
sounds from busy traffic in residential areas				
sounds from heavy traffic outside schools				
sounds from neighbours in apartments (shouting, loud music etc.)				
sounds from children shouting in day-care institutions				
sounds from outdoor concerts (which you are not voluntarily attending)				
sounds with high peaks from children's toys				

1. b. What is your impression of what is perceived as noise *by your profession*?

Please put one x in each row in the table

	mostly perceived as tolerable sounds	sometimes perceived as noise	often perceived as noise	mostly perceived as noise
sounds from busy traffic in residential areas				
sounds from heavy traffic outside schools				
sounds from neighbours in apartments (shouting, loud music etc.)				
sounds from children shouting in day-care institutions				
sounds from outdoor concerts (which you are not voluntarily attending)				
sounds with high peaks from children's toys				

Annex 5

United Nations Environment Programme's
Millennium International Children's Conference on the Environment

Noise and Children Workshop

A report on the quantitative and qualitative responses of children to noise exposure and perceived risk of noise pollution

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Summary

Introduction
The overall aim of this workshop was to further understanding about children's experience with noise and their perceived risk of noise pollution using quantitative and qualitative techniques with a sample of children attending the 'Noise and Children' workshop at the United National Environment Programmes' Millennium International Children's Conference (MICC). The specific objectives of this workshop were to:
a) understand children's experience with noise, sound and music
b) gather information about children's perception of noise, perception of risk from noise, coping strategies and reaction to research findings
c) inform children about noise pollution.

Protocol
The sample of children who took part in the workshop were 36 self-selected children aged 10-12, from 12 countries attending the MICC. These questionnaire data were collected: sociodemographic variables, environmental attitudes, perceived noise and noise annoyance. Annoyance and emotional responses to 10 acute noises played to children were collected. Qualitative data were collected through focus group sessions. The focus groups were semi-structured and were arranged into these four key themes.

1. How does noise affect you ?
2. Noise as a hazard
3. Coping strategies to deal with noise pollution and control over noise source
4. Reaction to research findings

Results and Conclusions
In both the qualitative and quantitative results, children report being most affected by neighbour's noise and road traffic noise. Children perceive the risk of noise pollution as low. Even though it affects their everyday activities, it is not perceived as a life threatening pollutant. These are the main conclusions drawn from the workshop:

1. Future research should employ qualitative methods to supplement quantitative investigations.
2. Children's noise annoyance requires further investigation to explore the beneficial impact of relaxing environments in providing psychological restoration.
3. Future research could focus on the effects of neighbour's noise on children. For example, does it affect homework, sleep, well-being and stress levels ?
4. Children can provide reliable responses about their perception of noise and should be involved with governmental debate about their environments.

Table of Contents

1. Introduction

The MILLENNIUM INTERNATIONAL CHILDREN'S CONFERENCE on the ENVIRONMENT (MICC) was organised in partnership with the United Nations Environment Programme (UNEP). The mission of the UNEP is "to provide leadership and encourage partnership in caring for the environment by inspiring, informing and enabling nations and peoples to improve their quality of life without compromising that of future generations". The first ever, International Children's Conference was held in 1995, as a result of the need for governments to pay attention to the concerns and opinions of children regarding the environment. The aim of the Millennium International Children's Conference on the Environment (MICC) was to give 1,000 child delegates from over 100 countries an opportunity to develop innovative ideas on protecting and improving the world's environment for this and future generations. The conference also provided a forum for 10-12 year olds to learn, share experiences, voice their concerns, join a worldwide environmental network to promote positive action and produce a Charter to present through the United Nations to their respective Governments. The conference was held in Eastbourne, England from May 22 – 24, 2000. The conference was focused on three topics: 1) Sharing the Planet, 2) Water is Life, 3) Living in Cities. The noise and children's workshop formed part of 'Living in Cities'.

This 'noise and children' workshop was included in the conference programme because noise pollution is increasingly being recognised as an environmental hazard in modern urban environments. Children are recognised as a high risk group vulnerable to the adverse effects of noise exposure (Evans & Lepore, 1993; Stansfeld *et al.,* 2000a).

