The health effects of environmental noise – other than hearing loss

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The enHealth Council, a subcommittee of the National Public Health Partnership, brings together top Environmental Health officials at the Federal and State/Territory level along with representation from the Australian Institute of Environmental Health, the environment and public health sectors, the Indigenous community and the wider community. The Council has responsibility for providing national leadership, implementation of the National Environmental Health Strategy, forging partnerships with key players, and development and coordination of advice on environmental health matters at a national level. The advice development process is strongly based on collaboration and consultation.

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- Dr Norman Carter, previously Honorary Research Associate, University of Sydney
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Executive summary

The primary aims of this document are to present:

- a review of the health effects, **other than hearing loss**, of environmental noise
- a review of the measures (national and international) directed at management of environmental noise, and to make recommendations on this aspect.

Community noise, or environmental noise, is one of the most common pollutants. It is defined by the World Health Organization as noise emitted from all sources, except noise at the industrial workplace.

> **'Community noise includes the primary sources of road, rail and air traffic, industries, construction and public works and the neighbourhood' (WHO, 1999).**

Environmental noise is increasingly becoming a community concern both internationally and in Australia. Considerable efforts have been made over about the last four decades to reduce noise impacts from transportation sources such as road and rail traffic and aircraft. Nonetheless, many of the benefits of these efforts have been lost due to increased traffic volumes (by all modes) for longer periods of the day and evening. At the same time increases in urban population have resulted in greater exposure of a larger percentage of the population to the increased noise levels.

The non-auditory health effects of noise, as reviewed in this report, are defined as 'all effects on health and wellbeing that are caused by exposure to noise, with the exclusion of effects on the hearing organ and the effects that are due to masking of auditory information (namely communication problems)' (IEH–MRC Institute for Environment and Health, 1997).

This report examines the range of environmental noise sources that may affect communities, with a focus on the primary sources of such noise (road, rail and air traffic, and industry). It examines the key literature on noise exposure and annoyance/quality of life, sleep disturbance, performance and learning, cardiovascular disease, mental health, and stress. Further, it seeks to refine our understanding of sensitive groups in the Australian population that are at risk from environmental noise exposure. It also summarises a number of international policy frameworks that address environmental noise and examines the feasibility of their application in Australia. In addition, some potential areas for further research are identified.

There is now sufficient evidence internationally that community noise may pose a general public health risk. Groups most exposed to this noise (by virtue of where they live, work and recreate) and those most sensitive to its impact, may face even greater risks. They include infants and school children, shift workers, the elderly, the blind, and those suffering hearing impairment, sleep disorders, and physical and mental health conditions. Australian surveys have found respondents were concerned about environmental noise from a wide range of transportation and other sources, as well as noise generated by neighbours' loud voices, loud appliances and pets (indoors and outdoors).

If this international experience holds true for Australia, the community and potential public health dimensions of this issue will grow significantly and the public health community will be required to provide policy and research leadership. There is a need to cross broad areas of social and environmental policy – in product design and safety, planning and transport – to tackle the acknowledged problems emerging from the scientific evidence on environmental noise and its human health effects.

This report recommends further research is needed to more fully assess the impact of environmental noise on community health. However, given the environmental and public health emphasis on prevention of adverse health outcomes, it may be prudent for relevant health agencies to immediately consider development of improved health-based noise guidelines, standards and policies. These tools would assist local government and environment, transport and planning agencies to better consider noise within relevant regulatory and policy frameworks. Strategic alliances with key sectors are also needed to advance necessary research on noise issues and advocate on behalf of sensitive groups within the population.

Recommendations

1. Recognise environmental noise as a potential health concern

Suggested actions:

- Promote awareness of the non-auditory impacts of environmental noise on health, in particular, the need for State/Territory and Commonwealth agencies to include noise as an important environmental health issue for strategic and local planning.
- Adopt the WHO Guidelines for Community Noise 1999 as a primary reference for environmental noise levels below which no health effects are expected.

The World Health Organization, European Community members and numerous other countries have determined there is 'sufficient evidence' linking noise with annoyance, school children's performance, sleep disturbance, ischaemic heart disease and hypertension. Currently, there appears sufficient information to merit public health action in Australia to reduce these health effects. Cardiovascular health and mental health (two national health priority areas for Australia) have been weakly linked with noise exposure, although the link between environmental noise and high blood pressure (hypertension) and ischaemic heart disease is by no means conclusive.

Although there is no strong evidence that noise causes mental ill-health, it is possible that some vulnerable groups, who are exposed to noise over which they have no control, may be vulnerable to mental health problems. What is more certain is that those with existing mental health problems, usually either depression or anxiety, are more prone to be annoyed and disturbed by environmental noise exposure than the general population.

There is growing evidence that chronic exposure to environmental noise leads to both impaired cognitive function (reading, motivation) and health (annoyance, blood pressure) in children. Impairment of early childhood development and education by environmental pollutants such as noise may have life-long effects on achieving academic potential and good health.

Responsibility for environmental noise is diluted across a range of national, state and local governments. This has effectively lowered the perception of noise as a health problem. While noise may occasionally elicit significant community and political interest, it generally remains within the province of acoustic and other engineers. Public health practitioners need to link with hearing conservation organisations and environmental regulatory authorities to raise the profile of noise as a potential health concern. Collaboration between health and environment agencies should be enhanced, given their overlapping interests in environmental, health and social impact assessment and sustainable development.

In promoting environmental noise awareness key stakeholders should include the environment sector, planning, transport, non-government organisations and the wider community.

Loss of performance and productivity, and industrial accidents have all been recognised (the adverse effects of occupational noise exposure are beyond the scope of this review).

2. Promote measures to reduce environmental noise and its health impacts

Suggested actions:

- Review noise arising from transportation, including noise criteria for areas adjacent to transport infrastructure.
- Promote noise mitigation measures (for example, noise insulation in residential buildings) and the use of licensing controls to limit noise impacts.
- Develop a national community noise education program, which could be supplemented with

additional State-specific campaigns.

- Ensure internal noise standards and recommended controls adequately address the impact of external noise sources (particularly in industrial and heavily trafficked areas), and internal noise transmission in multi-unit developments.
- Examine measures to reduce noise generated by consumer goods, including amending consumer protection legislation and policies.
- Consider the need for a mandatory national standard for noise labelling of equipment.
- Amend consumer protection and environmental legislation regarding machinery and equipment noise.

Public awareness of noise hazards is low, even though strong anti-noise feelings can easily arise in a community. Public education on sound, noise and the levels that cause harm warrants further attention.

Education strategies targeting public health practitioners and governments about the impacts on community health of exposure to increasing environmental noise are warranted.

The current building code does not adequately consider the impact of external noises on the internal noise environment. The Building Code of Australia should be revised to include advice on acceptable internal noise levels and be linked to relevant Australian Standards detailing how to determine the level of noise reduction from the facade, and what type of construction can be used to achieve that level of noise reduction. There also remains some question about the adequacy of current acoustic provisions for residential buildings in reducing noise transmission between units, given the limited use of floor coverings and increasing use of, and noise potential from, home appliances.

Australian Hearing has expressed an interest in working with the public health community on the issue of environmental noise. They would welcome joint efforts to educate consumers and manufactures on noise and noise reduction methods.

3. Address environmental noise in planning and development activities

Suggested actions:

- Include environmental noise in the Health Impact Assessment of proposed developments, where warranted.
- Review current noise control practices and how to further integrate noise control into planning processes, for all levels of government (with attention to future noise research findings).
- Determine baseline environmental noise levels to inform planning actions (including background noise, equivalent continuous noise and other percentile noise levels). Where appropriate, proponents should be required to conduct such monitoring.
- Foster national consistency regarding:
  - Guidelines on how to minimise/prevent environmental noise arising from developments (that is, appropriate attention to layout, design and construction)
  - Limiting noise arising from major sources (consider European Union directives)
  - Methods to set noise limits where standard limits are inappropriate.

Significant improvements in reducing community exposure to high levels of environmental noise could be made through better planning and design of urban areas. This is particularly important given increasing adoption of urban renewal schemes in brown lands and continued mixed-use expansion into new green spaces. The public health implications of siting communities in areas with exposure to existing and developing noise sources should be adequately considered in both environmental and health impact assessments and land use planning processes.

'Creeping ambient' environmental noise should be addressed. The lack of an holistic approach to environmental noise management, (generally due to the assessment of new developments in isolation) the fragmented regulation of noise sources and a proliferation of these sources, can result in creeping ambient noise in urban areas (also known as 'background creep'). Recent approaches include capping noise levels by defining noise goals adjusted to the acoustic quality objectives of a locality.

With planning frameworks more focused on performance-based criteria, the design and development of community infrastructure should also be based on criteria that protect health. This will require better understanding of existing external noise environments and the importance of housing design and construction.

An important aspect of planning that appears to have received little attention is guidance on how to best manage noise for noise-sensitive developments (for example, ways of reducing noise by subdivision design, building design and building construction, setting internal noise level criteria, standard method for measuring compliance etc.). In addition, while transport and environment agencies generally have 'ownership' they do not consider health-based performance and design criteria when managing environmental noise. Current noise criteria are often based upon levels that are achievable adjacent to transport infrastructure, but they do not necessarily protect health values (sleep, relaxation or communication).

4. Foster research on the non-auditory health impacts of noise

Research agenda should include:

- A national noise survey.
- Effects on learning performance in children, sleep disturbance, annoyance and cardiovascular health and mental wellbeing.
- Identification of populations most sensitive to noise and vulnerable to non-auditory health effects (the findings should inform environmental, planning and health policies).
- Given the prevalence of cardiovascular disease and its associated cost to society, further research appears prudent to examine noise as a risk factor (the link between environmental noise and high blood pressure [hypertension] and ischaemic heart disease, as suggested by cross-sectional literature, is by no means conclusive at the moment).
- Evaluation of noise reduction schemes on community health (intervention studies).
- Longitudinal studies, dose–response studies.
- Appropriate attention to study design, sampling and sample sizes, control of confounders, investigation of factors modifying the effects, precise exposure estimation and precise measurement of outcomes.

Further work is required to characterise the total noise environment of urban and rural areas. Pilot noise mapping programs should be developed in key capital cities and regional centres to determine current community noise environments. This will assist in quantifying existing noise problems and provide baseline measures against which future public health, environmental, transport and planning decisions in those localities can be compared.

Additional research is needed in Australia to replicate the results of international studies. Internationally it is accepted that further research is required to develop better measurements of noise exposure, better measurements of health outcomes and better consideration of confounding factors and the effect of modifiers in the association between noise and health. Longitudinal intervention and dose–response studies are required to confirm and extend the evidence from cross-sectional studies.

Priority areas for further research in Australia are sleep disturbance, annoyance, school childrens' performance, cardiovascular disease and wellbeing. Research that would have direct impact on policy would be intervention studies examining the effects of change in noise exposure on changes in population health. Health agencies have a critical role to play in developing the research framework with academic institutions, transport, and environment and planning agencies.

Sound, noise and human response

An introduction to sound and noise

Basics of sound and noise

Noise is an unwanted sound. 'Sound which is disagreeable, discordant or which interferes with the reception of wanted sound becomes noise' (Cantrell, 1975). 'Community noise' is one of the most common pollutants. It is defined by the World Health Organization (WHO) as noise emitted from all sources except noise at the industrial workplace. 'Community noise includes the primary sources of road, rail and air traffic, industries, construction and public works and the neighbourhood' (WHO, 1999).

In scientific terms, 'Sound is the result of pressure changes in a medium (usually air), caused by vibration or turbulence' (Suter, 1991).

We cannot see sound, yet it is a force with real dimensions which propagates from a source in all dimensions. It has several important properties:

- level or intensity (loudness) of sound – the sound pressure level relative to a reference sound pressure level which is measured in decibels (dB) using a logarithmic scale
- duration or time period – sound is heard and how it is distributed over time (continuous, intermittent or impulsive)
- frequency (pitch) – the number of sound waves (high and low pressure areas) or cycles per second (cps) or Hertz (Hz) passing a given point per second.

The higher the number of sound waves, the higher the frequency and the higher the pitch of the sound we hear. We can hear a wide range of sound frequencies, from 20 to 20 000 Hz with a wide range of intensities, from a whisper to the point of pain.

Noise can be classified into three broad ranges of frequency:

- low frequency – levels below 200 Hz
- medium frequency – levels between 200 and 2000 Hz
- high frequency – levels above 2000 Hz.

Low frequencies, below 16 Hz, are considered to be infrasonic. Sounds from 2 Hz to 200 Hz are perceived through both hearing and through touch. This may account for the greater annoyance of those exposed to infrasound. Low frequency noise is part of urban background noise through road vehicle and aircraft emissions and industrial activities as well as construction activities, ventilation and air-conditioning units, and compressors. Recently, greater attention has been given to the effects of low-frequency noise because it is pervasive and many structural attempts at remedy are inadequate due to the longer wavelength of low-frequency sound.

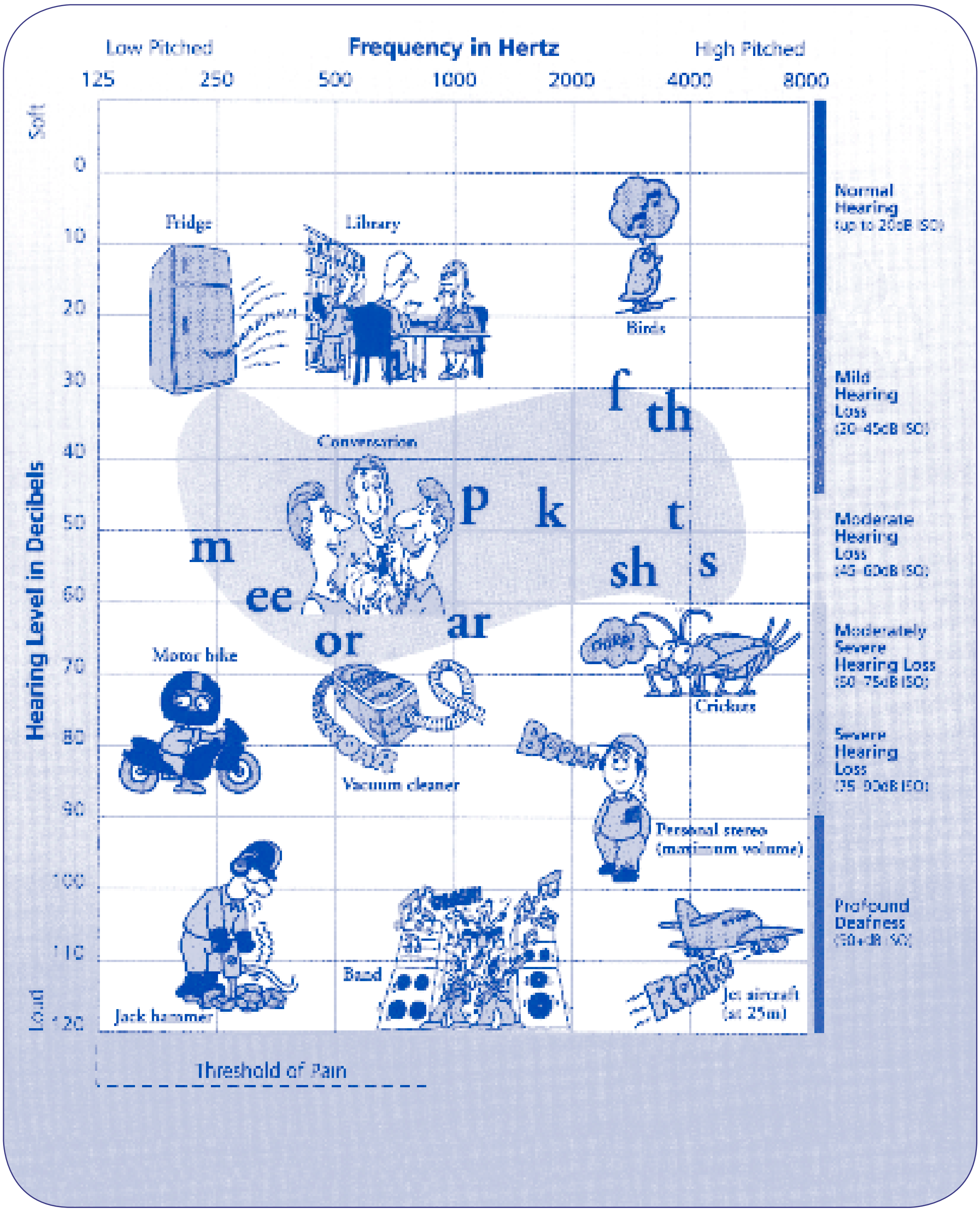
High frequencies above 20 000 Hz are ultrasonic and cannot be heard.

The classifications of noise into three frequency ranges is not, however, universally accepted. For example:

- German Standard DIN 45680 – 1997 classifies infrasound as less than 20 Hz
- Draft American National Standard ANSI S 12.9 – Part 4 describes low frequency as 8 Hz to 100 Hz
- Danish proposal rates infrasound as 1 Hz to 20 Hz and low frequency as 10 Hz to 160 Hz
- Swedish National Board of Health and Welfare (SOSFS 1996:17) classifies the low frequency range as 31.5 Hz to 200 Hz
- Dutch criterion for audibility is 20 Hz to 100 Hz.

Figure 1 shows examples of familiar sounds at their frequency (Hz) and intensity (dB) against a scale of normal hearing to profound deafness; and Table 1 gives an indication of apparent loudness associated with changes in decibels.

Figure 1. Frequency and intensity of familiar sounds



(Used with permission from Australian Hearing, 2002)

We hear and respond to some frequencies more acutely than others, so that sound measurements are often filtered to reflect this sensitivity. The most common example, the 'A-weighting', focuses on the mid- and high-range frequencies we hear and gives less emphasis to low frequencies to which our hearing is less sensitive. A 'C-weighting' is often used to measure sources where low frequencies are a problem.

As noise is emitted from a source it spreads in the air and its level decreases as the distance from the source increases (see Figure 2). This 'attenuation' is due to several factors:

- the distribution of acoustic energy over a geometrically expanding area within increasing distance
- noise screening by barriers between noise sources and receivers
- sound absorption by the air
- sound absorption by the ground.

Other factors influencing noise propagation include wind, temperature gradients and humidity (WHO, 1990). These are important factors to consider when determining noise impacts on the community.

Basics of noise measurement

When interpreting acoustical data it is important to recognise that not all metrics are directly comparable and different metrics are often used for different classifications or types of noise having varying characteristics.

A knowledge of sound, noise and human response leads to a selection of noise measurement equipment and various noise descriptors, frequency and time weightings in an attempt to describe and replicate human responses to sound and its impact. A number of different noise descriptors are commonly used to quantify the noise environment and are described below.

$L_{Aeq,T}$ or the equivalent continuous A-weighted sound pressure level measured over a time period T – that level of constant noise equivalent to the varying noise level occurring over a measurement period T, often termed the energy-average noise level. Time periods can vary from 1 minute to 24 hours and include:

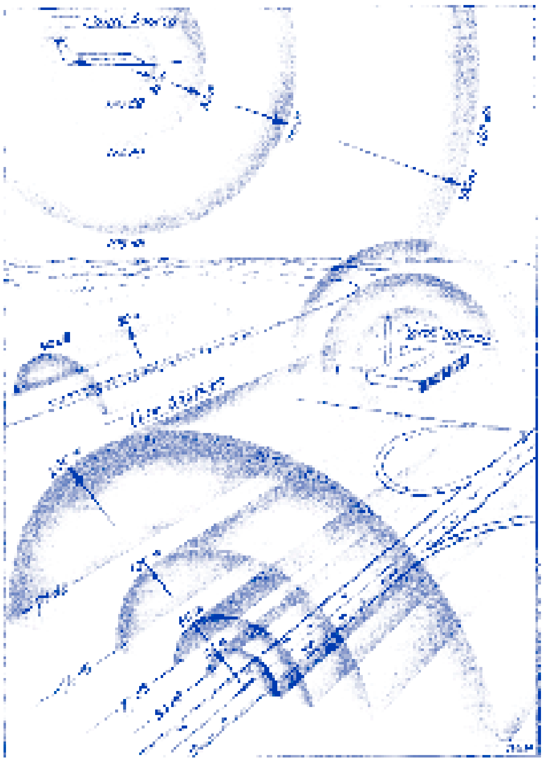
- $L_{Aeq,\ 1\ min}$ previously used in recommending design sound levels for building interiors, for example, AS 2107
- $L_{Aeq,\ 15\ min}$ commonly used in compliance assessment of industrial noise
- $L_{Aeq,\ 1\ hr}$ used in setting acceptable planning noise criteria for development

Table 1. Subjective effect of changes in sound pressure level

Change in sound level (dB)	Change in power		Change in apparent loudness
	Decrease	Increase	
3	1/2	2	Just perceptible
5	1/3	3	Clearly noticeable
10	1/10	10	Half or twice as loud
20	1/100	100	Much quieter or louder

(Source: Bies & Hansen, 1996)

Figure 2. Attenuation of noise from different noise sources



(Source: Acoustics: An Engineering Handbook, 1979)

- $L_{Aeq,\ 4\ hr}$ used in setting noise criteria for evening period, for example, 6pm to 10pm
- $L_{Aeq,\ 9\ hr}$ used in setting noise criteria for night-time, for example, 10pm to 7am
- $L_{Aeq,\ 11\ hr}$ used in setting noise criteria for day-time, for example, 7am to 6pm
- $L_{Aeq,\ 24\ hr}$ used in setting noise criteria for the total 24-hour period

Note: Day, evening and night-time periods are defined differently in various countries and sometimes the evening period is included in the night period.

$L_{Aeq,8\ hr}$ used in setting hearing conservation noise limits for normal work day.

$L_{peak\ (linear)}$ used in setting hearing conservation limits for impulsive noise.

$L_{Aeq,T}$ is often used to measure road and rail noise, industrial noise, noise from heating, ventilation and air conditioning and occupational noise exposure.

$L_{Ar,T}$ is the time average A-weighted sound pressure level of a sound source during a specified time interval, plus specified adjustments for tonal and impulsive character of the sound.

L_{dn}, day–night sound level is the equivalent A-weighted sound level during a 24-hour time period with a 10 dB weighting applied to L_{Aeq} during the night-time hours of 10pm to 7am to reflect greater annoyance experienced during the night-time.

L_{den}, the day–evening–night level is the equivalent A-weighted sound level during a 24-hour time period with a 5 dB weighting for evening and a 10 dB weighting for night. Day is 12 hours, the evening 4 hours and the night 8 hours and is determined over a year.

L_{night}, the night-time noise indicator is the A-weighted long-term average sound level determined over all the day periods of a year and in which the night is 8 hours. The definition of L_{night} does not include an addition of 10 dB. Lnight has a proven relation with self-reported sleep disturbance.

L_{ax}, L_{AE} or SEL, sound exposure level of a discrete noise event is the instantaneous A-weighted sound pressure level integrated over the specified time duration of the noise event and referenced to a duration of 1 second. SEL is used for measuring noise from individual pass-bys of transportation from which a cumulative L_{Aeq} over a reference period can be determined. SEL is also sometimes used for sleep disturbance criteria.

L_{Amax} or the maximum instantaneous sound pressure level measured on 'F' time weighting over a fixed time period often used for setting sleep disturbance criteria.

$L_{An,T}$ the A-weighted sound pressure level obtained by using time-weighting 'F' that is equalled or exceeded for a percentage of the time interval considered. Common examples are:

- $L_{A10,T}$ the A-weighted sound pressure level which is exceeded 10 per cent of the time, T often used to represent the average of the maximum noise levels during a measurement period
- $L_{A90,T}$ the A-weighted sound pressure level which is exceeded for 90 per cent of the time, T often used to represent the average of minimum noise levels during a measurement period or the background noise level in the absence of the noise under investigation.

Other noise descriptors are also used in some circumstances, including N70 (number of aircraft events >70 dB(A) over any specified time period) is used to describe overflight noise exposures. The 70 dB(A) sound level is chosen because an aircraft noise event of this, or louder, magnitude is likely to disturb conversation or interfere with listening to the radio or television inside a house with an open window.

Australian Noise Exposure Forecast System

The aircraft Noise Exposure Forecast technique was first developed in the United States of America in the late 1960s.

The Noise Exposure Forecast System is a scientific measure of the aircraft noise exposure levels around aerodromes. It can be used for assessing average community response to aircraft noise and for land-use planning around aerodromes. In the Australian Noise Exposure Forecast (ANEF) System, noise exposure levels are calculated in ANEF units, which take into account the following factors of aircraft noise:

- the intensity, duration, tonal content and spectrum of audible frequencies of the noise of aircraft take offs, approaches to landing, and reverse thrust after landing
- the forecast frequency of aircraft types and movements on the various flight paths, including flight paths used for circuit training
- the average daily distribution of aircraft arrivals and departures in both day-time and night-time (day-time defined as between 7am and 7pm and night-time defined as between 7pm and 7am).

ANEF charts are provided for most aerodromes throughout Australia. The charts are simply plans of the aerodrome and the surrounding localities on which noise exposure contours of 20, 25, 30, 35 and 40 ANEF units have been drawn. These contours indicate land areas around an aerodrome that are exposed to aircraft noise; the higher the ANEF value, the greater the noise exposure.

The ANEF System was refined for Australian conditions in 1982. Personal interviews were conducted with 3575 residents around the major airports in Sydney, Adelaide, Perth and Melbourne, and the Royal Australian Air Force Base in Richmond, New South Wales.

Subjective reaction to aircraft noise was measured in terms of general reaction, a composite of a number of ratings of dissatisfaction, annoyance and fear, as well as reports of activity disturbance and complaint disposition. A high score on general reaction was used to define whether or not respondents were 'seriously affected' by aircraft noise. Noise measurements were made at several sites around each airport either by tape-recording flyovers or by the unmanned logging of noise levels over periods of two weeks. The noise exposure at each of the dwellings in the social survey was estimated in terms of 20 different noise indices. Analysis by the National Acoustic Laboratories showed that 'equal-energy' indices, such as Noise Exposure Forecast, were more highly correlated with community reaction than other types of index, including 'peak-level' indices.

Attitudes towards the aviation industry, personal sensitivity to noise, and fear of aircraft crashing were found to be important in modifying the extent to which a person will be affected by a given amount of aircraft noise. Demographic variables such as age, sex, occupation and education were found to be of generally minor importance in explaining subjective reaction.

On the basis of this study the Noise Exposure Forecast System was renamed the Australian Noise Exposure Forecast System. The following changes were made to the new system:

- the 'night-time' period was changed from between 10pm and 7am to between 7pm and 7am – the weighting of noise in the 'night' hours was lowered from 12 dB to 6 dB
- the 20 ANEF contour was included on all newly issued ANEF charts
- tabulations of aircraft movements and runway usage were included on ANEF charts.

The findings of the National Acoustic Laboratories survey (Hede & Bullen, 1982) also provided information on the percentage of residents living around established aerodromes who are either moderately or seriously affected by aircraft noise.

This information on the relationship between measured noise levels and objective measures of annoyance provided the basic information necessary for making recommendations on compatible land use around Australian aerodromes.

The benchmark for acceptability of aircraft noise was that no more than 10 per cent of the population be severely affected. Accordingly, a 25 ANEF contour as a residential land usage criterion was recommended in 1985 by the House of Representatives Select Committee on Aircraft Noise, and subsequently adopted as policy by the Australian Government.

Airport planners operate on a 15–20 year horizon. The use of measures of community annoyance as the criterion for land usage or noise abatement measures is likely to come under close scrutiny in the near future. The quantification of the effects of noise on other measures of amenity and health, such as sleep disturbance and cognition are likely to achieve greater prominence in the aircraft noise debate.

Australian airport operators are required to review the ANEF as a licence condition. It will be prudent that these regular reviews assess the need for a more thorough review of the validity of the ANEF system and in particular the continued use of annoyance as the criterion of infringement of amenity.

Noise and human response

Humans are designed to respond to noise and ears have evolved to locate and analyse a wide variety of different sound characteristics and differentiate sound levels and pitch. Hearing has evolved from our need to alert, to warn and to communicate. As a result sound, wanted or unwanted, directly evokes reflexes, emotions and actions, which can be a stimulant and a stressor. The extent to which noise can act as a stimulant and stressor is related to the noise source, onset of the noise, duration and characteristics of the sound and whether noise exposure is voluntary or involuntary. For example, a baby crying is likely to elicit a different physical and emotional reaction than a car alarm, a fire engine or ambulance, a military jet flyover, the neighbour's barking dog and lawnmower.

With the exception of low frequency noise, which can be perceived as noise and vibration, our response to noise requires us to hear it and our brains to interpret this auditory information. Some of the hearing and auditory processing systems central to further physiological responses are summarised below.

The outer, middle and inner ear all have a role to play in our ability to detect sound. However, in the middle ear, three connected bones transmit incoming sound pressure levels to a chamber in the inner ear, the cochlea. The cochlea is filled with fluid and lined with a basilar membrane embedded with numerous hair cells, each connected to a nerve leading to the brain. Internal pressure in the cochlea changes in response to external sound pressure level changes, resulting in fluid movement. Fluid movement causes the hair cells to bend and triggers nerve impulses communicated by the membrane to nerve fibres ascending to the brain and autonomic nervous system. The fibres are grouped by the frequency of the sound signal they carry. The number of fibres a sound requires gives the brain a gauge of its intensity (see Figure 3).

Descending nerve fibres carry instructions from the brain back to the ear to filter out and thus eliminate some signals that the brain determines are of no importance, and allowing focus on others. Some of the descending nerves to the middle ear control muscles that are used to fend off dangerously loud sound.

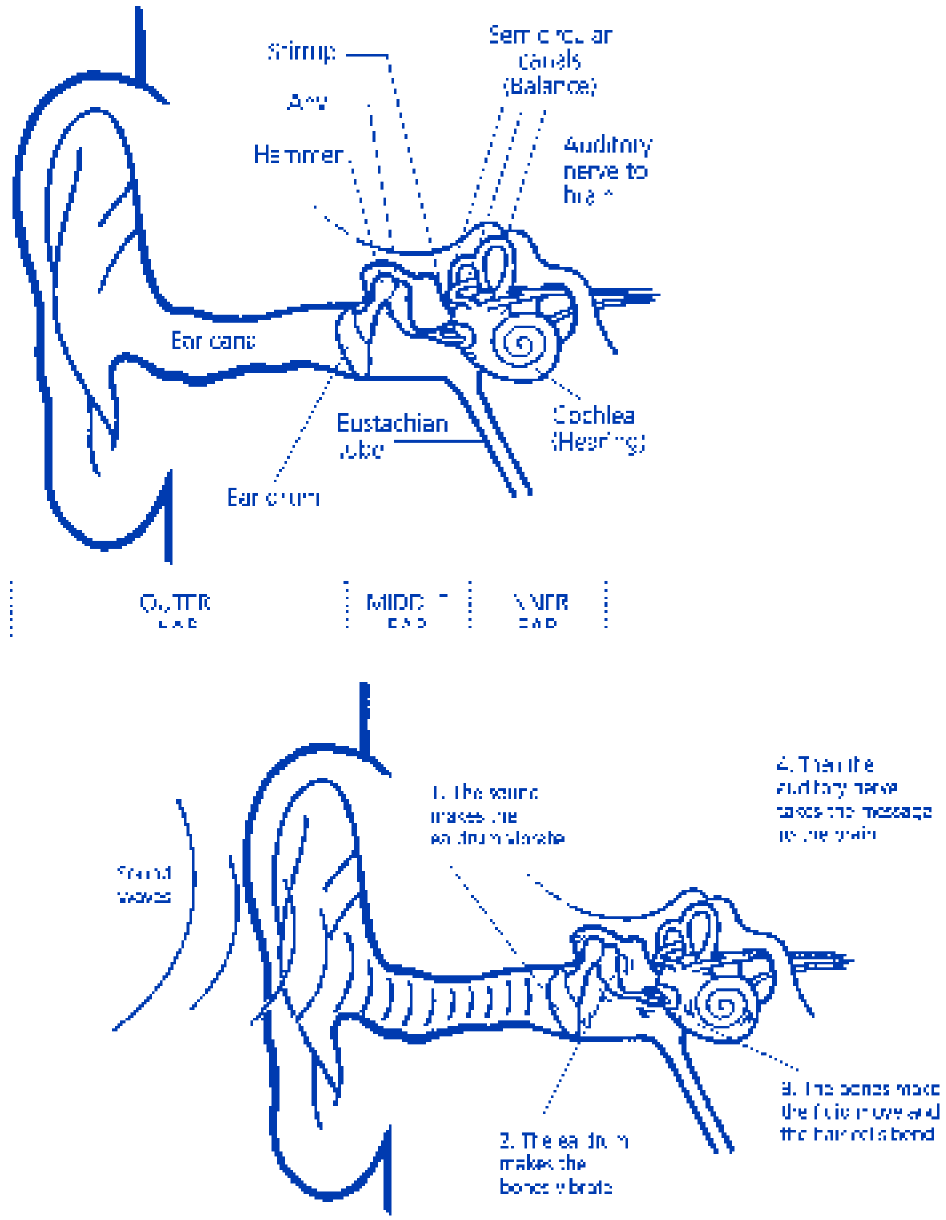
The cochlea and hearing sensory organs are developed *in utero*. A stable startle reflex has been found in foetuses from 28 weeks and a hearing threshold at 27 to 29 weeks of 40 dB is postulated, which reduces to 13.5 dB by 42 weeks (American Academy of Paediatrics, 1997).

If unimpaired, children, teenagers and young adults will experience good hearing until the age-related hearing loss or presbycusis begins at 35 to 40. This results from the deterioration of hair cells beginning first with those hair cells sensitive to higher frequencies. Hearing then continues to deteriorate progressively to lower frequencies as we get older.

Our response to noise is linked to the sound characteristics. Physiologically, we may reflexively orient to and away from a sound, startle or demonstrate a defensive response depending on the nature of the sound and our rapid ability to localise and interpret the sound and attribute meaning to it. The auditory system processes information hundreds of times faster than photoreceptors or olfactory neurons – in microseconds versus hundreds of milliseconds. Researchers have also found that the auditory system has the fastest metabolic rate in the brain (Hudspeth & Konishi, 2000).