The most consistent effects of chronic environmental noise exposure (rail, road and aircraft) on children are effects on cognitive performance, especially tasks that involve central processing and language comprehension (Cohen *et al.,* 1986, Evans *et al.,* 1991; Evans & Lepore, 1993; Stansfeld *et al.,* 2000a). Three studies (Bronzaft & McCarthy, 1975; Evans *et al.,* 1995; Haines *et al.,* 1998) have tested whether children are annoyed by chronic noise exposure and all have confirmed that chronic noise exposure is associated with annoyance levels in children. There is moderate evidence to suggest that children's motivation and blood pressure may be adversely effected by prolonged exposure to environmental noise, although the results are not consistent (Stansfeld *et al.,* 2000a). One study has found that children exposed to aircraft noise have raised catecholamine secretion (Evans *et al.,* 1995, 1998), however there is no evidence that cortisol section is associated with chronic noise exposure (Evans *et al.,* 1995, 1998, Haines *et al.,* 2000a). There is some evidence that chronic noise exposure is associated with stress responses such as well-being and perceived stress, but chronic noise exposure does not seem to be associated with psychological disorders (depression, anxiety).

The recent increase in empirical research into the non-auditory health effects of noise on children (Evans *et al.,* 1995, 1998; Haines *et al.,* 1998, 2000a, 2000b), has been exclusively quantitative. There is a need to employ qualitative methods in research with children to: a) increase understanding of childrens' perception of noise exposure; b) perceived risk of noise pollution and c) the annoyance response. By gathering these qualitative data further understanding about children's response to noise exposure can be incorporated into quantitative study design. The noise and children's workshop at the MICC provided us with an opportunity to collect data from an international sample of children that will be able to inform researchers and policy makers about how children perceive that they are affected by noise pollution.

The aim of the noise and children's workshop was to:

a) understand children's experience with noise, sound and music;
b) gather information about children's risk perception of noise, risk perception of noise, coping strategies and reaction to research findings;
c) inform children about noise pollution.

2. Protocol for the Workshop

Sample

The sample of children who took part in the workshop were 36 self-selected children aged 10-12, from 12 countries. These children were delegates at the MICC. The criteria for being a delegate at the conference was being between the ages of 10 and 12 on 1st April 2000. The delegates had to demonstrate interest in environmental issues and be part of a school or community environmental group. Most children could speak English but this was not an essential requirement because interpretation facilities were available.

Workshop Overview

In order to comply with the MICC workshop guidelines the workshop had to involve modern technology, music, art and science. The workshop involved child-friendly activities including: a class about noise pollution, responses to audio recordings and soundwave demonstrations, questionnaire completion, qualitative focus groups and an interactive class on global instruments.

The workshop lasted 2 ½ hours and was divided into four sections:
1) introduction to workshop and definition of noise;
2) small group activities (Station 1: Opinions, Station 2: Soundwaves, Station 3: Global Instruments) with rotation in small groups around stations;
3) making a musical instrument;
4) dancing/disco and final session.

The description of the protocol will focus exclusively on the data generating small group activities because the results from these activities will be reported. These activities were designed to allow the research group to collect quantitative and qualitative data from children, as well as being informative, fun and challenging for the children. In small groups of (11,12, 13) the children took part in 3 activities, each lasting 30 minutes (for a copy of the workbook completed by the children during the workshop see Appendix 1). For a report on the work conducted in Station 3 Global Instruments see Appendix 2.

Questionnaire Data Collection

These sociodemographic data were collected: age, sex, country, city/town/region, whether they lived in a city, a town or a village/countryside.

The environment questionnaire focused on the child's home environment. The questions and scales included had been reliably used with child samples (Haines *et al.,* 1998, 2000a, Stansfeld *et al.,* 2000b)

Perceived noise at home was rated for: road traffic, train noise, aircraft, industrial/factory and neighbours noise.