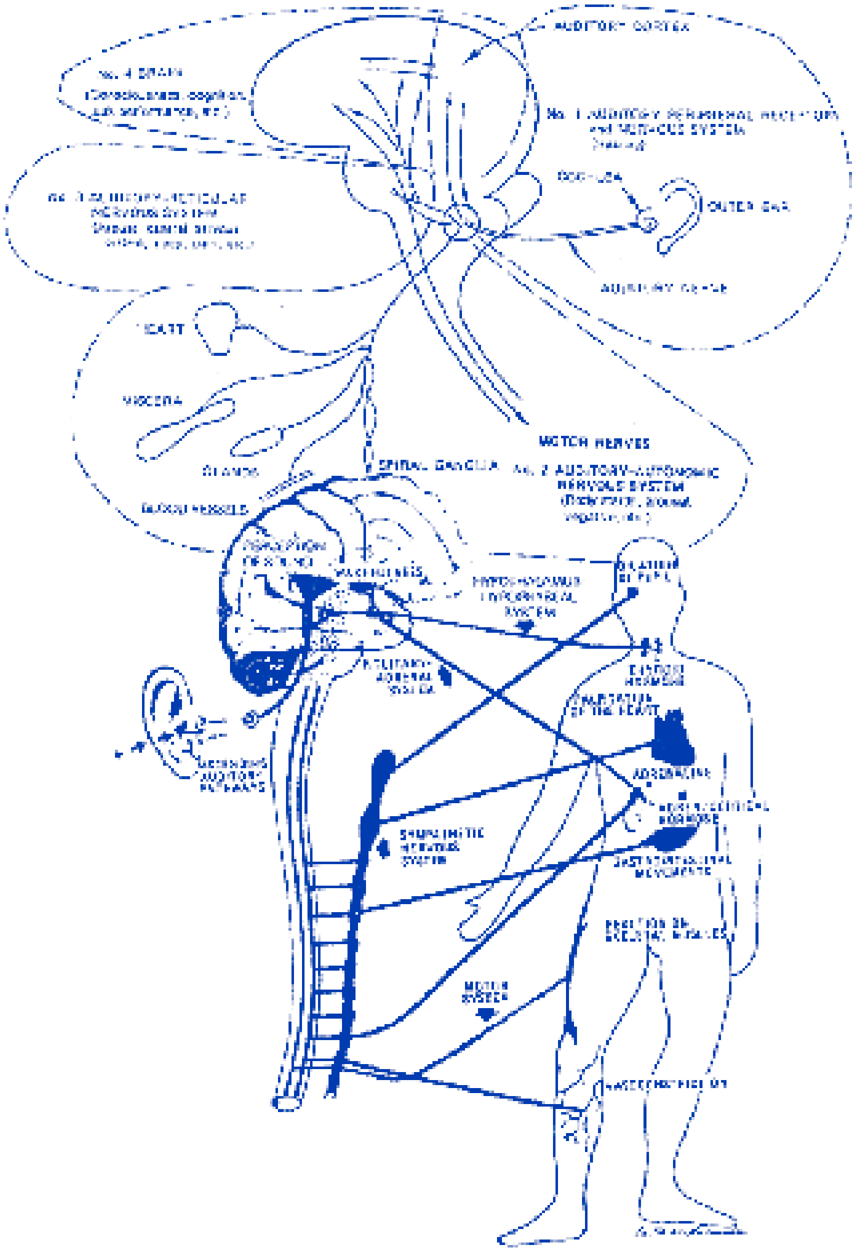
Noise stimulates the brain's reticular activating system. Neural impulses spread from the reticular system to the higher cortex and throughout the central nervous system. Noise can, therefore, influence perceptual, motor, and cognitive behaviour, and also trigger glandular, cardiovascular, and gastrointestinal changes by means of the autonomic nervous system (Suter, 1991) (see Figure 4).

Figure 3. Cross-sectional diagram of the auditory system and how the ear works



(Used with permission from Australian Hearing, 2002)

Figure 4. Major response mechanism of the body and their interconnections with the central and autonomic nervous–glandular systems



(Reprinted from *The Handbook of Hearing and the Effects of Noise: Psysiology, psychology and public health.* (1994) Kryter KD (ed.), with permission from Elsevier)

The noise annoyance reactions of individuals are partly due to acoustic factors and partly due to so-called moderating variables, that is, personal and social aspects of the individual.

Guski (1999) explains that the term 'moderator' or 'moderating variable' (see Figure 5) goes back to Saunders (1956) and denotes a feature or an attribute of persons that changes the degree of the effect of an independent variable (the so-called stimulus variable, for example, the noise level in a community) on a dependent variable (the so-called reaction variable, for example, the noise annoyance, as expressed in interviews). Baron & Kenney (1986) point out the distinction between moderating and mediating variables: moderating variables are independent of the stimulus, but they co-vary with the reaction variable – that is: moderating and reaction variables may depend on each other. Mediating variables can be seen as 'primary reactions', they depend on the stimulus variable, and they also influence the 'secondary reaction'.

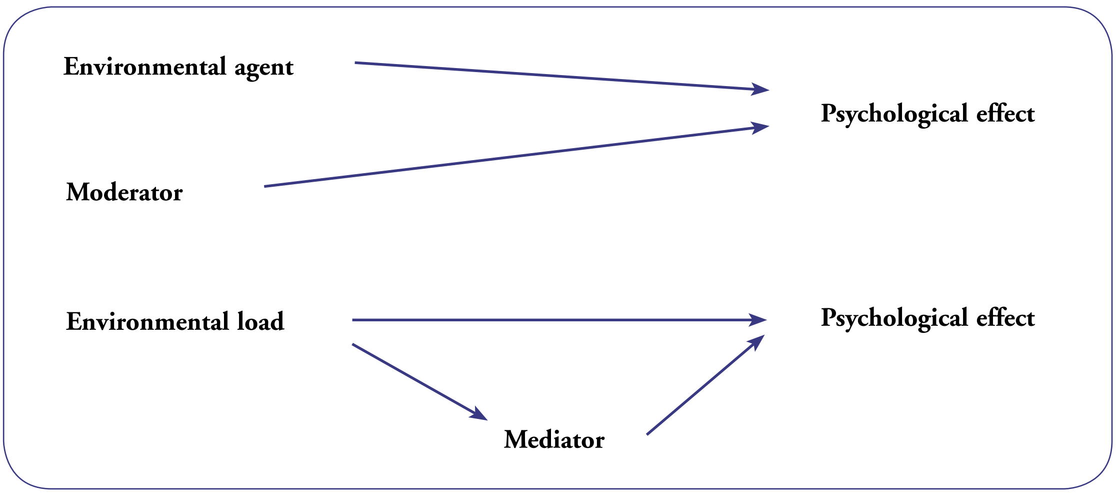
Theoretical models to account for how noise effects human response

The research evidence reviewed in this report focuses on how noise directly affects certain health outcomes, which does not address the critical question of how does one explain the link between chronic exposure to noise and adverse health effects. Theoretical understanding of noise effects is limited and knowledge about mechanisms and modifiers suggestive (Babisch, 2002; Guski, 1999). The non-auditory health effects attributed to noise exposure may be mediated through a 'physiological stress response' and others through 'psychological response'.

Briefly, the two broad physiological and psychological theoretical models are presented.

Physiological models: This model hypothesises that the link between noise and health is mediated by either the:

Figure 5. Structure of relations between environmental agent, moderator, mediator and psychological effect in two models



(The upper figure shows a moderator model; the lower a mediator model. Source: Guski, 1999)

- sympathetic nervous system and the secretion of catecholamines, or
- pituitary–adrenocortical axis based on a process called the general adaptation syndrome (Selyle, 1956, 1975).

Apart from the physiological effects of noise, individuals are psychologically affected by noise exposure. It is sometimes difficult to distinguish between the physiological and psychological effects, especially when physiological symptoms, may be the underlying cause of the psychological stress.

Psychological models: From the psychological perspective there are many models to account for noise effects. Four major constructs have been adapted to account for the effects of noise on human performance and health. The four broad theories are:

- information overload
- arousal
- coping strategies
- loss of control.

Effect modifiers: Noise exposure alone accounts for only part of the variance in individuals' responses to noise, whether this be annoyance and dissatisfaction, sleep disturbance, or effects on hearing and task performance. It is therefore also important to consider social and psychological effect modifiers. There is now a growing body of literature on the psychological and psychosocial modifiers of annoyance, and dissatisfaction due to noise (Fields, 1993; Flindall & Stallen, 1999; Guski, 1999; Hatfield et al., 2001; Job, 1999). Less is known of factors modifying other responses. Research into all of these is necessary for scientifically-based noise control.

Adverse health effects of noise

Introduction

The World Health Organization defines **health** as: 'A state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity' (WHO, 1946).

In 1999, the National Environmental Health Strategy defined **environmental health** as: 'Those aspects of human health determined by physical, chemical, biological and social factors in the environment.'

The **non-auditory health effects of noise** as reviewed in this report, are defined as 'all effects on health and wellbeing that are caused by exposure to noise, with the exclusion of effects on the hearing organ and the effects that are due to masking of auditory information (namely, communication problems)' (IEH–MRC, 1997).

The WHO 1999 definition of **community noise** is: 'Community noise (also called environmental noise) is defined as noise emitted from all sources except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic; industries; construction and public work and the neighbourhood. The main indoor noise sources are ventilation systems, office machines, home appliances and neighbours.'

This review focuses on the primary sources of community noise namely, road, rail and air traffic, and industrial noise. For information on the other sources of noise mentioned above see the WHO guidelines (1999).

The strength of the research evidence for the non-auditory health effects of noise is reviewed. In particular, the review highlights the research reporting an association between community noise and the following health outcomes in adults and children: annoyance, sleep disturbance, cardiovascular disease, performance and learning, school performance, mental health and stress. The main health outcomes for which there is sufficient evidence and the populations most at risk are identified. The effects of noise on health probably operate through a number of different pathways including direct effects, interference with cognitive processes and through reaction to interference in daily activities and communication.

It is generally agreed that there is sufficient evidence that community noise adversely affects:

- annoyance
- sleep disturbance
- children's school performance
- cardiovascular health.

Children, people with existing physical and mental illness, and the elderly are most susceptible to noise on the basis of current limited evidence.

There is some evidence that interventions that reduce noise have health benefits. Some suggestions are:

- reduction of noise at source
- introduction of noise barriers and insulation
- public education about noise sources
- a commitment to maintain and develop quiet places.

Assessment of research evidence

The following important questions need to be considered when assessing research evidence for a possible association between environmental noise exposure and health:

- What is the quality of the research evidence?
- What are the most likely casual pathways to explain the health effects of noise?
- What population groups are most susceptible to these effects?
- How can noise be reduced and interventions applied in ways likely to improve health?

Strength of evidence from environmental epidemiology

Epidemiology gathers evidence in the field, largely either in a descriptive manner or an analytical manner, to investigate the cause of adverse health effects. For environmental causes, these methods may be used to characterise population exposures, investigate clusters of people experiencing the problem or to monitor the effectiveness of interventions.

Descriptive methods may help in the development of hypotheses, but analytical methods are required in order to work out the strength of an association or possible causal link between a hazard and an effect. For example, a cross-sectional study is descriptive, while a case-control study is analytical and can test hypotheses.

We must not expect, however, that epidemiology will provide clear-cut answers. There are many ways in which errors can be introduced. The potential for random errors, due to chance alone, has to be anticipated. Consideration of systematic errors also has to be given in planning epidemiological studies and interpreting results. The two key systematic errors are bias and confounding.

Bias occurs if there is a systematic tendency for the study to provide inaccurate results. An example of a bias is applying a different method for the selection of cases compared to control subjects. Attempts to avoid bias occur at the study design stage.

Confounding occurs when an observed association between an environmental factor and a health effect is, in fact, due to a third factor associated with the exposure, and which independently affects the risk of developing the disease. Confounding can lead to either a false positive observation or a false negative. Confounding must be controlled for in the design of the study, as far as is reasonably possible.

The strongest evidence for environmental noise as a public health concern comes from longitudinal data on individuals followed up over time. This type of information can show the extent to which changes in noise are followed by changes in health. However, there are few of these studies in the noise and health literature, not least because they are difficult and expensive to carry out. We, therefore, also include cross-sectional studies that consider the association between noise and poor health at one moment in time.

In these studies it is difficult to be certain of the direction of causation, whether noise is leading to ill-health or whether ill-health may be leading to increased reaction to noise, or to selection effects such as inability to move away from disadvantaged, in this case, noisy areas. We focus on studies of individuals, which can clearly show the link between environmental noise and the health of the individual person, rather than ecological studies that compare population data from the same geographical area.

A subgroup of analytical epidemiological studies called ecological studies involves the investigation of a group of people, such as those that might be affected by a single source of noise. A general criticism of ecological studies is that it may be unclear whether the same people in the group who experience ill effects are the same people exposed to the hazard, if measured as average exposure levels. It might be assumed in a study of a group located together that they all hear the noise, but assessment of exposure would be better taken from individual's perceptions of noise. A time series study should further clarify the influence of the noise if it is intermittent.

Throughout this review, evidence from well-controlled studies has been highlighted, as well as dose–response and intervention studies. Also, it is noted if there is a consistent body of evidence available from cross-sectional studies. The review articles (for example, Health Council of the Netherlands, 1994, 1999; IEH–MRC, 1997; WHO 1999; Babisch, 2000) balance their discussions with an understanding of strength of the evidence.

For further discussion on the strengths and limitations of epidemiology in assessing the relationships between a noise source and specific health effects, additional reading is recommended. See, for example, 'Hazard Assessment Part 2: Hazard Identification – Epidemiology' in *Environmental Risk Assessment: Guidelines for assessing human health risks from environmental hazards*, pp. 51–72, enHealth Council 2002, available at <www.health.gov.au/pubhlth/strateg/envhlth/risk>.

Health effects of noise – strength of the evidence from international reviews

Much of the early work on the health effects of noise dates from research in occupational health, and subsequently environmental health, in the 1960s and 1970s in Scandinavia, Europe and the United States of America as well as Australia. Studies on the health effects of noise have increased substantially in the last three decades as environmental noise has emerged as an increasingly important issue. In that time, studying the health effects of noise has shifted from studying the effect of noise on hearing and cardiovascular health to more broadly encompassing the effect of noise on wellbeing, quality of life and amenity.

While it is generally recognised that environmental noise is a problem, the extent to which noise adversely affects health, particularly where subjective measures are used, has remained the subject of continued discussion.

In 1994, the Health Council of the Netherlands reviewed the international literature and concluded there was ''sufficient' evidence to link community noise to the health endpoints identified in Table 2 (Passchier-Vermeer, 1993). This was updated in 1999 with the Health Council of the Netherlands report 'Public Health Impact of Large Airports'. In 1997 the Institute for Environment and Health–Medical Research Council in the United Kingdom published a report on the non-auditory effects of noise.

The strength of the effects of environmental noise on health, from three recent reviews, is summarised in Table 2. It can be seen that these international groups of experts considered that there was sufficient evidence for the effects of noise on health regarding annoyance, school performance, ischaemic heart disease, hypertension and various aspects of sleep disturbance (including awakening, subjective reports of sleep quality and disturbed mood the next day following sleep). Hearing loss is also indicated in one review, although much of the research data on hearing loss relates to occupational exposure.

Target noise levels and health effects – strength of the evidence from international reviews

The noise levels, below which health effects would not be expected, derived from previous reviews of the environmental noise and health literature, are reported in Table 3. Although not all reviews agree on the threshold levels for each specific health effect, there is a fair degree of consensus. These noise levels provide guidelines for how ambient noise levels might be controlled in Australia in order to reduce the risk of noise effects on health.

Annoyance and quality of life

Introduction and definition

The most widespread subjective response to noise is annoyance, which may include fear and mild anger, relating to a belief that one is being avoidably harmed (Cohen & Weinstein, 1981). Noise is also seen as intrusive into personal privacy, which may be particularly important in urban settings. The meaning of noise and the attitude of the person towards the source of the noise may be important in determining the level of annoyance. Annoyance is the general term used to describe individuals' responses evoked by a loud noise. It is also related to the effects of noise in disrupting conversation, activities requiring attention, rest and relaxation activities.

One of the challenges in studying and managing noise is its subjective nature: one person's noise is another's music. In 1998, the International Commission on the Biological Effects of Noise published guidelines for reporting results of face-to-face surveys. Community face-to-face and phone noise annoyance surveys have been further developed to enhance national and international survey comparisons and to expand the body of knowledge on community noise annoyance to support policy development.

Table 2. Summary of recent reviews on the strength of effects of environmental noise on health

Health outcome	Passchier-Vermeer, 1993	Institute for Environmental Health (IEH), 1997	Health Council of the Netherlands (HCN), 1999
Annoyance	+	+	+
Hearing loss	+		
School performance		+	+
Ischaemic heart disease	+	+	+
Hypertension	+	+ –	+
Sleep			
Sleep pattern			+
Awakening	+	+	+
Subjective sleep quality	+	+	+
Mood next day	+	+	+
Performance next day	+	+ –	+ –
Psychiatric disorder	+	+ –	+ –
Psychiatric wellbeing			+ –
Birth weight	–	+ –	+ –
Immune effects	+		+ –

\+ effect observed, Passchier-Vermeer, 1993: sufficient evidence for a causal association, IEH, 1997; sufficient evidence, HCN, 1999.

\+ – possibly an effect, Passchier-Vermeer 1993, inconclusive evidence, IEH, 1997; 1: limited evidence, HCN 1999.

– no effect, Passchier-Vermeer, 1993; not used by IEH; inadequate, inconclusive evidence, HCN 1999.

Research findings

Studies of annoyance have been conducted both within the laboratory and in the field to quantify annoyance and determine what noise factors contribute to annoyance. Community surveys of both traffic and aircraft noise studies, noise levels have been found to be associated with annoyance in a dose–response relationship (McKennell, 1963; Griffiths & Langdon, 1968; Shultz, 1978) such that in general, high levels of intensity of noise are associated with higher annoyance levels (Fields, 1994; Miedema, 1998). Although there is variation between different studies related to different ways of measuring annoyance and noise.

People have widely varying reactions to noise. This wide variation between individuals in response

Table 3. Summary of recent reviews on noise levels below which health effects would not be expected

Health outcome	WHO 1999			Passchier-Vermeer 1993		
	Measure	**Value**	**In/outdoors**	**Measure**	**Value**	**In/outdoors**
Annoyance	dBLAeq16hr	50-55	Out	Ldn	42	Out
	dBLAeq16hr	35	In			
Hearing loss[1]	dBLAeq16hr[2]	70	In	LAeq24h	70	In
School performance	dBLAeq16hr	50–55	Out			
	dBLAeq16hr	35	In			
Ischaemic heart disease				LAeq06–22h	65–70	Out
Hypertension				LAeq06–22h	70	Out
Sleep	dBLAeq16hr	30	In			
	dBLAeq16hr	45	Out			
Sleep pattern						
Awakening	dBA	45		SEL	55	In
Subjective sleep quality				LAeqnight	40	Out
Mood next day				LAeqnight	60	Out
Performance next day				LAeqnight	60	Out

Impulse noise in not dealt with here. For further information see Vos (1992).