Noise annoyance was measured with 5 child adapted standard questions for the above sources of noise (Fields *et al.,* 1998). These questions assessed the level of annoyance on a 5 point likert scale (extremely, very much, quite a bit, a little, not at all) and a 10 point scale felt by the child when they heard aircraft, road traffic, trains, industrial/factory and neighbours noise at home, in the last 12 months. These questions produce two scores on which the higher the score the higher the noise annoyance (range 0 – 4 for likert scale) and the ten point scale (0-10). General environmental questions were asked to assess satisfaction with other aspects of the home environment: clean air, safety and friendliness.

Annoyance and emotional response to acute noise:
10 sounds were played to children through headphones. These 10 sounds were:

1 mobile phone
2 nose blowing (man)
3 chalk on blackboard
4 dentist drill
5 traffic noise
6 giggling girls
7 creaking door
8 vacuum cleaner
9 office clock ticking
10 man snoring

These sounds were selected because they occur frequently in everyday life. The sounds were played using a standard soundcard using a Dell Optiplex GXi computer to children wearing individual stereo headphones type Bass nic MH - 1401. The sounds were played so that they were audible to the children at a comfortable level. Sound intensity was controlled across all trials. The 10 sounds were played separately for 10 seconds each. The children were instructed to indicate how each of the 10 sounds made them feel. The children recorded their annoyance response during the sound presentation and their emotional reponse after the sound presentation. All responses were recorded in their workbooks after each sound presentation. Annoyance was rated with a culturally sensitive 10 point scale with a cartoon depiction of a face with increasing annoyance (range 1 –10, for scale see workbook in Appendix 1). The children were instructed to 'tick the face that shows how much this sound annoyed you'. The emotional response was recorded with a Bond Lader Mood Scales (Bond & Lader, 1974). The Bond Lader mood scale is a visual analogue of mood. Three dimensions were recorded: Happy to Sad, Calm to Irritated, Tense to Relaxed. These emotional scales were scored by measuring the distance to the point where the child marked each line from 'sad', 'irritated' and 'relaxed' (score ranges from 0 – 210 millimeters).

Qualitative Data Collection:
Qualitative data was collected through two group interviews or focus group sessions. A focus group is essentially a qualitative data gathering technique that finds the interviewer/ moderator directing the interaction and inquiry in a structured or unstructured manner depending on the interviewers purpose. A focus group has the advantage of being inexpensive, data rich, flexible, stimulating to respondents, recall aiding, cumulative and elaborative (Denzin *et al* 1994). Focus groups allow for a large amount of interaction on a topic in a limited period of time. Taking account of time frame and sample population they are relatively swift, amicable and efficient (Walker, 1985). Focus groups were a workable alternative to individual interviews, which under the 'Noise and Children' workshop constraints and conditions would have been impossible.

Semi-structured interviews were favoured over unstructured and fully structured styles. A semi-structured interview is where the interviewer has worked out a set of questions in advance, but is free to modify their order based upon perception of what seems most appropriate in the context of the 'conversation', can change the way they are worded, give explanations, leave out particular questions which may seem inappropriate with a particular interviewee or include additional ones (Robson, 1993). The semi-structured style enabled the interviewer to use simplified language that is needed when working with children in general and especially children without English as a first language.

Two focus groups were held with the children. The first focus group aimed to collect data on children's experience of noise and their perceived risk of noise. The second focus group aimed to collect feedback on responses to research results.

The First Focus Group
The first focus group involved a brief introduction to the aims and style of the session. It utilised a semi-structured discussional format posing a set of questions to each group with some response dependent variation. The session commenced with an ice breaker, general questions in order to engage thought and progressed into more detailed, specific areas.

The questions were structured using three key themes:
1. How does noise affect you;
2. Noise as a hazard;
3. Coping strategies, control/prevention.

The questions posed in the focus group were:
1) What noises do you hear in your environment?
2) How do they make you feel?
3) What noise do you dislike the most?
4) How do you rate noise pollution in importance against other sources of pollution such as air pollution or water pollution?
5) How does noise pollution affect you in your day to day lives compared with other sorts of pollution such as air pollution or water pollution?
6) Do you feel you have control over the noise in your environment?
7) What do you do to stop noise affecting you?