1 Noise levels below which hearing impairment would not be expected;

- Industrial, commercial shopping and traffic areas (in and outdoors) dBLAeq24hr 70
- Ceremonies, festivals and entertainment events (<5 times per year) dBLAeq4hr 100
- Public addresses, (in and outdoors) dBLAeq1hr 85
- Music and other sounds through headphones and earphones dBLAeq1hr 85

2 The 16hr period in the rows above refers to the period 0600 to 2200 hours.

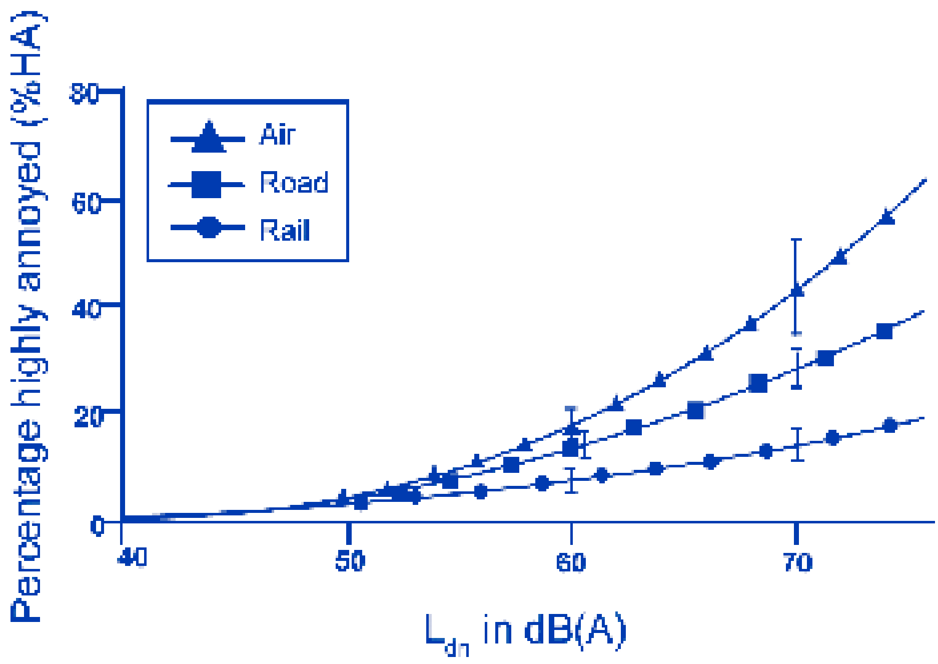
(Source: Berglund, Livdvall & Schwela, 1999)

to different noise levels, in part, prompted the derivation of population noise annoyance curves. It has been known for some time that average noise reaction consistently increases with noise level, and that such data can be aggregated to yield consistent relationships (Schultz, 1978). However as many community annoyance studies are cross-sectional this limits our ability to establish causation (Gunn, 1987).

Miedema and Vos (1999) reviewed available population annoyance data on transportation noise as seen in Figure 6 and found that, regardless of the traffic mode studied, the percentage of highly annoyed individuals begins to increase above a level of 42 dB(A) L_{dn}.

We may become accustomed to the noise level in our area but the introduction of new noise source

Figure 6. Percentage highly annoyed by transportation noise



(Source: Miedema and Vos, 1999)

has a greater effect, than might be predicted, on sleep and annoyance (Griffiths & Raw, 1989). A study of a community living near a new motorway in New South Wales found community reaction equated to a 9 dB difference when compared to response in a community with existing traffic. As many community annoyance surveys have been conducted in areas with stable noise environments, the results of these surveys may prove less useful in predicting community annoyance in changing noise environments. Further annoyance studies may be required in areas undergoing changes in the noise environment.

Australian studies

Specific studies in Australia on the impact of noise on the population are limited in number and scope and mostly pertain to a particular traffic mode in select capital cities. In 1986, the Australian Environment Council commissioned a survey on the extent of community annoyance from a wide range of noises (Australian Environment Council, 1988). The survey found road traffic and barking dogs were the noises reported to have the greatest impacts and 21 per cent of respondents were moderately annoyed by them. Two community noise surveys have been conducted in Brisbane. Duhs et al. (1989), examined annoyance as well as the relationship of noise to other environmental concerns between 1986 and 1988, while Brisbane City Council commissioned an additional survey in 1998 to assess attitudes to, and impacts of, noise in the community (Henry & Huson, 2003).

Figure 7 contrasts the results of the national study with that conducted shortly afterwards in Brisbane. As part of the 1988 Brisbane Noise survey, when asked about noise in relation to other environmental problems, 66 per cent of respondents were concerned about noise compared to 35 per cent concerned about the next highest response (dust, smoke or petrol fumes in the air).

Complaints are often used as an annoyance measure but these clearly under-report community concerns given that only a small percentage of those affected complain. The 1998 Brisbane Community Noise Survey found while noise significantly annoys 48 per cent of Brisbane's adult population, 66 per cent of people reporting to be seriously affected by noise did not complain. Approximately nine percent of residents surveyed who were seriously annoyed by noise also indicated they had become aggressive due to the extent and nature of noise impacts.

The greatest effect of noise reported by respondents was sleep disturbance (Henry & Huson, 2003; Brisbane City Council, 2003). This suggests complaint measures significantly under-report community annoyance and should not be treated as indicative. In addition, complaining about noise to the authorities may be influenced by beliefs in effectiveness of complaint handling, styles of coping, exposure to other stressors and personality factors.

Acoustical predictors of annoyance

Research has found the following general characteristics of noise, which generates more annoyance:

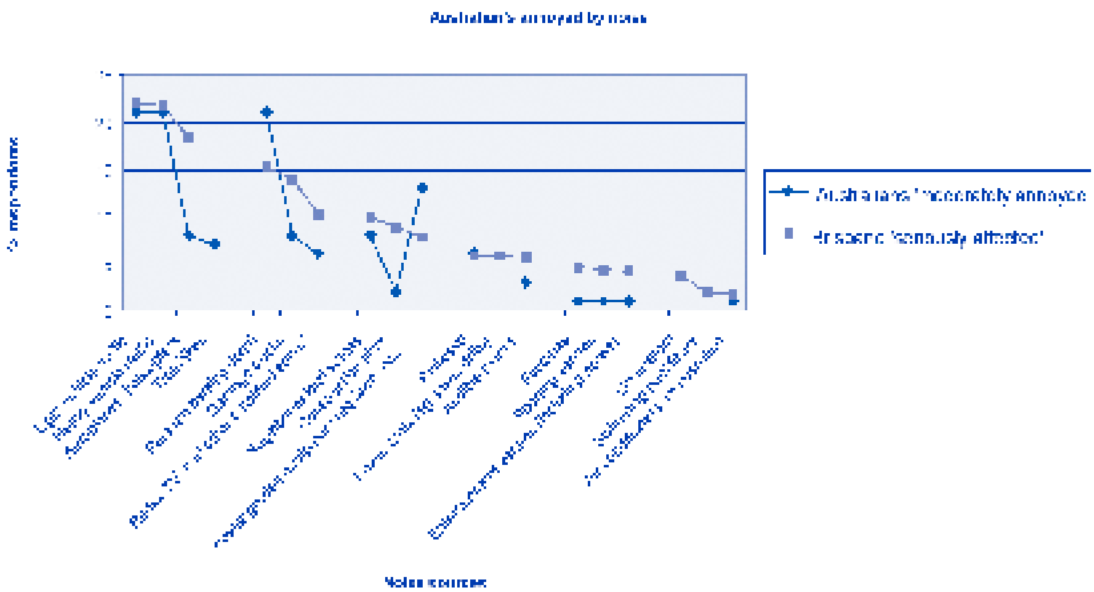
- loudness, frequency, duration
- increasing intensity generates increasing annoyance
- frequency of the interruption
- duration of the interruption
- high frequencies are more annoying than low frequencies.

Intermittent, irregular, tonal, pulse or rhythmic noise generates more annoyance than steady noise of the same intensity.

Non-acoustical predictors of annoyance

Studies of individual annoyance have found a high variability between individual response and

Figure 7. Comparison of Australian and Brisbane community noise annoyance



(Adapted from Duhs T et al. 1989, *Brisbane noise survey 1986-1988*) noise levels and the relationship between noise and annoyance is more difficult to discern. The low correlation is not due to unreliability of noise or reaction measurements. Individuals' correlations are improved when noise measurements are combined with measures of modifying factors to predict annoyance (Job, 1988).

The actual noise level itself has been found to explain 10 to 25 per cent of an individual reaction to noise (Job, 1996). Individual reactions depend on characteristics of the noise, the noise source and the individual's attitude to the noise and noise source. In many instances, the reaction is linked with individual beliefs about the effects noise may have on them as well as other concerns such as safety, fear of accidents and exhaust and air pollution (Hede & Bullen, 1982).

More recently, Miedema and Vos (1999) looked into the factors influencing annoyance. Of particular interest is the role of fear and noise sensitivity in annoyance. One study reviewed found that participants who reported fear and noise sensitivity, related to a transportation source of noise, also reported higher annoyance (Job, 1999). In this study, the difference in annoyance between the lowest and highest fear levels is equivalent to an $L_{eq\ den}$ difference of up to 19 dB; noise sensitivity was equivalent to a $L_{eq\ den}$ difference of 11 dB (Miedema & Vos, 1999). As these differences in annoyance are mediated by fear and sensitivity, further examination of fear and noise sensitivity might provide useful tools for addressing individual annoyance that may have wider application to community annoyance.

Other important predictors of annoyance include the predicability and controllability of the noise, a general dislike of the environment and a feeling of misfeasance, that is, the authorities responsible for the noise are not taking sufficient care. Individuals differ in their self-reported sensitivity to noise, and those of higher sensitivity tend to report higher levels of annoyance in general. It is possible that noise annoyance is more common in people of higher socioeconomic position although the results are inconsistent. If it is so, this may be associated with a higher expectation of good environmental conditions, related to socioeconomic position. The importance of psychological and psychosocial factors in modifying noise reaction raises the possibility of altering or using our understanding of these factors to reduce noise impact.

Conclusions

Noise annoyance is clearly a reflection of impaired quality of life. Individual experience of annoyance to noise varies, depending on personal characteristics and factors, such as ability to control the living environment and psychological stressors. It is not clear whether a longer duration of noise exposure increases the vulnerability to serious health impairment. Undoubtedly, people who are already stressed (for example, already have a high level of depression or anxiety) are also more likely to develop higher annoyance levels when exposed to environmental noise, than those who are not so affected.

Where environmental noise is relatively constant, reported noise annoyance levels remain constant over time. Nevertheless, in general most individuals exposed to chronic noise do seem to adapt to it or develop some mechanism of coping.

The noise-annoyance curves produced by Hank Meidema and colleagues at the Netherlands Organisation for Applied Scientific Research are of significant value to policy makers developing guidelines on exposure classifications. Perhaps Australian noise-annoyance curves would be useful.

Further research could include:

- a national noise survey to monitor noise reaction in the population in relation to changing exposures
- longitudinal studies examining the effects of:
  - new noise exposures on annoyance
  - change in noise exposure on change in annoyance
  - strategies to reduce noise on health.

Sleep disturbance

Introduction

Sleep is necessary to restore biological processes and the cycle of waking and sleeping provides a rhythm to life. Studies of sleep have found that sleep occurs in various stages categorised as 1, 2, 3, 4, and rapid eye movements (REM) based on patterns seen in electroencephalograph (EEG) recordings. The study of sleep patterns has helped us understand normal sleep, how sleep changes as we age, and sleep disorders. It also shows that sleep involves body chemistry, mental outlook, behaviour, and emotion all interacting with changes in the physical and social environment.

Noise is only one of many factors that can influence sleep. Others factors include temperature, physical activity, and drugs as well as subjective and individual factors such as motivation, interest, age, type of sleeper (for example, long, short, good, poor), personality, and sleep loss experience. The reason for the sleep loss can mediate the long-term effects of sleep loss and the recovery. This will be the case whether the sleep loss is due to a voluntary condition created by a specific demand (for example, work schedule, project) or an 'involuntary' situation such as insomnia.

Both objective and self-reported evidence for sleep disturbance by noise have been reported. Noise interferes with sleep in a number of ways:

- awakening – it can cause a sleeper to awaken repeatedly resulting in poor sleep quality (as reported) as well as other impacts
- alter sleep pattern – noise may cause sleep to change from heavier to lighter sleep
- reduce the percentage and total time in REM sleep
- increase body movement
- change cardiovascular responses
- cause effects on slow wave sleep.

These changes can affect mood and performance the next day.

The standard method for monitoring sleep is by polysomnography, which consists of vertex EEG, electrooculograph for monitoring REM (as in dreaming) and electromyograph for monitoring muscle tone under the chin (which is decreased during REM sleep) and electrocardiography (Carskadon & Rechtschaffen, 1989; Carter, 1998).

Sleep disturbance studies also rely on self-report (pressing a switch when awakened or rating the sleep quality the next morning), sleep diaries. More recent laboratory and field studies are frequently using actimetry (monitoring of arm movements and hence arousal).

At this stage it is generally felt by the scientific community and policy makers in Europe that the noise exposure guidelines for sleep disturbance are premature. To address this issue, the Directorate-General Environment in the European Commission will be publishing a position paper on 'night-time transportation noise and sleep disturbance'. This paper will feed into the European Union Directive on the Assessment and Management of Environmental Noise (European Commission, 2002). There is also a recent United States standard: American National Standard, ANSI S12.9-2000/ Part 6. Quantities and Procedures for Description and Measurement of Environmental Sound – Part 6: Methods For Estimation of Awakenings Associated With Aircraft Noise Events Heard in Homes. These standards could form the basis for guidelines developed or modified by Australian policy makers.

Research findings

Some laboratory studies have found small changes in EEG recordings indicate changes in sleep stage and that REM sleep is most resistant to sleep stage changes. Studies also indicate that participants in sleep observations in laboratory settings are more sensitive to noise than field study participants suggesting an effect from unfamiliar surroundings (Pearsons et al., 1995). An alternative view is that when the likelihood of noise causing an arousal is 'corrected' for the likelihood of a spontaneous arousal, all sleep stages appear to be about equally vulnerable to disturbance by noise (Carter et al., 1994).

More recently, researchers have examined the impact of noise on sleep taking into account other health outcomes. One of these studies found a cardiovascular response to noise, without awakening and increases in blood pressure, without any indication of sleep disturbance in the sleep polygraph. The significance for these effects is unknown.

There is a relationship between night-time noise and changes in sleep including changes in sleep pattern, sleep stages, awakenings, sleep quality, heart rate and mood. In a community study of exposure to road traffic noise, perceived sleep quality, mood and performance, in terms of reaction time, were all decreased following sleep disturbed by road traffic noise (Ohrstrom, 1982).

Measurable sleep disturbance effects have been observed as levels exceed 35 dB(A) L_{eq} and increase with increasing noise level. While some adaptation or habituation can occur where continuous noise, such as traffic noise, is present, a small number of high-level noise events can affect sleep (Carter, 1996; Vallet, 1998). This has prompted researchers and regulators to use different noise measurements that consider the importance of noise emergence as a factor in sleep disturbance (that is, the difference between a high noise level event and the background noise level). The WHO *Guidelines for Community Noise* 1999 recommend that, 'where noise is continuous, the equivalent sound pressure level should not exceed 30 dB(A) indoors, if negative effects on sleep are to be avoided'.

The ability to get to sleep and, when asleep, the probability of experiencing a change of sleep state or ultimately of awakening, are related to both the ambient and maximum instantaneous noise levels at the ear of the sleeper, and the number of events during the night time period (WHO, 1999).

As a rule in planning for short-term or transient noise events, for good sleep over 8 hours the indoor sound pressure level measured as a maximum instantaneous value should not exceed approximately 45 dB(A) L_{Amax} more than 10 or 15 times per night.

Sleep loss reduces cognitive function and can affect physiology, behaviour and subjective outcomes. Statistically significant reductions occur in vigilance, memory, learning, and speech and increases in divergent thinking with varying amounts of sleep loss as well as with different 'forms' of sleep loss, such as acute total sleep loss and cumulative partial sleep loss. One possible problem for sleep study self-reporting is that a sleep-deprived individual is not likely to provide accurate estimates of performance capability.

In an Australian study, Grunstein and colleagues (2000) recently completed research for the NSW Roads Traffic Authority analysing the connection between noise and sleep disturbance. Their report was released in November 2000. An associated study (Carter et al., 2002) looked into the effect of traffic noise on the cardiovascular and autonomic nervous system. Research findings provide useful information on sleep disturbance related to sound energies of a particular level. It may be useful for such research to be extended so that more definitive answers to the questions on how noise affects sleep and performance can be provided.

Conclusions

Noise affects people's ability to gain the appropriate amount and type of sleep needed for maintenance of good health and there are suggestions of disturbed sleep leading to more serious health problems. On the whole, community studies have tended to show much smaller effects on sleep (Horne et al., 1994) than laboratory studies. Data from community studies are more relevant for public health policy. The extent to which environmental noise levels are creating sleep disturbance and other sleep related adverse health effects requires further attention.

This is an area where a relatively small amount of additional research could provide useful information that could protect people's health. It must be noted that high quality research in this field is hard to conduct: ideally both subjective and objective sleep measures need to be taken, along with precise noise exposure assessment. By reducing indoor noise level, REM sleep and slow wave sleep may increase (Vallet et al., 1983) – this may be a fruitful avenue to pursue.