8) Where do you go for a quiet space?
9) Would you like to change the noise in your environment or do you think it is fine as it is?
10) Do you think there should be better regulations and control over noise pollution?
11) If so, who do you think should be responsible for making such changes?

Responses were simultaneously recorded on a Sony TCS-50V Cassette Recorder and noted using a marker pen and flip chart.

The Second Focus Group

In the second focus group the children were given a short class on a research project that was conducted with children at primary schools very close to Heathrow Airport in West London (Haines *et al.,* 1998, 2000a). The class contained brief details on the aim of the study to study the effects of aircraft noise on children's reading, concentration and annoyance. The method of testing 340 children from four schools exposed to high levels of aircraft noise compared with children from four schools exposed to low levels of aircraft noise. These results were presented: that the children in the four high noise schools had poorer reading, poorer attention and higher annoyance than the children from the four low noise schools.

After the class these focus group questions were asked:

1) Do you think that if you went to school near an airport that you would be affected like these children? Why?
2) What do you think is the reason that these children are affected by aircraft noise?
3) Do you think that something else might be causing these results? Something about the teachers? Something else about the schools? Something else about the children?
4) What do you think can be done to stop the children being affected by aircraft noise at school?

Data Analyses:

Quantitative data analysis was conducted in SPSS 10.0 for windows. Analyses reported contain frequencies and means for the sample as a whole.

The qualitative data analysis involved firstly transcribing the interviews verbatim for each group and session using the tape recorder and flip chart notes. The focus group data had been gathered in a structured manner with questions devised from topic areas following a logical progression, and a similarly structured approach to analysis was adopted. Each group discussed the same topics in the same order therefore the main analysis involved addressing these topics. This analysis involved a Group by question 'grid' method which systematically summarised what each group said in response to each question (Morgan, 1997). Each of the groups' responses were assessed and then analysed using a coded topic method. The children's responses were coded into broad and loose categories or 'reasons' (Silverman, 2000). The broad categories always covered all the answers given by the children. In some cases the codes were counted to give a general estimate of group feeling towards a certain issue. Quotes were also used as supporting evidence.

3. Results

3.1 Quantitative Results

Socio-demographic characteristics of the sample

The 36 children who took part in the workshop came from 12 countries: England (13); Germany (4); Bahrain (4); Jamaica (4); Malaysia (3); Norway (2); Hungary(1); Yugoslavia (1); Palestine (1); Oman (1); Malawi (1); Swaziland (1).

The mean age of this sample was 11 years and 7 months (range from 10 years to 13 years 7 months, see Table 1). Two thirds of the sample were girls (see Table 1). 80 % of the sample lived in a city or town (see Table 1).

Table 1: *The socio-demographic characteristics of the child sample at the workshop*

Socio-Demographic Characteristic Total	**N=36**
Mean Age	11yrs 7mnths
Range from	10yrs 0mnths – 13yrs 7mnths
Gender	
Girls	23 (64%)
Boys	13 (36%)
Home	
City	11 (31%)
Town	17 (47%)
Village/Countryside	8 (22%)

Perception of chronic noise and environmental satisfaction at home

Neighbours noise and road traffic were the most frequent sources of noise perceived at home (see Table 2). Aircraft noise was perceived by 42% of the sample (see Table 2). Very few children perceived industrial and rail noise exposure at home (see Table 3).

92% felt that their home environment was safe or very safe. 89% of the children reported that their home environments were clean or very clean. 89% reported that their home environment was friendly or very friendly.

Table 2 : *Proportion of children who could hear these sources of noise at home*

Noise Source at Home	% (frequency) who perceived noise
Road Traffic	58% (21)
Rail	8% (3)
Aircraft	42% (7)
Industry/Factory	6% (2)
Neighbours	64% (23)

Noise annoyance to chronic noise exposure at home
The children attending the workshop were most annoyed by neighbours noise at home, although the level of annoyance reported was fairly low with most reporting 'a little annoyed' (see Table 3). The children attending the workshop had very low levels of noise annoyance for road traffic, rail, aircraft and industrial noise at home (see Table 3).

Table 3
Mean annoyance scores in the workshop sample in response to noise exposure at home

Annoyance Outcome at Home		Mean (sd)
Road traffic noise annoyance		
	5 point scale	0.7 (0.8)
	10 point scale	1.9 (2)
Rail noise annoyance		
	5 points	0.2 (0.5)
	10 points	0.9 (2.2)
Aircraft noise annoyance		
	5 points	0.4 (0.8)
	10 points	1.0 (2.0)
Industrial noise annoyance		
	5 points	0.1 (0.4)
	10 points	0.4 (1.3)
Neighbours noise annoyance		
	5 points	1.1 (1.2)
	10 points	2.6 (3)

NB: Higher the score the greater the annoyance

Annoyance and emotional response to acute noise

The most annoying sounds were: traffic noise, a creaking door and a man snoring. The least annoying sounds were giggling girls and office clock (see Table 4 for all results). Mobile phone was rated as moderately annoying (mean 5.6) and the ringing tone induced a mixed emotional response of tension and happiness.

Tension was the emotion that most strongly associated with the most annoying sounds (traffic noise, creaking door and man snoring). Chalk on the blackboard was the only sound where irritation was rated more highly than tension. Compared to 'tension' and 'irritation', 'sadness' was not as frequently reported as an emotional response to the sounds.

Table 4: *Noise annoyance and emotional reaction to acute noise sources. Mean score and standard deviation of annoyance and the three dimensions of the mood barometer (in millimeters).*

Noise	Annoyance	Happy - Sad	Calm-Irritated	Relaxed-Tense
Mobile phone	5.6 (2.5)	89 (46)	142 (68)	163 (53)
Nose blowing (man)	6.7 (2.4)	105 (70)	155(64)	175 (44)
Chalk on blackboard	6.0 (2.2)	96 (57)	122 (64)	119 (136)
Dentist drill	6.4 (2.0)	98 (58)	118 (70)	141 (62)
Traffic noise	8.9 (1.6)	139 (67)	168 (63)	192 (33)
Giggling girls	3.2 (2.3)	29(35)	58(63)	75(73)
Creaking door	8.5 (1.5)	137 (59)	171 (56)	189 (32)
Vacuum cleaner	5.9 (1.7)	103 (55)	109 (65)	111 (65)
Office clock ticking	4.4 (1.9)	73 (51)	76 (60)	102 (66)
Man snoring	8.3 (2)	147 (57)	172 (57)	187 (29)

NB: Higher the score the greater the annoyance, sadness, irritation, tension

3.2 Qualitative Results

The main themes and summarised results for each question of the semi-structured focus groups are outlined below.

Focus Group 1: Children's experience of noise and their perceived risk

Q1. What noises do you hear in your environment?

The children listed many noises they heard in their environment, the most popular being noises made by people, for example, screaming and crying. The second and third most reported noises were from animals and road traffic respectively.

Q2. How do they make you feel?

The children listed many emotions associated with the listed noises. They reported negative emotions (18 reported) more frequently that positive ones (13 reported). "Annoyed" was the most reported emotion followed by "happy" and "sad".

It was apparent that different sources of noise were linked to different emotions. Negative emotions were associated mainly with traffic noise, industrial noise, sirens, alarms and nails on a blackboard. Positive emotions were linked to natural sounds such as the wind and household noises such as washing up, fans and the television.

Interestingly human and animal sounds elicited a mix of emotions. Children screaming or crying, snoring, shouting and dogs barking and flies buzzing were all negative. People laughing and clapping and birds singing were all associated with positive emotions. Music was also expressed as both positive and negative, only receiving a positive response depending upon whether the respondent had control over the source.

Q3. What noise do you dislike the most?

The children reported most frequently noises from humans as their least favourite noises such as screaming and snoring amongst an extensive list of 10 noise sources. Noises from animals and the household were secondly most frequently reported. It must be noted here that frequency of reporting and dislike are linked as the top 3 most reported noises, noises from people, animals and road traffic were found in the top 4 most disliked noises (household sounds being the only exception).