Performance and learning – school children

Introduction

There is good evidence, largely from laboratory studies that noise exposure impairs performance and speech perception (Loeb, 1986; Smith, 1989; Stansfeld et al., 2000; WHO, 1999). Noise can contribute to increased arousal resulting in improved performance on a simple task (particularly in conditions of sleep deprivation), but performance is impaired on more complex tasks. The tasks most susceptible to noise effects are sustained attention or vigilance tasks (tasks that have a large component of working memory). Unexpected noise also can distract from social or auditory cues that are important in work place and other settings. Other studies have demonstrated behavioural effects of noise after uncontrollable and unpredictable noise has ceased (Glass & Singer, 1972).

Speech cannot be used to communicate effectively when background sound drowns out the voice. Normal speech at a one-metre distance in a quiet background is 45–50 dB(A) though this varies with gender and vocal effort. Background noise containing sound energies at frequencies similar to those of the spoken voice may mask speech at these and resonant frequencies depending on the characteristics of the noise and the room. The higher the masking noise level and the more energy it carries at important speech frequencies and the higher the reverberation characteristics of the room, the greater the percentage of speech or other sounds that become inaudible. 'Noise interference with speech comprehension results in a large number of personal disabilities, handicaps and behavioural changes' (WHO 1999, p. 42).

The most important implications of these effects are for vulnerable persons such as: children just learning to understand and speak language; children and adults learning a second language; those with hearing impairments; and people with sensorineural hearing loss are especially disadvantaged in hearing speech in noise. The elderly, very young children and people with sensorineural hearing loss require lower background noise for adequate speech intelligibility than normal hearing adults [cf. Elliott, 1982].

Field and community studies of performance have focused primarily on those occupationally exposed to noise while a growing number of studies have focused on school children. In occupationally exposed populations, tasks requiring auditory signals may be masked or interfered with by noise and this may affect performance and result in accidents. It must be noted that there are a number of health benefits to be gained if hearing protection is worn in high noise levels [cf. Kryter, 1970]. Noise effects in the occupational setting and experimental studies are beyond the scope of this report because the exposure sources are not encompassed in the definition of 'community noise' (for further information: WHO 1999; Smith & Broadbent, 1992; Stansfeld et al., 2000).

Research findings

In the last 20 years there has been increased empirical research investigating the effects of noise on children, with the Los Angeles Airport Study (Cohen et al., 1980, 1981); The Munich Airport Study (Evans et al., 1995, 1998); The Schools Environment and Health Study (Haines et al., 2001a, 2001b) and West London Schools Study (Haines et al., 2001c) around Heathrow Airport in London; in New York City (Evans & Maxwell, 1997); and the Sydney Airport Health Study (Morrell et al., 1998). The evidence for the effects of noise exposure on child health is strongest for cognitive effects, though these effects are not uniform across all cognitive tasks (Cohen et al., 1986; Evans et al., 1991; Evans & Lepore, 1993). Tasks which involve central processing and language comprehension, such as reading, attention, problem solving and memory, appear to be most affected by exposure to noise (Cohen et al., 1986; Evans et al., 1995; Evans & Lepore, 1993; Hygge, 1994). The effect of environmental stress on cognitive tasks with high processing demands is widely accepted in the environmental stress literature examining the general sources of environmental stress on cognition (Cohen et al., 1986; Smith, 1989).

The effects of noise on child cognition are summarised below (for more complete details of these studies see Evans & Lepore, 1993; Haines et al., 2001c). In studies examining the effects of chronic aircraft, rail and road traffic noise on school children's cognitive performance, the following results summarised below have been found in children exposed to high levels of environmental noise:

- deficits in sustained attention and visual attention
- difficulties in concentrating in comparison with children from quieter schools according to teachers' reports
- poorer auditory discrimination and speech perception
- poorer memory that requires high processing demands of semantic material
- poorer reading ability and school performance on national standardised tests.

Noise exposure has also been consistently associated with noise annoyance and impaired wellbeing. There is moderate evidence that chronic noise exposure affects motivation, blood pressure, and catecholamine hormone secretion. There is equivocal evidence that chronic noise exposure affects child mental health and sleep. Most of these studies relate to aircraft noise, but in a more limited number of studies the pattern of results has also been found in relation to road and rail noise.

Stronger evidence for the existence of noise health effects comes from intervention studies and natural experiments where changes in noise exposure are shown to be accompanied by changes in health and cognitive performance. To date, there have been three studies examining the effects of noise reduction on children's cognition: two intervention studies (Bronzaft, 1981; Cohen & Weinstein, 1981) with methodological limitations that effect their generalisability, and one well-designed natural experiment, the Munich Airport Study (Evans et al., 1995, 1998; Hygge et al., 2002).

The most convincing evidence for noise related cognitive effects came from the prospective longitudinal natural experimental field research around Munich Airport in older children with a mean age of 10.8 years (cross-sectional results Evans et al., 1995; longitudinal results Evans et al., 1998; Hygge et al., 2002). In 1992 the old Munich airport closed and a new airport was opened. The cross-sectional results indicate an association between high noise exposure and poor long-term memory and reading comprehension; habituation to auditory distraction; less motivation; raised annoyance; poorer quality of life; raised catecholamine secretion; and lower reactivity in systolic blood pressure (Evans et al., 1995). Longitudinal analyses, after three waves of testing, indicate improvements in long-term memory and reading after closure of the old airport. Strikingly, these effects were paralleled by impairment of the same cognitive skills after the new airport opened (Hygge et al., 2002). Questions remain about mechanisms for these effects and vulnerable sub-groups within the child population (hearing impaired, learning disabilities).

It is difficult to give precise figures on how many children are taught in schools with noise levels that may adversely effect their health or to set limits for noise exposure levels. This question will be addressed in the RANCH project (road traffic and aircraft noise exposure and children's cognition and health: exposure-effect relationships and combined effects) funded by the European Commission <www.ranchproject.org>. RANCH began in January 2001 and is expected to be completed by the end of 2003.

Conclusions

There is sufficient evidence supporting a conclusion that chronic noise exposure at schools affects child health and performance. The importance of these impairments of early childhood development have been recognised by the United States Federal Interagency Commission on Noise; the World Health Organization and the European Commission.

Nonetheless, we need further data to derive dose–response curves for guidance on the noise threshold level before effects become manifest and to determine the potential negative and positive effects of interventions. One consideration when conducting this research in Australian schools is that outside learning, sport and recreation are more common than in European schools. In addition, studies are required to provide a more precise insight into the mechanisms that underlie child noise effects and the identification of vulnerable subgroups.

Cardiovascular disease

Introduction

Ischaemic heart disease is the most common cause of sudden death in Australia. Hypertension or high blood pressure was the second most commonly reported recent illness (8%) in the National Health Survey. It is also a major risk factor for coronary heart disease, stroke, heart failure and peripheral vascular disease. Risk factors associated with high blood pressure include high cholesterol, physical inactivity, overweight, diabetes as well as dietary salt intake and mental stress. The extent to which those with pre-existing cardiovascular conditions experience further hypertension or other adverse effects from noise remains unclear.

The effects of noise on cardiovascular health, particularly hypertension[1] and ischaemic heart disease,[2] have been studied in animals and humans in laboratories, occupational settings and in the wider community. The majority of the studies examining the impact of noise on cardiovascular disease have been conducted in occupational setting with very high noise exposure levels. Babisch (2000) makes the point that it is difficult to separate the effects of occupational noise from environmental noise (broadly, noise at home), but for the purposes of this report the focus is on environmental noise.

Research findings

The evidence on the effects of environmental noise on cardiovascular parameters is not yet conclusive. Babisch reviewed 22 articles on the impacts of traffic noise on hypertension and ischaemic heart disease. Three studies conducted in Amsterdam, Bonn and Erfurt (Germany) found statistically significant relative risks of hypertension for those living in areas exposed to 65–70 dB(A). However, other reviewed studies found no consistent findings between noise and hypertension unless subjective responses to noise were considered (Babisch, 1998, 2000). There appear to be questions regarding the control of possible confounders in the Erfurt study.

Babisch also concludes that there seems to be greater evidence of ischaemic heart disease risk among those exposed to noise levels above 65–70 dB(A). Increased risks of ischaemic heart disease with relative risks of 1.1 to 1.5 (not statistically significant) were found in those most highly annoyed by or disturbed by traffic noises (65–70 dB(A)) compared to noise levels of 51–55 dB(A) (6–22h). The relationship between annoyance to noise and increased relative risks of ischaemic heart disease merit further attention given the increasing levels of community concern and annoyance and the significant prevalence of cardiovascular conditions within the Australian adult population.

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1 Hypertension or high blood pressure is defined as: Systolic blood pressure greater than or equal to 160 mmHg and/or Diastolic blood pressure greater than or equal to 95 mmHg (Australian Institute of Health and Welfare, Australia's health 1998)

2 Ischaemic heart disease or coronary heart disease is the most common cause of sudden death in Australia. It comprises mainly heart attack and angina. No national data are available on the number of Australians with ischaemic heart disease though it is the most costly cardiovascular disease accounting for 24 per cent of total cardiovascular disease costs.

More recently, there has also been an increase in research on the impact of noise and childhood hypertension. Seven out of nine studies (1968–90) reviewed by Evans and Lepore (1993) report elevations of resting blood pressure among children who are chronically exposed to aircraft and road traffic noise. Babisch (2000) also concludes that consistent blood pressure increases were found in children. A cross-sectional study in Los Angeles found significant increases in mean diastolic and systolic blood pressures in children attending schools near the airport (Cohen et al., 1980). While socioeconomic factors were accounted for, differences in ethnicity between case and control schools may have confounded results.

The Munich Airport study provides evidence that aircraft noise weakly associated with increased systolic blood pressure and lower reactivity. A well-controlled cross-sectional study of blood pressure in the Slovak Republic grouped 1542 children in three traffic noise exposure categories: quiet [<60 dB(A)], noisy [61–69 dB(A)], and very noisy [>70 dB(A)] based on noise measurements at their kindergarten. Noise measurements were collected at their homes as well. Statistically significant elevation in systolic and diastolic blood pressure was seen in children attending kindergarten and living in the noisy and very noisy environments (Regecova & Kellerova, 1995).

It must be pointed out that the results from all studies have not consistently demonstrated a blood pressure effect of noise exposure. A cross-sectional study of school children near Sydney airport found no significant effect of airport noise on children on systolic and diastolic blood pressure apart from a negative effect on diastolic pressure since the time of the runway opening (Morrell et al., 2000).

Noise, acting as a stressor, is thought to have an impact on the cardiovascular system through certain stress response mechanisms such as the release of cortisol, adrenalin and noradrenalin which have cascade effects, including raising blood pressure and increasing vasoconstriction. There are also a few studies of cardiovascular effects that measure both noise reaction and its psychological modifiers (for example, subjective noise sensitivity, negative attitudes to the noise source, predicability and control). A cross sectional study found an association between noise, annoyance and cardiovascular disease (Belojevic & Saric-Tanaskovic, 2002).

Conclusions

Given the seriousness and the costs to society of cardiovascular disease through early deaths, disability, days lost to work, health care costs and deterioration in quality of life, small changes in risk, such as provided by environmental noise, might have significant population health effects and societal costs. The results from community studies provide little evidence that noise is related to hypertension, but it may be a risk for cardiovascular disease for those who live in highly exposed areas (65–70 dB(A)) although the magnitude of the effect is likely to be small. The ranges of blood pressure elevation in noise-exposed children reported in the studies reviewed are within normal levels and do not suggest hypertension.

Further research is needed to examine the impact of noise on cardiovascular health in the general population as well as in those with pre-existing hypertension and other cardiovascular conditions.

There is also a need for prospective, 'longitudinal' or cohort designed studies measuring possible confounding and modifying variables in individuals as well as tracking their noise exposures over time, in order to assign causal connections between noise and health.

Mental health

Introduction

Mental health is one of seven national health priority areas designated by the Australian Government and the State governments. Mental health relates to emotions, thoughts and behaviours. The International Classification of Diseases – 10th revision (ICD–10), Classification of Mental and Behavioural Disorders definition of a mental disorder implies 'the existence of a clinically recognisable set of symptoms or behaviour associated in most cases with distress and with interference with personal functions' (WHO, 1992). A person with good mental health is generally able to handle day-to-day events and obstacles, work towards important goals, and function effectively in society. People who are depressed lose their enjoyment of life, lack energy and concentration, and may suffer sleep and appetite disturbances. However, even minor mental health problems may affect everyday activities to the extent that individuals cannot function as they would wish, or are expected to, within their family and community.

Research findings

The relationship between noise exposure and mental health remains unclear. The association between noise and mental health has been examined using a variety of outcomes including individual symptoms as well as psychiatric hospital admission rates, use of health services and community surveys of common mental disorder.

The best studies of aircraft noise and hospital admissions have been carried out by Jenkins and colleagues (1979, 1981) who found very inconsistent associations between aircraft noise levels and hospital admission rates – these studies were carefully controlled for potential confounding factors. The West London Survey, although cross-sectional, has been the most thorough study of noise and community mental health carried out in London: 5885 adults were randomly selected from within four aircraft noise zones around Heathrow airport according to the then current measure of aircraft noise exposure, the Noise and Number Index (Tarnopolsky & Morton-Williams, 1980). This study showed little effect of noise on mental health using a standardised screening instrument, the General Health Questionnaire.

Similarly, studies of medication and health service use from the same study showed no consistent effects of aircraft noise (Watkins et al., 1981). One prospective study, in a small South Wales town, found little association between traffic noise level and common mental disorders, although there was a small non-linear association between traffic noise level and increased anxiety levels (Stansfeld et al., 1996). Overall, although there is reasonable evidence that noise exposure can result in psychological symptoms, there is no good evidence that it is responsible for serious mental ill-health.

Sensitivity to noise and annoyance from noise is possibly related to certain types of mental disorders such as depression. But the nature of that relationship is not clear and the question remains whether pre-existing mental disorders result in a greater sensitivity to annoyance, an inability to habituate to noise or whether excessive noise exposure exacerbates latent neuroses.

Noise sensitive people pay more attention to noise, discriminate more between noises, find noise more threatening, out of their control and react and adapt to noise more slowly than less noise sensitive people. And while no association has been made between noise and psychiatric disorders, it appears there is a close relationship between noise sensitivity and the propensity to develop or suffer from psychiatric symptoms (Stansfeld et al., 1996). Several studies report that noise sensitivity does not interact with noise exposure to increase vulnerability to mental ill-health (Stansfeld et al., 2000).

The term 'stress' has been defined in a number of different ways by different fields of study and is general and non-specific in character. One definition of stress for the study of environmental noise comes from psychology: 'It is when an individual perceives an imbalance between the demands of their experience and their ability to cope' (Selye, 1956). It has been suggested noise can be a source of stress of a psychological, behavioural or somatic nature.

Conclusions

As reviewed in this report earlier, noise exposure predicts annoyance, psychological symptoms and impaired quality of life in both adults and children. Research should explore further how community noise is associated with wellbeing and health functioning. Psycho-physiological and psychological stress reactions have both been studied as the main effects of noise and as mechanisms to account for other noise effects (such as cardiovascular effects).

Noise exposure cannot be blamed for serious mental health problems but certain people, such as those already stressed, are more sensitive to noise than other, less stressed, people.

Noise and neuro-physiological stress – main effect

The normal stress response consists of a set of connected changes and feedback responses between the nervous and endocrine or hormonal system developed for evolutionary advantage to respond to threats. The response enables the body to produce energy quickly and put muscles to work for strong quick movement. The faster, stronger force of the heartbeat increases the required blood flow but could cause damage if sustained over a longer term (Aicher, 1988).

Introduction

In examining auditory and non-auditory health impacts of noise, researchers place particular emphasis on using non-intrusive testing to measure autonomic system responses as elements of a stress response. Physiological responses that have been studied include:

- a circulatory response dominated by vasoconstriction of peripheral blood vessels and other cardiovascular changes affecting blood pressure
- heart rate and blood pressure variabilities
- a reduced rate of breathing
- galvanic skin response, a reduction of the electrical resistance of the skin
- a brief change in the skeletal–muscle tension, measured electrically (electromyograph) (Kryter, 1994)
- hormonal changes.

Research findings

In some studies animals exposed to high intensity sound exhibit temporary increases in neuro-endocrine excretions, which reduce over time, whereas in other studies no long term physiological changes are observed. The period and intensity of noise exposure in different studies may explain differences in results.

In an early review article, Kryter reported sudden or impulsive noise bursts resulted in stress reaction changes that included changes in cardiovascular blood pressure and volume, breathing, pulse rate, gastrointestinal motility, endocrine gland secretions and neural activity changes in animals and humans. With the exception of one response, the eye-blink, many of these responses can be reduced as habituation to noise occurs (Gunn, 1979).

Exposure to infrasound or low frequency sound has been found to elicit stress reactions and in some instances resonance responses in vocal cords (10 Hz) and internal organs. Responses to very high levels of infrasound may resemble stress reactions that include bizarre auditory sensations termed 'pulsation and flutter'. Further research is needed to determine the health effects of low frequency noise exposures.

The most studied effects of noise on physiological reactions are for elevated levels of stress hormones (HCN, 1999).

Mechanisms for coping with stress include increased release of stress hormones such as adrenaline, noradrenaline and cortisol. Cortisol is secreted at an increased rate in almost all stressful situations. It is an essential part of control of energy metabolism and exerts a wide range of effects on the metabolism of proteins, carbohydrates and fats providing rapid energy for combating situations such as fright, bleeding, trauma and temperature extremes. Cortisol raises blood pressure and reduces inflammation. It can also temporarily suppress the immune response and sharpen attention. The general pattern of endocrine responses to noise is consistent with noise as a stressor, exciting short-term physiological responses. Most international reviews consider the evidence from the epidemiological studies in both adults and children as limited or suggestive only (HCN, 1994, 1999; IEH, 1997; Stansfeld et al., 2000).