Q4 & 5 How do you rate noise pollution in importance against other sources of pollution such as air pollution or water pollution?

How does noise pollution affect you in your day to day lives compared with other sorts of pollution such as air pollution or water pollution?

The groups all agreed and rated noise pollution less important than water pollution and air pollution. They rated water the most important source followed by air and lastly noise. However when asked about the effects of water, air and noise pollution on them in their day to day lives they rated air pollution as having the most effect followed by noise and finally water.

'It depends where you are. Long term it's water pollution and air pollution but walking down the street it's noise pollution that affects you more.'

Interestingly the children reported noise affecting them daily but rated it less important than sources that did not affect them in such a manner. The children expressed that….

'Because you can just stop noise pollution'

'Because when there is no water there is no life'

'You can sort of put up with noise pollution but you can't put up with water pollution.'

Q6. Do you feel you have control over the noise in your environment?

Many children felt the noise source influenced how much control they had. The majority (19) expressed that they felt in control of noise inside their homes. They thought they could tell neighbours to be quiet or close the door as a solution.

'Well you can tell someone to be quiet if they are making a noise.'

However mainly they did not feel they had control of outside noise (5) such as over busy roads and planes flying over head.

Q7. What do you do to stop noise affecting you?

The children expressed a range of coping mechanisms to deal with noise. Most popular as a preventative strategy were blocking devices such as wearing headphones or playing music. Second most reported was *'thinking about something else'* and thirdly taking action by telling the person to '*turn it down*' or '*off*'.

Q8. Where do you go for a quiet space?

Their bedroom was the most popular place for the children to retire to as a quiet space, followed by outside areas such as gardens.

'I go to the countryside'

'Bedroom'

Q9. Would you like to change the noise in your environment or do you think it is fine as it is?

Two thirds (21) of the sample wanted to change their environment and make it quieter, whilst a third (11) thought it was acceptable at the present level.

Q10. Do you think there should be better regulations and control over noise pollution?

Most wanted better regulations to be introduced against noise pollution (18 versus 8)

Q11. If so, who do you think should be responsible for making such changes?
The children had multiple suggestions for who should be responsible for making such changes. The popular choice expressed was the responsibility lay equally amongst the general public and the government to improve noise regulations. Others mentioned were businessmen and the police.

'Everybody, mostly adults though'

'Yeah, the people'

'The Government'

Focus Group 2: Reaction to Heathrow Research Project.

Q1. Do you think that if you went to school near an airport that you would be affected like these children? Why?

There was a consensus across all the children they felt that if they lived near an airport they would be affected in the same way as the sample studied in around Heathrow Airport. They also expressed confidence in the data in that they believed the reading, attention and annoyance results.

Q2. What do you think is the reason that these children are affected by aircraft noise?

The children proposed many reasons why the aircraft noise would have an effect on the children in the study. The most favoured effect expressed was that the children in the schools would feel annoyed and irritated by the aircraft noise, which in turn would affect their work. Secondly, the children attending the workshop thought the Heathrow children in the study would not be able to concentrate because of the noise interference and they would also be visually distracted by the planes. Also they thought the children in Heathrow Schools would not be able to hear the teacher because of the increased noise level (2).

“Because you can’t concentrate”

“Planes distract the children.”

“Because when the teacher talks they can’t hear what the teachers are saying.”

Q3. Do you think that something else might be causing these results? Something about the teachers? Something else about the schools? Something else about the children?

The group solely focussed on the teacher annoyance levels as an explanation for the results. They did not mention the schools, buildings or the children. It was expressed that the teachers would be annoyed by the aircraft noise and this in turn could have a negative impact on the children’s learning.

“The teachers would be annoyed”

“The teacher could have been at the school for many years so would have heard the noise a long time so could be very annoyed.”

Q4. What do you think can be done to stop the children being affected by aircraft noise at school?

The children suggested many measures to mitigate the effects of aircraft noise. The most popular was to move the schools away from airports. Many felt they should not have been built near the airports originally and would move their own children from such a location. The second most popular suggestion was insulation such as double glazing. Other suggestions was altering the aircraft both in number and noise emissions and reducing the number of airport customers.

“I would move my child from there and less schools near airports.”

“Sound proof the windows.”

“Change the direction of the planes.”

“Don’t build schools near airports.”

4. Discussion

The aim of this workshop was to further understanding about children's experience with noise and their perceived risk of noise pollution using quantitative and qualitative techniques with a sample of children attending the 'Noise and Children' workshop at the Millennium International Children's Conference. The sample of children who took part in the workshop came from a range of countries and most lived in urban environments so they would have been exposed to a range of sources of noise pollution. Nearly all the children felt that their home environment was safe, clean and friendly so responses to noise pollution were probably not influenced by another source of environmental stress.

The children reported neighbours and road traffic as the most frequent sources of noise perceived at home. Perceived noise exposure is known to correlate reliably with actual exposure in child samples (Haines *et al.,* 1998). This response pattern for perceived noise at home mirrors community noise surveys of adults with neighbour's noise and road traffic noise also being the most frequently reported (Grimwood, 1993). This indicates consistent and reliable responses from this child sample.

The most striking result was that children report the highest annoyance for neighbours noise at home. Neighbour noise has been neglected in previous research examining the non-auditory health effects of noise exposure on children. Noise annoyance levels in this sample were generally very low across all noise sources. Previous studies examining child noise annoyance have found that when children are exposed to a specific noise source (e.g aircraft) they only report noise annoyance in relation to that noise source exclusively and low levels of other sources of noise pollution (Stansfeld & Haines, 1997; Stansfeld *et al.,* 2000b). The low annoyance levels reported by the children in the focus group may indicate that these children aren't exposed to extremely high levels of any source of noise pollution at home.

The children's emotional responses to acute noises played to the children through headphones indicate that traffic noise, creaking door and snoring were the most annoying noises. This could be because these sources of noise interfere with sleep and recreation more than the other sources of noise presented. Road traffic and snoring might also be annoying for children because they are constant and uncontrollable. The association between annoyance and the emotional response is consistent with the definition that annoyance involves mild irritation, fear and anger (Cohen & Weinstein, 1981). This association is also consistent with adult responses to acute noise being associated with anxiety. It is clear from the Bond-Lader results that tension and irritation were more strongly related to annoyance than sadness. These results also suggest that annoyance might involve a feeling of being unable to relax. This inability to relax might be due to persistent noise exposure polluting environments, such as homes, parks and playgrounds, where children expect to be able to play and rest.

In the focus group the children reported noises from people affecting them most in their everyday lives. They felt that these noises were both positive and negative and that they could have some control over moderating these human sources of noise. Road traffic also affected the children in their everyday lives and this was uniformly perceived as negative. In contrast to the noises from people, the children felt they had little control over noise emitted from transport. This result is consistent with the quantitative results where children report neighbour's noise and road traffic as the most frequent sources of noise in their home environments. These qualitative results suggesting how noise affects children are also consistent with their emotional reactions to acute noises, for example man snoring and road traffic were rated as most annoying, irritating and tense and girl's giggling not very annoying at all. These consistent responses across quantitative and qualitative results indicate that the children gave consistent and reliable results.

In comparison with water pollution the children reported that air pollution and noise pollution would affect them most on a day-to-day basis. However they felt that noise pollution was of a lower priority than water or air pollution to be addressed by environmental policy makers. Water pollution was perceived as a hazard having immediate adverse impacts on health and mortality, whereas noise pollution, even though it affected them on a daily basis, was not perceived as having a detrimental effect on their health. The perceived risk of noise pollution as a hazard was minimal. Even though noise was not considered a threat, when asked the children expressed that they would like to reduce the amount of noise in their environment. They felt that this responsibility of reducing noise levels resides with governments and the general public.