Conclusions

Those with existing mental health problems, usually either depression or anxiety, are more prone to be annoyed and disturbed by environmental noise exposure than the general population. It is possible that certain vulnerable groups, who are exposed to noise over which they have no control, may be vulnerable to mental health problems. There is no strong evidence that noise causes mental ill-health. The evidence is that acute noise has an impact on psychophysiological arousal, but whether chronic noise exposure has an equivalent long-term effect is as yet unanswered.

Certain neurological disorders result in a failure to filter out background noise, such that the sufferer experiences stimulus from even distant sound.

Further research on adverse health effects

- Additional research is needed to replicate the effects found in international studies in the Australian context.
- Internationally it is accepted that further research is required to include better measurement of noise exposure, better measurement of health outcomes and more attention paid to considering confounding factors and the effect modifiers in the association between noise and health.
- Longitudinal, intervention and dose–response studies are required to confirm and extend the evidence from the cross-sectional studies.
- Research that would have direct impact on policy would be intervention studies examining the effects of change in noise exposure on changes in population health. A good first step would be to commission an exhaustive literature review of all intervention studies.
- Priority areas for further research in Australia are: sleep disturbance, annoyance, school childrens' performance, cardiovascular health and wellbeing.

Sleep disturbance – some research issues for consideration:

- sleep disturbance due to traffic, industrial noise and neighbourhood noise
- physiological response to noise during sleep
- the role of psychological and physiological modifiers, demographic factors and lifestyle (for example, shiftwork) in noise induced sleep disturbance and physiological response
- the likelihood of short or long term health consequences of noise induced sleep disturbance.

Annoyance – some research issues for consideration:

- establish a national noise survey to monitor noise reaction in the population in relation to changing exposures
- longitudinal studies examining the effects of new noise exposures on annoyance
- longitudinal studies examining the effects of change in noise exposure on change in annoyance
- longitudinal studies evaluating the effects of strategies to reduce noise on annoyance.

Effects on children – some research questions for consideration:

- Do interventions reduce exposure and reduce the adverse health effects of environmental noise on children?
- Above what exposure threshold are effects manifest?
- What mechanisms underlie child noise effects?
- The identification of vulnerable sub-groups within the child population.

Cardiovascular health – a question for consideration:

- What are the impacts of noise on cardiovascular health in the general population as well as in those with pre-existing hypertension and other cardiovascular conditions?

The long-term health consequences of noise effects are as yet unknown.

Noise sources and impacts in Australia

Extent of noise impacts in Australia

The extent to which Australians experience non-auditory health effects from occasional and routine environmental noise exposure hinges on two elements:

- information on environmental noise exposures of the Australian population apart from road traffic noise
- information on physical and mental states thought to influence reactions to noise, for example, attitude toward noise source and its appropriateness.

Information is needed to characterise environmental noise in urban centres without which it is difficult to quantify the community noise environment. In the absence of this information, researchers have used exposure information from significant noise sources, aircraft and road traffic as well as community annoyance surveys.

Based on available information, certain groups of the Australian population are exposed to high levels of noise. The background noise levels are increasing and levels already experienced are likely to affect health, quite apart from the observed annoyance effects.

Clearly, annoyance effects and sleep disturbance effects have been documented and these alone warrant attention and action to reduce environmental noise levels. Where the noise environment has not yet been compromised, it is important that health-based guideline levels are used to minimise noise impacts from current and future noise sources.

The impact of noise on children in day care centres and primary schools calls for examination of policies for locating these facilities and the feasibility of facility improvement in areas most severely affected.

The potential for adverse effects on cardiovascular health through increased relative risks of those with existing hypertension and ischaemic heart disease is concerning. If the impact of masking, speech interference and annoyance in those experiencing and those soon to experience hearing impairments are factored in, the public health dimensions of the problem increase further.

Noise sources in Australia

There is a wide variety of noise sources that contribute to environmental noise in Australia. Research focuses on a wide range of noise sources including:

- aircraft, road and rail transport
- industrial and military operations, industrial equipment (compressors, pumps)
- commercial premises such as pubs, hotels, discotheques and music clubs
- consumer goods, appliances and garden equipment
- recreational activities such as shooting, gardening, motorboats
- residential noise such as televisions and stereos, slamming doors, loud voices and barking dogs.

As shown in Figure 8, the sources that contribute the most to environmental noise are generally transportation noise sources, particularly road traffic and aircraft noise. Road traffic contributed an estimated 73 per cent of noise followed by aircraft at an estimated 17 per cent.

Noise is a local issue however, and the source of noise of greatest concern in a particular environment may be commercial premises such as hotels or noise generated by neighbours. There is emerging interest in identifying the contribution of individual noise sources to the larger community noise environment as seen in 'noise mapping', which is becoming increasingly common in Europe. Noise maps are colour-coded maps showing noise levels from either individuals or collective noise sources. Computer systems for noise mapping have a combination of noise propagation calculation capacity with a mapping and scheme editing facility. They can process geo-referenced, three-dimensional input data, usually associated with Geographical Information Systems.

Noise mapping may also be useful in Australia, particularly where residential growth, or significant changes to noise sources such as transportation corridors or industrial activities, are expected. It is useful for consultations with the public or planning new developments.

Road traffic noise

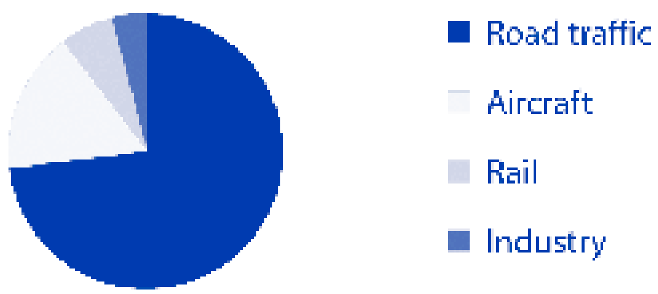
Road traffic noise depends on the amount of traffic, traffic speed, relative amount of truck, bus, car and motorbike traffic, and distance from the road to the receiver. Vehicle engine operations and air turbulence and friction between road surface treatment and vehicle tyres also contribute to noise generation from traffic (WHO, 1999). The 1998 Brisbane Community Noise Survey found that road transport noise was the noise source of greatest concern to Brisbane residents, with 35 per cent of respondents claiming to be 'seriously affected' by noise from light vehicles and 25 per cent by heavy vehicles (Brisbane City Council, 2003).

Brown and Bullen (2003) concluded that 8 per cent to 20 per cent of dwellings in Australian capital cities (excluding Canberra and Darwin) are exposed to levels above 63 dB and 5 per cent to 11 per cent of dwellings above 68 dB, Figure 9 shows results of their study on the exposure of Australian city populations to road traffic noise using 1997–98 data. 200 random locations were chosen to determine traffic noise exposures in major capital cities. Sydney had a higher percentage of the population exposed to traffic noise levels measured at levels between 55 dB(A) and 65 dB(A) $L_{Aeq,24h}$. At levels above 65 dB(A), all surveyed cities shared similar results. These levels of noise are considerably higher than those recommended by a WHO expert task force (Berglund et al., 1999) as necessary to protect against annoyance and sleep disturbance.

There has been an increase throughout the nineties in vehicle kilometres travelled. The Australian Bureau of Statistics Survey of Motor Vehicle Use (1 August 1998 to 1999) found vehicles registered for road use travelled 177 635 million kilometres; an increase of 3 per cent from the previous year. Passenger vehicles represented 80 per cent of all vehicles on the road and accounted for 78 per cent (137 885 million kilometres) of total distance travelled in Australia (Australian Bureau of Statistics, 2000).

Freight-carrying vehicles contributed 21 per cent (36 631 million kilometres); buses 1 per cent (1843 million kilometres); motor cycles 1 per cent (1003 million kilometres); while non-freight-carrying trucks travelled 274 million kilometres. From previous years, Australian freight vehicle travel increased by 5 per cent in kilometres travelled and

Figure 8. Contributors to environmental noise in Australia



(Adapted from EPANSW 1993, *NSW State of the Environment 1993*)

11 per cent in the total tonnes carried, while rigid and articulated trucks accounted for 92 per cent of all goods carried (Australian Bureau of Statistics, 2000).

Given the increased traffic and freight volume, traffic movements and extended traffic hours, it is likely that environmental noise levels in capital cities have further increased since the 1998 data were collected.

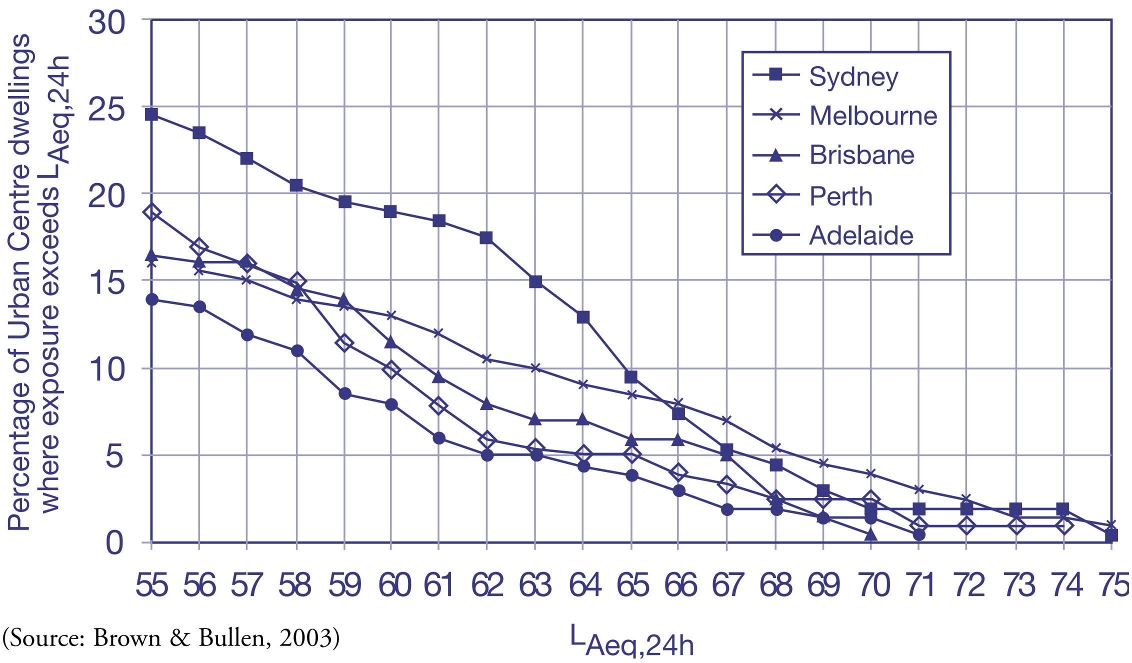
Aircraft noise

In the last three decades, Australia has seen a significant increase in aircraft numbers and movements. In the last decade, the phase-out of older, noisier aircraft has reduced noise exposure to communities under flight paths. However, as with road traffic, the increase in aircraft and aircraft movements, as seen in Figure 10, has resulted in the continued impact of aircraft noise, particularly on communities close to airports and under flight paths. Twenty-three per cent of respondents claimed to be seriously affected by aircraft noise in the 1998 Brisbane Community Noise Survey (Brisbane City Council, 2003).

In Australia, Sydney's Kingsford-Smith airport has seen the greatest impact for increased flight movements (AirServices Australia web site). Cargo (freight and mail) carriage to and from Australia rose at an even faster rate than passengers, from 97 900 tonnes in 1977–78 to 669 200 tonnes in 1997–98, to achieve an annual average growth of 10.1 per cent. A high percentage of those freight movements would be directed to capital cities. However freight movements and the growth of other aviation activities (for example, charter, training, acrobatics, agriculture) are likely to have had an impact in rural areas where increased traffic and noise in quieter environments may have a disproportionately more noticeable effect on the population.

National and international trends suggest increasing passenger and freight movements and expanded

Figure 9. Select Australian city road traffic noise exposures



(Source: Brown & Bullen, 2003)

traffic to regional and capital city airports. This suggests greater attention needs to be paid to planning for increased movements at existing and planned airports. One strategy would be to expand buffer zones around airports. Another strategy would be for local and state governments to give greater consideration to the placement, acoustic considerations and design of new residential developments, schools, and public facilities in areas close to airports and military bases.

Rail traffic noise

Rail noise is generated from rolling car operation, noise from locomotive engines, horns and whistles, and switching and shunting operations in rail yards.

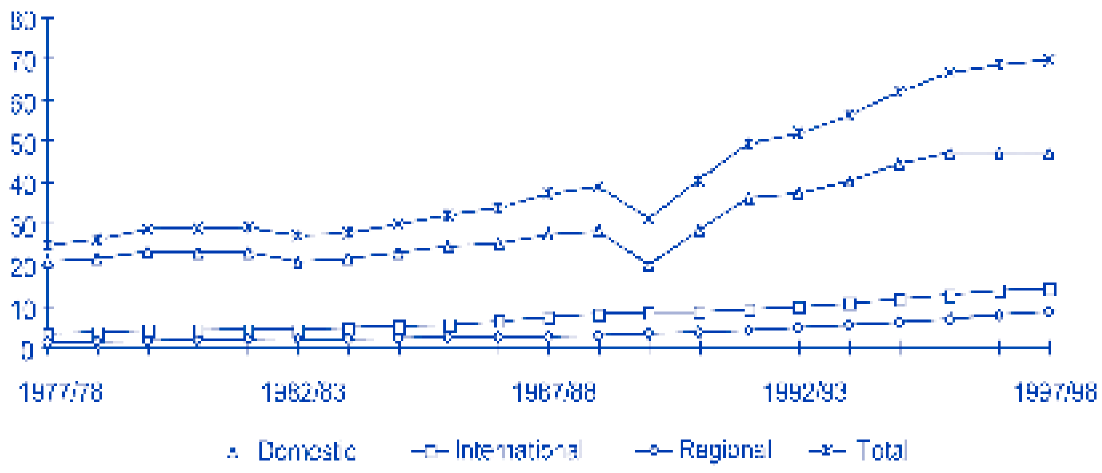
Rail car braking devices can produce a high-frequency, high-level screech that can reach peak levels of 120 dB at a distance of 100 feet which translates to levels as high as 138 or 140 dB at the railroad worker's ear (Suter, 1991).

Rail traffic contributes less to the overall noise environment compared to road and aircraft movements. As a noise source, rail traffic has been found to be less annoying to the general community than other forms of transport. However, this may reflect the limited population exposure to rail compared to other transport modes as well as the decreasing importance of rail. According to Commonwealth Bureau of Transport Economics, rail accounts for less than 5 per cent of the non-urban passenger market.

Major national, state and private infrastructure investments and activities to increase rail infrastructure, passenger traffic and freight movements are likely to result in an expanded rail network in the next two decades. This may change the contribution of rail to environmental noise and community impacts.

Very-high-speed trains are envisioned to connect Brisbane, Sydney and Melbourne with the first proposed link between Canberra and Sydney. Given

Figure 10. Passenger movements (millions) on flights, 1977–98



(Source: AirServices Australia web site, 2000) the relatively low levels of background noise in some of those areas at present, the community along some routes will experience a greater impact from the introduction of new noise sources than other communities already affected by noise. This will be further exacerbated by the higher levels of noise generated by high speed rail through wheel-track contact, brakes, rail car connections, wind resistance and turbulence. It is expected that the rapid onset of noise from a rapidly approaching train can be more annoying (US Federal Highway Administration, 1998).

Industrial noise

Control of industry noise affecting communities is the province of local government and state environment protection agencies. The proximity of industrial sites to residential areas is a function of planning controls. Councils have caused problems by rezoning land near old established industries, still attracting unaware buyers when displayed on quiet weekends. Nonetheless, site design elements can reduce noise intrusion in surrounding communities.

In many communities, historical planning and siting decisions have resulted in residents within close proximity of industrial operations to suffer significant environmental and health impacts.

The control of environmental noise from industry is a function of company decisions regarding equipment selection and operations, operating hours and licences for noise control activities under local or state environment and planning laws. Planning and environmental policy in Victoria, New South Wales, Queensland, South Australian and Western Australia establish noise limits for different industries and guidelines for noise measurements and consideration in environmental impact assessment. City and local government ordinances may govern smaller industry noise emissions.

The control of construction noise may be required in environment agency licences or permits. Local ordinances or operation restrictions may also be required if construction activities will take place in an area of sensitive use, such as schools or hospital zones.

Noise from industrial plants and construction sites can have a significant impact on neighbours and the surrounding community. The impact can be particularly severe where industry operates 24 hours such as in some manufacturing industries, power plants, and mining operations.

In the 1997 State of the Environment report, the New South Wales Environment Protection Authority identified key industrial areas for environmental noise issues. Larger industries regulated under the Protection of the Environment Operations Act would be required to meet environment conditions stipulated in their licence. The inclusion of similar information in State of the Environment reporting would assist in defining the industry contribution to environmental noise levels, particularly in rural areas where intensive agricultural activities and machinery and extractive industry may significantly affect communities.

Limited information is available regarding the impact of industry on environmental noise levels and surrounding communities.

Neighbourhood noise

Within the neighbourhood environment, in addition to road and air traffic, a number of noise sources are raised in surveys of community annoyance. These include a range of activities from the neighbour's barking dog, stereo or car alarm to local government garbage collection (see Figure 11).

Certain household equipment, such as vacuum cleaners, kitchen appliances, and home stereos have been, and continue to be, noisemakers, although they make a small contribution to the noise environment. Added to this list would be yard maintenance equipment, such as lawn mowers, leaf blowers and 'whipper snippers', which can create problems with neighbours.