In general the children felt that they had control over the noise inside their homes but little control over external noise. Most of the coping strategies suggested focused on alleviating neighbour's noise permeating their homes. Some children suggested closing doors, and moving away to quieter places and others opted for a direct action strategy of approaching the people creating the noise nuisance. No strategies for coping with transport noise were suggested. General strategies for blocking the effects of noise pollution were to use blocking devises such as headphones/walkman and putting on music to drown out the noise. It must be noted that this blocking strategy may be harmful to the children's auditory system and requires future investigation. When asked, children selected their bedrooms and green areas in their neighbourhoods as quiet places to find some respite from noise pollution.

When children were given the example of a specific source of environmental noise affecting a specific population namely, aircraft noise at school, all agreed that they would be adversely affected by aircraft noise exposure. The children suggested that adverse effects of aircraft noise on children attending exposed schools could be explained by child distraction, reduction in concentration, not being able to hear the teacher teach, teacher annoyance levels and child annoyance. In it interesting to note that the children did not offer focus group did not offer schools and buildings as explanation. The children strongly felt that schools should not be sited near airports and existing schools should either be moved or provided with sound insulation.

This focus group was the first time qualitative data has been collected from children in relation to noise exposure. The Millennium International Children's Conference was never going to be an opportunity to conduct a tightly controlled study, rather it was a good opportunity to gather pilot data from an international sample of children and provide a forum for children to express opinions about noise pollution. The sample of children were not representative of all international children because they had to meet the criteria to attend the MICC. These criteria were financial support and interest in environmental issues. In addition the children self-selected themselves to attend the 'noise and children' workshop. From an opinion gathering perspective these children were already very interested in environmental themes which means that they may have express more extreme opinions than a randomly selected sample of children. On the other hand, these children might have presented more considered and cautious opinions balancing the relative importance of noise pollution in relation to other environmental hazards. From a research perspective these results must be viewed as pilot work to collect data from an international sample of children.

The qualitative technique did not pose any problems for the children because they were familiar with focus groups as they had been engaged in qualitative work during the conference and our workshop was on the final day. The collection of the qualitative data were limited because of the workshop being structured into a three tier rotational format. This meant that each group took part in the qualitative session having experienced difference aspects of noise through the other workshop stations. The responses show that the groups might have been somewhat primed by these other stations. For example, the children cited music primed by the 'global instruments station' and the children suggested snoring and nose blowing as annoying noises if they had already attended the acute sounds played at the 'soundwaves station'. The group that had not yet experienced these other stations was less likely to mention these sounds.

Summary and Conclusions

In both the qualitative and quantitative results, children report being most affected by neighbour's noise and road traffic noise. Children perceive the risk of noise pollution as low even though it affects their everyday activities it is not perceived as a life threatening pollutant. These are the main conclusions drawn from the workshop:

1. Future research should employ qualitative methods to supplement quantitative investigations.

2. Children's noise annoyance requires further investigation to explore the beneficial impact of relaxing environments in providing psychological restoration.

3. Future research could focus on the effects of neighbour's noise on children. For example, does it affect homework, sleep, well-being and stress levels?

4. Children can provide reliable responses about their perception of noise and should be involved with governmental debate about their environments.

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Health effects of noise on children and perception of the risk of noise

Children's daily lives are full of noise, and children make noise themselves. High levels of noise are found in homes, day care, schools, clubs and discothèques. Noise in incubators is measured to be 80–90 dB(A) with peaks up to 120 dB(A).
Toys and tools can emit harmful noise, some exceeding 100 decibels.

Noise can adversely affect children. Infants reared in noisy homes manifest lower mastery scores on development tests. The most serious consequences of noise are hearing damage and tinnitus. Noise can provoke a stress response in children that includes increased heart rate and increased hormone response. Noise can disrupt sleep and thus hinder needed restoration of the body and brain. Noise can negatively affect children's learning and language development, can disturb children's motivation and concentration and can result in reduced memory and in reduced ability to carry out more or less complex tasks.

The report gives an overview of the levels of noise in children's settings and an overview of the harmful effects of noise. The report also presents children's own perception of noise and discusses what definitions of noise could be useful in relation to children.

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