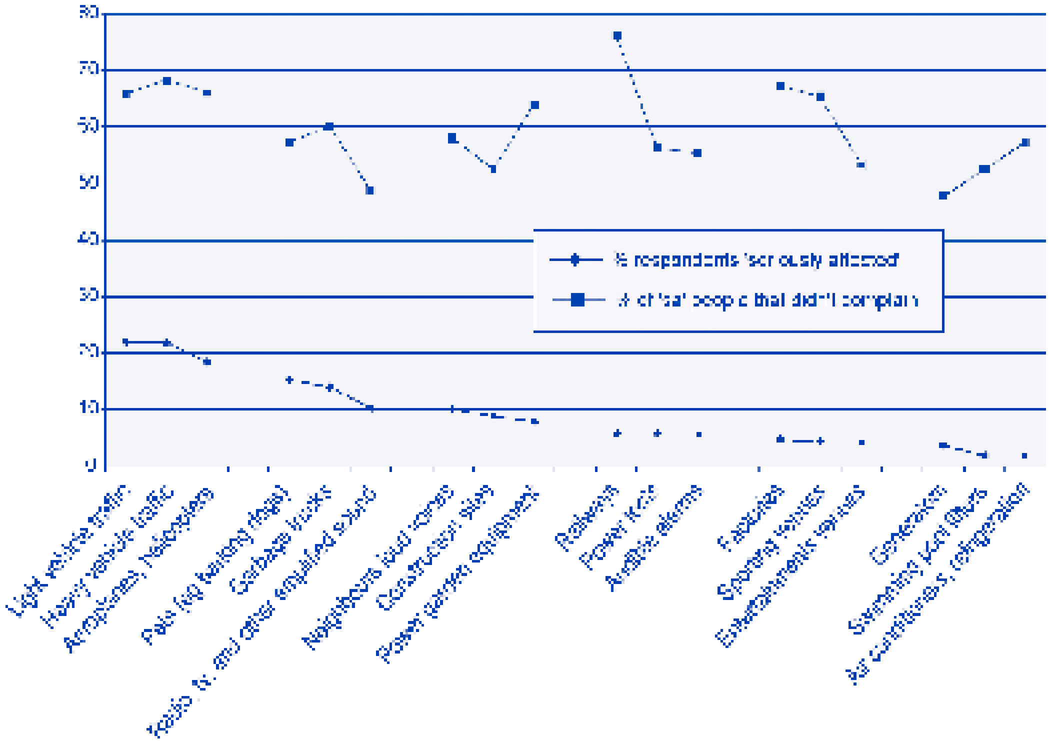
The gasoline-powered leaf blower is reported to have an average A-weighted sound level at the operator's position of 103.6 dB, and maximum levels of 110–l12 dB. In an extensive review of non-occupational noise exposures, Davies et al. (1985) report that the manufacturers of household devices have been reluctant to release sound level information. Consequently, it could be difficult to assess the magnitude of the problem and the extent to which noise levels are increasing or decreasing (Suter, 1991).

Power tools are another noise source of concern both for those using them and those nearby. A recent review of power drills by the Australian Consumers Association, and published in *Choice* (July 2000), included noise levels ranging from 93 dB to 115 dB. The National Acoustics Laboratory has recently embarked on assembling a database on noise emission test results based on decades of noise testing data and experience. This may prove a useful foundation for further community education. Farm Safe Australia has developed a similar database of noise emissions from agricultural equipment (personal communication, Warwick Williams, National Acoustic Laboratories, 2000).

There is anecdotal evidence that awareness of noise is not considered in consumer purchasing decisions (personal communications, Norm Crothers, Australian Consumers Association, 2002). Greater awareness of the noise emissions from equipment and the impact they have on neighbours might be the focus of community education by local government and state health and environment agencies. This might also be done in conjunction with a larger hearing conservation education program for children and the general public.

In October 1999 the Resource Management and Planning Appeal Tribunal in Launceston issued orders preventing the use of a heat pump 'so as to

Figure 11. Annoyance results from Brisbane Noise Survey



(Adapted from Duhs T et al 1989. *Brisbane Noise Survey 1986-1988*) produce a sound pressure level of over 10 dB(A) (measured in accordance with AS 1055-1997), above ambient (background) noise'. This application was pursuant to Section 48 of the *Environmental Management and Pollution Control Act 1994*, which caused an environmental nuisance contrary to Section 53.

Many state and local government requirements restrict certain activities and equipment operation within certain hours. Yet recognition of these restrictions appears to be low.

Recreational noise

Noise generated through entertainment activities seems to be increasing and may affect community environmental noise levels as well as having an impact on patrons and employees.

Noise from restaurants, hotels, entertainment clubs and departing customers has been a source of complaints to local government in a number of areas. Research from noise measurements at discotheques and concerts reported measured sound levels above 100 dB (Suter, 1991).

In entertainment venues, efforts taken to reduce noise exposure of workers can have added public health benefits by reducing noise exposures of patrons. The WorkSafe Western Australia Commission developed and published a code of practice for control of noise in the music entertainment industry in July 1999 (WorkSafe WA, 1999). Some consideration may need to be given to educate and encourage local government and licensing agencies to restrict noise levels in venues for the express purpose of protecting public health.

One of the loudest sources of recreational noise is sport shooting, where peak sound pressure levels at the ear can range from about 144 dB up to more than 170 dB (Suter, 1991). Shooting club rules usually make it compulsory to wear hearing protection. Those participating in recreational shooting activities as well as attending concerts and discotheques may be exposed to noise levels that can result in permanent hearing damage. Limited information is available regarding non-auditory health effects that may be related to excessive recreational noise in Australia.

International best practice noise management

The management of noise, like many other environmental and occupational health hazards involves three options:

- elimination or reduction of noise at the source
- elimination or disruption of the transmission path
- isolation or insulation of the receiver from the noise.

Combinations of these three options represent much of international 'best practice'. The legislation, regulation and policy frameworks for noise management differ substantially internationally.

Appendix B identifies frameworks in a number of countries discussed in the international literature.

As with other countries, the regulatory management of noise in Australia has evolved in a haphazard way. It operates in a fragmented fashion across different levels of governments and quasi-government bodies as illustrated below.

International noise control

The reduction of noise generation at the source has been an issue of significant policy and technical interest since the 1970s. This approach has garnered many of the international successes in noise reduction, primarily from transportation sources. However, many of the gains resulting from reduced noise by individual transportation noise sources have been lost due to increased numbers and movements of vehicles and aircraft and extended traffic hours through the day, evening and night.

Previous successes in reduced noise generation have prompted governments and industry to seek further noise generation reductions while also considering a wider range of technical and policy noise management measures. Some general themes are discussed below.

Aircraft noise

International requirements to reduce the impact of aircraft operations on the general population include:

- adherence to the International Civil Aviation Organization phase-out of older aircraft that do not meet current noise emissions standards or have not been fitted with 'hush kits'
- aircraft operation curfews and penalty charges (which support further community insulation projects)
- use of noise measurement contours to inform insulation and residential construction planning permission.

Limited international information was found regarding the need or efforts to control ground-running operations at airports internationally.

Many countries in the European Union integrate noise monitoring activities with community noise mapping. This information is used to support planning and design decisions to reduce community noise exposures.

Community groups can force governments to improve legislation. In the United States, increasing numbers of community groups are being organised to oppose airport expansions and construction of residential areas in close proximity to airports. Recent federal legislation requires the Federal Aviation Administration to become more actively involved in long-term airport planning around the country.

However, there is also growing concern about increasing regional hub operations and flight path impacts in more rural and national park areas. Increasing flights and community concern has directed attention to the impact of introducing airport operations and aircraft noise in areas with previously low background noise levels. The impact is far greater in areas with lower background noise levels. This may require further attention in Australia should rural air operations expand significantly or tourist air operations expand to areas where quiet amenity benefits are highly valued.

Given the increased annoyance and adverse health effects of increasing noise in the community, future airport location decisions to account for this increased impact is one of a number of factors influencing transport infrastructure.

Road traffic noise

Best practice to reduce vehicle and road traffic noise focuses on noise sources: motor vehicle engine, tyres and road surfaces as well as controlling internal noise environments for passengers through active noise control. Efforts also focus on reducing noise exposure to the community at large and integration of transport planning and environmental concerns including noise.

Since 1972, European Community controls reduced noise emission limits for passenger vehicles, urban bus and heavy lorries from levels of 82 dB(A), 89 dB(A) and 91 dB(A) to 74 dB(A), 78 dB(A), and 80 dB(A), respectively. Noise emissions have also been reduced from motorcycles.

The noise of trucks in Germany dominates road traffic noise if the number of trucks exceeds 4 per cent of total vehicle traffic. It was found 10–20 per cent of residential neighbourhood road traffic was trucks, suggesting the greatest noise reduction gains may be made by changing truck size and reducing truck traffic on residential streets.

In Austria, financial incentives are encouraging the transport industry to purchase low polluting, low noise vehicles. This investment by the industry is further encouraged by restricting access to night-time traffic in residential areas to low-noise vehicles (Newman & Kenworthy, 1999).

As the United States and other large car markets require noise reduction measures, some cars imported to Australia from manufacturers serving these markets may already be quieter and comply with these requirements. However, national efforts directed at ensuring imported vehicles meet international best practice noise emission standards will assist.

Traffic noise barriers have proven to be the method of choice to reduce noise exposure to nearby residential areas. A highway noise barrier prevents sound from reaching the listener by the direct path, but some sound can still reach the listener by diffraction, scattering from air turbulence or refraction (bending over the barrier by atmospheric wind or temperature gradients) (Rosenberg, 1997). The best that can be expected is a 5 to 10 dB(A) decrease in the noise level. Where this is insufficient, road tunnels are being used increasingly. However, the main drawback is that they are expensive and difficulties can arise in providing efficient ventilation for the safety of users and the discharging of the tunnel exhaust.

Rail noise

In 1998, the European Rail Research Institute undertook numerous rail research projects identified in the European Union 4th Research and Technical Development Framework Program and the International Union of Railways Rail Plan. The European Union has supported a number of projects to reduce rail noise including Silent Freight, Silent Track, Eurosabot and Basnoise. These projects confirmed that there was considerable scope for lower noise creation at source through the adoption of a number of measures, including reducing wheel and rail roughness, developing new types of brake blocks, new rail fastening systems, and shape-optimised wheels etc.

Many European countries also consider rail traffic noise in planning decisions and insulation funding projects in older residential areas.

Industry noise

In 1975, the European Commission determined machine noise should be represented by sound power level in dB(A). A series of European Commission directives in the 1980s and 1990s established noise limits on a range of industrial and construction equipment including excavation equipment, loaders, cranes, hydraulic lifters, mobile compressors and pumps. In December 1996, the European directive 89/514/EEC prescribed the limits and measuring methods for certain classes of equipment. Recent analysis of the changes in noise levels since testing, have found reductions in maximum noise emission to within limits soon to become effective.

One example, hydraulic excavators as tested in accordance with 89/514/EEC, found all machines tested prior to these requirements were noisier than machines tested since the directive went into effect. This suggests greater work can be done in European and in other countries to reduce noise generation by industrial equipment.

While progress has been made in reducing noise generation from manufacturing and physical plant, some noise emissions are inevitable. In those instances, facility design and operational planning is required to reduce environmental noise impacts. Planning also ensures residential areas will be located to minimise impact and where the impact is unavoidable, planning measures can establish conditions to reduce the impact on residents. Industrial activities also are included in many of the European noise monitoring programs.

Residential noise

Annoyance studies have found the loud voices of neighbours, their parties and stereo equipment, though not as highly ranked as transportation sources, are of universal concern. In addition to the need for building and structural remedies and insulation to address noise in residential apartment buildings, there appears to be universal concern about the increasing sound power levels of stereo systems, appliances and power tools.

Other noise sources of concern in many residential areas include air conditioners and swimming pool and spa pumps. The low frequency component of these noise sources is thought to contribute to annoyance.

Testing consumer appliances and equipment has prompted the introduction of noise labelling and incentives to reduce equipment noise, measures that are already providing benefits. Further information about test results in European and other markets and examining their implications for the Australian markets may be warranted.

Latest developments

In May 2002 the European Noise Directive became European law after many years of discussions and negotiations. The European Noise Directive requires that all large communities and major transportation routes will have to be noise mapped every five years. Action plans will further study problem areas and make recommendations for improvements.

The noise maps will be based upon L_{den}, the L_{eq} for day, evening and night. As the L_{den} has not been included in European standards to date, all regulations will need to be amended.

The European Noise Directive has a cousin named Harmonoise, the Harmonised Accurate and Reliable Method, for the European Union Directive on the Assessment and Management of Environmental Noise. Harmonoise will ultimately replace all national European noise prediction standards with one, uniform set of standards for road, rail and industry noise (Berndt, 2003).

At the General Assembly of I-INCE (International Noise Control Engineering) held in Fort Lauderdale, December 1999, it was decided to commence a large-scale, internationally-coordinated program to assess the effectiveness of noise control and exposure policies, and guidelines and regulations around the world. Technical Study Group, TSG3 'Noise Policies and Regulations' met first in Nice in August 2000 and decided the work plan to assemble and catalogue the noise regulations and standards of each participating country as the first phase of the study.

The second TSG3 meeting was held in August 2001 in Den Haag, Netherlands. The tasks of related I-INCE TSGs were identified as:

- TSG5 'Noise as a Global Policy Issue' to study the 'Global Policy' regarding environmental noise and the relationships of tasks and responsibility between international organisations and each country. Not only environmental/community noise, but also occupational noise and consumer product noise will be included in the investigation.
- TSG6 'Community Noise' is to take an international approach to strategies for managing exposure to environmental noise, and to make recommendations for improving

current practices. The emphasis will be on developing an updated 'Environmental Impact Analysis Process', and will also address such social aspects as dose–response relationships, noise exposure criteria, and community involvement in environmental decision making.

Australian noise control

Australian activities to reduce noise and noise impacts are summarised in Table 4.

Aircraft noise

At the Commonwealth level, Australia amended regulations in 1991 to implement the International Civil Aviation Organisation phase-out operations of aircraft that did not meet the noise standards of Chapter 3, Volume 1, Annex 16. Aircraft that do not meet these requirements must be phased out of use by the 25th anniversary of their first certificate of airworthiness, or 31 March 2002, which ever comes first.

Flight activities and aircraft curfews are the responsibility of AirServices Australia, individual airport authorities, and often, state and local government bodies operating airports.

Airport operations on the ground also generate noise that may have an impact on environmental noise levels. The *Airports Act 1996* established environmental protection regulations to govern ground running issues including noise and other environmental issues. But this is only required of the 21 airports governed under the Act and need not be complied with by the other 239 airports in Australia. Individual airport authorities and operators may seek to adopt these environmental management practices as 'best practice' models to reduce the impact on public health of ground running environmental noise and other aircraft operations.

The Australian Government has introduced a range of measures to reduce or ameliorate noise levels associated with the Kingsford-Smith Airport in Sydney. These include expenditures of over $370 million on home/land acquisition and on insulating houses, schools, childcare centres, nursing homes, hospitals and churches.

In the 2000–01 budget, the Australian Government allocated more than $60 million over the next three years to initiate a similar project in Adelaide.

Standards Australia's AS 2021 stipulates acoustical insulation requirements in residential dwellings near airports. The extent to which this is integrated into council planning and building requirements is not clear.

Notwithstanding the cost efficiencies, a more equitable distribution of noise insulation funds in the vicinity of airports might be based on population measures, project flight movement increases and might seek to influence local government planning and zoning to address resident concerns from aircraft noise.

Road traffic

There are three Australian Design Rules that apply to noise from vehicles:

- ADR 28/01 defines the limits on external noise generated from motor vehicles (cars, trucks and buses)
- ADR 39/00 defines the limits on external noise emitted from motor cycles
- ADR 56/00 defines the limits on external noise emitted from mopeds.

The Australian Trucking Association is also reported to be developing a code of practice on the use of engine brakes. In the interim, the National Road Transport Commission and the National Environment Protection Council are considering use of the existing stationary Australian Design Rule noise test for truck engine brake noise (National Road Transport Commission, 2000).

Table 4. Australian activities to reduce noise and noise impacts

Noise source	Type of measure	Legislative or policy	Agencies
Aircraft	Reduce aircraft noise emissions	International Civil Aviation Organisation requirements, national requirements	Aircraft manufacturers, Civil Aviation Organisation, AirServices Australia, Civil Aviation Safety Authority
	Restrict certain aircraft operation	National requirements	AirServices Australia, Civil Aviation Safety Authority
	Flight path control	National requirements, airspace control	AirServices Australia
	Aircraft movements curfews and penalties	Planning controls to restrict residential/sensitive uses close to airports/flight paths	State and local planning agencies, private/public airport authorities
	Restrict sensitive receptors through land/property purchase and buffer zones		
	Insulate residential/sensitive uses	Special Commonwealth initiative	Australian Standard, Airport Noise Insulation Project (Sydney and Adelaide)
Passenger vehicles	Reduce vehicle noise emissions	Australian Design Rules	Manufacturers, National Road Transport Commission, state transport and environment agencies
	Restrict/penalise noisy vehicles	Highway and road barriers and easements	State transport and environment agencies
	Restrict noise transmission		
Motorcycles	Reduce vehicle noise emissions	Australian Design Rules	Manufacturers and state transport and environment agencies
	Restrict/penalise noisy vehicles	Motorcycle dealers and repair shops	
	Noise emission testing and labelling		Road transport
	Restrict noise transmission	Highway barriers and easements	
Rigid trucks	Reduce vehicle noise emissions	Australian Design Rules	Manufacturers, National Road Transport Commission
Articulated trucks	Reduce exhaust brake noise	Australian Design Rules	Manufacturers, National Road Transport Commission
	Restrict/penalise noisy vehicles	State road designations	State road authorities, local government
	Truck route restrictions	Local ordinance	
	Restrict noise transmission	Highway barriers and easements	State road authorities

Noise source	**Type of measure**	**Legislative or policy**	**Agencies**
Buses	Reduce vehicle noise emissions	Australian Design Rules	National Road Transport and Environment agencies
	Restrict/penalise noisy vehicles		State road authorities, local government
	Restrict noise transmission	Highway barriers and easements	State road authorities
Rail	Reduce rolling stock/wheel noise emissions	Environmental regulations/ guidelines	State transport agencies
	Reduce rail traffic in sensitive hours	Rail scheduling	State rail authorities
	Reduce noise transmission	Noise barriers and easements	State rail authorities
Industry	Reduce industry noise emissions	Environmental regulations/ guidelines	State and local government planning agencies
	Industry siting restrictions		
	Industrial plant site design	Planning regulations/ guidelines	Environment agencies, local government
	Reduce noise transmission	Best practice guidelines on equipment selection. location and facility orientation	Environment agencies, local government
		Barriers/berms	
Construction and demolition industry	Reduce noise emissions of machinery	Australian Standards, Industry standards	Manufacturers, construction industry
	Operation engineering controls	Environmental regulation, license conditions	Operators, construction management
	Establish emission limit	Environmental regulation, license conditions	State environment agencies
	Time restrictions on operations		Local government
	Site barriers		State environment agencies and local government
Residential dwellings	Reduce external noise transmission	Local planning, easements and building requirements	Building industry, developer
	Reduce external noise reception	Australian Building Code, local planning/building requirements	State and local planning agencies
	Reduce internal noise		
Consumer goods	Appliance and equipment selection	Product safety information and regulations	Consumers
	Market restrictions	Australian standards	Fair Trading
	Labelling	Australian standards	Fair Trading

The Motor Vehicle Environment Committee will be undertaking a review of noise standards during 2000–01.

However, given the slow fleet turnover in Australia, some noisier vehicles may remain on the road for another decade. If the projected expansion of vehicle traffic through early evening hours continues according to current trends, traffic noise will be a source of ever increasing concern in the general community.

While national attention is being directed at increasing long distance freight movements by rail, trucks will continue to be needed in urban areas. The road movement of freight traffic in late hours is of significant concern given the noise profile of the vehicles and the hours of freight movement. Further attention may need to be given to incentives to encourage the industry to adopt quieter, more environmentally friendly freight vehicles for urban and regional centre movements similar to policies in Europe.

Integrating noise measurement into vehicle safety inspection and registration processes for older vehicles may prove a useful avenue for controlling vehicles that are excessively noisy. This is of particular importance given the high capital costs of trucks and the length of their road life.

Some brands of high-end luxury vehicles now use internal active noise control to cancel internal operational noise. No information could be found regarding the use of active noise control to reduce external vehicle noise. If feasible, retrofit technology of this kind would have a substantial impact on current road traffic noise levels. This is of particular importance as engine noise dominates vehicle noise emission at speeds below 50 km per hour common in urban and rural centres and residential areas most likely to be concerned about road noise.

National attention is also being directed at road surface treatments and tyres that reduce noise and should be encouraged.

Transportation and town planners may need to explore freight traffic patterns, particularly in areas with increasing urban density and consider approaches such as special routing, freight traffic centres and ways to encourage more environmentally friendly freight traffic.

Traffic restrictions and traffic calming measures have generally resulted in reduced traffic noise due to changes in traffic volume and composition, road layout and surface, vehicle speed and driving style. The use of traffic calming and restrictions may require further attention to address urban noise in residential areas. There have also been efforts made to reduce noise exposures through home insulation and construction of noise barriers in select communities exposed to road traffic noise.

Standards Australia AS 3671 provides guidance on acoustic requirements in residential dwellings near roads. The National Road Transport Commission has estimated national figures on the costs of road traffic noise at $200 million to $400 million. What percentage of this figure is directed to noise exposure control is unclear. In New South Wales alone, the Road Traffic Authority spent in excess of $22 million between 1995 and 1997 in the construction of noise attenuation devices such as mounds, walls and quieter road surfacing. This also included insulation and other retrofits such as air conditioning in 1200 homes, five schools and three churches. Further work is needed to quantify these costs nationally.

Rail noise

There has been a great deal of discussion at the Commonwealth level about rail infrastructure and ways to improve rail operations in Australia. To that end, funds currently being directed at improving track and rolling stock could be invested in equipment with reduced noise generation. Limited information was found about national efforts to reduce rail traffic noise in concert with rail improvements.

New South Wales environmental requirements have given rise to a number of initiatives to reduce noise resulting from rail operations that include:

- retrofitting existing locomotives to reduce emitted noise
- upgrading existing track to continuous weld, reducing noise and vibration at track joins
- designing new bridges to reduce noise and retrofitting existing bridges with noise attenuation devices
- using quieter rolling stock in noise sensitive areas
- changing train traffic patterns to reduce signal delays and holding patterns in residential areas.

Two specific examples include $2.5 million to reduce rail noise on the Sydney Harbour Bridge from 66–99 dB(A) to 56–91 dB(A), and $5 million to modify freight trains and improve track conditions in the Hunter Valley (Environment Protection Authority, 1999).

Industry noise

State and Territory planning and regulatory regimes are generally responsible for ensuring that environmental noise arising from industry does not cause problems for residential areas and particular noise-sensitive sites such as schools, hospitals and aged care facilities.

More particularly, State and Territory government development agencies and local government zoning and planning bodies typically administer the licensing and siting controls applicable to significant noise emitting industries. For smaller industries, local government is often solely responsible for setting the conditions of operation, and environmental noise issues may not always be adequately considered.

Noise emissions, like other environmental emissions, may also be licensed or regulated under relevant State and Territory environmental statutes. For instance, in New South Wales, noise pollution, like air and water pollution, is regulated under the *Protection of the Environment Operations Act 1997.*

Implementation of noise management measures in the planning stages rather than after a problem arises is obviously preferable. In recent years planning legislation has adopted a performance-based approach that requires development proposals to demonstrate a capacity to achieve specific noise performance criteria. This means that whereas in the past regulators could prescriptively prohibit development and prescribe buffer zones between incompatible uses, they can now only prescribe preferred uses and outcomes to be achieved. Under this approach to planning the adoption and implementation of satisfactory health-based environmental noise criteria, to effectively assess development proposals, is essential.

Measures used to address industry noise problems include:

- appropriate siting
- use of buffers and other noise mitigation measures
- good design of industrial premises and specific equipment
- controls on the timing of noise-producing activities.

A measure being increasingly used to address environmental noise problems in Victoria, Queensland and New South Wales is a pollution reduction program. Under current pollution reduction programs incorporated into licenses in New South Wales, the following facilities have managed significant noise reductions:

- TRW Forging has achieved noise levels below background, at a cost of $3.8 million
- Visy Paper has spent $1.375 million to reduce noise
- CSR Hume has achieved noise levels below background
- Bega Cooperative has achieved a 9 dB(A) reduction in noise levels, at a cost of $100 000.

Agricultural activities may also generate significant environmental noise. For example, frost-fans to reduce crop damage have come into wider use in some areas and are having an adverse impact on communities not previously subject to high levels of evening and night-time noise. In some instances agricultural equipment is subject to planning or environmental regulatory controls.

Noise from extractive industries is a significant issue, particularly for mines that operate 24 hours a day. Noise and vibration from blasting and machinery operations can be a significant issue for nearby communities.

State of the Environment reporting provides a valuable framework for noise reporting in the context of human settlement and industrial activities. A cursory review of State and Territory environmental reports revealed that while noise is mentioned, few specific examples are provided of monitoring measures or noise reduction measures. South Australia, New South Wales and Brisbane City Council detailed noise issues within their State of the Environment reports for 1997 and 1998. This may be an area for improvement on the part of environmental agencies. The 1997 New South Wales State of the Environment report included a map of industries for which noise is a problem, such as extractive industries and some manufacturing industry. This approach may be a useful adjunct to national reporting measures such as the National Pollutant Inventory.

Australian Standard AS 1055 provides general guidance on the description and measurement of environmental noise. AS 2436 Guide to Noise Control on Construction, Maintenance and Demolition Sites includes guidance on identifying noise sources, sound measurement and assessment of planning measures for noise control and the monitoring of effectiveness. The Australian and New Zealand standard AS/NZS 2107 recommends sound levels and reverberation times for building interiors.

Education and awareness building for effective environmental noise management is an important part of an integrated strategy to manage the impact of industrial noise. Various government bodies, such as the New South Wales Environment Protection Authority and Brisbane City Council, have produced environmental guidelines for industrial activities. These guidelines include practical advice on how to meet noise limits, as well as best practice environmental management suggestions.

Machinery is a common source of environmental noise. The use of low-noise machinery should be further encouraged and additional measures taken to educate governments, industry and consumers on the benefits of choosing quieter products.

The Education Department of Western Australia has developed a Noise Control Manual for Schools, to assist teachers and staff to reduce noise levels through 'buying quiet guidelines' and reducing noise arising from existing equipment. Table 5 is an example of the detail provided in the Western Australian 'Buying Quiet' guidelines. Noise levels produced by different equipment are included in the manual. Adoption of this and similar information by State and Territory and local governments is expected to assist in reducing environmental noise. An added benefit may be increased market pressure on manufacturers and distributors to make available quieter equipment.

Table 5. Example from the Buying Quite Guidelines

Honda model number	Muffler	Noise level dB(A)
G200	Standard	91
G200	Silent	88
G300	Standard	92
G300	Silent	89
G400K1	Standard	95
G400K1	Silent	93
GX390K1	Standard	94
GX390K1	Silent	90

(Source: Department of Education WA, 2003)

In the United States and Australia, unlike Europe, limited national attention has been directed to noise labelling of consumer goods, educating consumers about noise issues or reducing the noise emissions of domestic appliances. Noise labelling (similar to

EnergyStar, recycle logo, etc) has proven effective in Europe in increasing consumer pressure on manufacturers to develop products with lower noise emissions.

In New South Wales, the revised Protection of the Environment Operations (Noise Control) Regulation 2000 requires the labelling of domestic equipment, including grass cutting machines, chainsaws, domestic air conditioners, mobile air compressors, pavement breakers, and mobile garbage compacters.

Residential noise

The Building Code of Australia, and some local government planning laws, specify sound reduction construction standards for walls and floors in residential apartment buildings. The Building Code of Australia is managed by the Australia Building Codes Board to encourage national consistency based on minimum code safety and health requirements. The current Building Code of Australia requires international noise control in residential apartment buildings and hotel and motel buildings. Relevant Australian Standards are AS 2021 and AS 2107.

Recent CSIRO research has called into question the adequacy of current building requirements; research which has been supported by acoustic consultants. They are reported to be substandard given current interior design trends like removing carpets and using wood and metal surfaces. These current requirements also only govern certain building classes for internal noise generation and do not consider the external noise environment as an influence on the internal environment (personal communication, Peter Knowland, Australian Association of Acoustics Consultants, 2000).

The City of Sydney Council commissioned Arup Acoustics to research internal noise in residential buildings. The results of the research have prompted the Council to include acoustic privacy conditions in the development control plan.

Floors are required to have 'impact isolation class' and 'field sound transmission class' of no less than 55 (roughly 55 dB sound attenuation) between wet areas and habitable rooms on other floors (City of Sydney, 1996).

Recent Sydney newspaper articles document an increase in noise complaints related to contemporary construction. In one instance, building inspectors, found basic building requirements, such as the fire code, were not met. This suggests both private third party inspectors and local government building inspectors may need to randomly spot-check construction sites to ensure compliance with fundamental building requirements. It is unclear to what extent residential buildings and developers comply or even exceed current Building Code of Australia acoustic requirements. The Australian Acoustical Consultants Association has prepared a report to the Australian Building Control Board documenting concerns about acoustic privacy and recommendations to resolve these issues.

An alternative approach being proposed by acoustic consultants is a star rating system for new residential construction to which consumers may respond, particularly given recent complaints.

Residents concerned about neighbourhood noise are directed by legislation and public education materials to a broad range of different organisations depending on the noise source of concern. Police respond to complaints about car alarms, loud parties and other disputes, and local councils respond to calls about barking dogs. In some instances, complaints about public hotels and entertainment venues are directed to the Liquor Licensing Commission. Environment agencies and local government are the contact for industrial noise while transportation and construction noise complaints may be directed to AirServices Australia, individual airports, road or rail authorities and their agents performing construction activities.

Environmental noise is a localised issue but it affects a broad range of localities as a result of decisions made beyond that locality and outside of the control of the affected parties. It therefore may be reasonable to consider if a more streamlined approach can be used to respond to community noise issues and educating the general public about things they can do to reduce environmental noise they generate and can control.

Planning controls

The principles of land use planning involve separation of incompatible land uses such as residential and industrial. However, changes in land use, previous poor practices and rapid changes in transport, urban and rural industrial development and environmental noise sources have resulted in some high noise levels in areas that would now be considered unacceptable.

Standards Australia has developed AS 2021 for noise attenuation within ANEF contours for local government to use and adopt in zoning, planning and development control plans. It is unclear how extensively councils have adopted this standard. AS 3671 provides guidance on acoustic requirements in residential dwellings near roads. Increased traffic increases the need for local government and developers to ensure that all available methods are used to reduce noise through noise source generation controls and transmission controls (barriers, increased easements, planning measures and traffic calming). There is also an increased need to reduce the reception of noise in homes, public buildings and sensitive use structures such as hospitals and places of worship.

Major infrastructure projects and new developments require environmental impact statements that often include assessment of noise impacts. Noise impacts might then be assessed against particular government environmental or planning guidelines at the Commonwealth, State or local level depending on the location, activity and sensitivity of involved issues. Health end-points such as sleep disturbance, interference with speech and communication, annoyance and hearing impairments linked to noise should be considered in health impact assessments. As further research provides insight into the links between noise and sensitive populations, additional focus on health impact assessment for these populations is warranted.

One planning challenge that presents itself is the limited community environmental monitoring or trend data available against which to measure project proposals. One avenue for addressing this is noise mapping.

Noise mapping has been widely adopted in Europe. In Great Britain it is being proposed as part of a national strategy to monitor and explain the noise environment and test and integrate the impact of local strategies and management options.

A pilot project to measure traffic noise using traffic project data compared with measurement data has recently been completed in two regional areas by the New South Wales Roads Traffic Authority. It is hoped that this project will provide useful information for further noise projections based on traffic movement data and road characteristics. This would also provide useful data to inform state, regional and local planning decisions related to traffic volume, measured noise backgrounds and appropriate planning controls to reduce impact.

As part of a development application noise-related activities are often required to meet a goal of ambient noise measured at levels +1, 2, or 5 dB(A) above background, as measured by the proponent. This approach, coupled with fragmented regulation of noise sources and proliferation of sources has resulted in 'creeping ambient' noise in urban areas. The accuracy of background noise measures has been questioned given that over-reporting of background noise provides greater latitude for noise generation. Recent approaches (South Australian Department of Environment and Conservation, 2002) include capping noise levels by defining noise goals adjusted to the amenity of a locality. The proposed policy in South Australia stipulates that developments be designed to achieve a noise level that is 5 dB(A) below the goal.

Responding to environmental noise in Australia

Community concern over environmental noise is growing, particularly as a result of increasing urban density, significant shifts in inner city land use and growing residential use of rezoned industrial areas.

While environmental noise may have previously been largely viewed as an amenity issue and not associated with significant public health consequences, this report indicates that this is unlikely to be the case. Indeed, it would now appear prudent to view environmental noise as a growing public health problem, and one that deserves more attention than it currently receives.

The following recommendations are presented as possible measures to address the non-auditory health impacts of environmental noise. They are not considered to be exhaustive and may, in some instances, be subject to minor changes in the light of further collaboration with relevant sectors. The associated Table 6 links key recommendations with the agencies responsible for their implementation, and ascribes each action a priority.

This work was commissioned by the enHealth Council, the Environmental Health Advisory Sub-committee of the National Public Health Partnership Group, and it is these bodies to which the recommendations are directed, for consideration and appropriate action. However, others with an interest in this matter may choose to respond to the recommendations in their own right.

Recommendations

1. Recognise environmental noise as a potential health concern

Suggested actions:

- Promote awareness of the non-auditory impacts of environmental noise on health, in particular, the need for State and Territory and Australian Government agencies to include noise as an important environmental health issue for strategic and local planning.
- adopt the WHO Guidelines for Community Noise 1999 as a primary reference for environmental noise levels below which no health effects are expected.

2. Promote measures to reduce environmental noise and its health impacts

Suggested actions:

- Review noise arising from transportation, including noise criteria for areas adjacent to transport infrastructure.
- Promote noise mitigation measures (for example, noise insulation in residential buildings) and the use of licensing controls to limit noise impacts.
- Develop a national environmental noise education program, which could be supplemented with additional State-specific campaigns.
- Ensure internal noise standards and recommended controls adequately address the impact of external noise sources (particularly in industrial and heavily trafficked areas), and internal noise transmission in multi-unit developments.
- Examine measures to reduce noise generated by consumer goods, including amending consumer protection legislation and policies.
- Consider the need for a mandatory national standard for noise labelling of equipment.
- Amend consumer protection and environmental legislation regarding machinery and equipment noise.

3. Address environmental noise in planning and development activities

Suggested actions:

- Include environmental noise in the Health Impact Assessment of proposed developments, where warranted.
- Review current noise control practices and how to further integrate noise control into planning

processes, for all levels of government (with attention to future noise research findings).

- Determine baseline environmental noise levels to inform planning actions (including background noise, equivalent continuous noise and other percentile noise levels etc). Where appropriate, proponents should be required to conduct such monitoring.
- Foster national consistency regarding:
  - guidelines on how to minimise or prevent environmental noise arising from developments (that is, appropriate attention to layout, design and construction)
  - limiting noise arising from major sources (consider European Union directives)
  - methods to set noise limits where standard limits are inappropriate.

4. Foster research on the non-auditory health impacts of noise

Research agenda should include:

- A national noise survey.
- Effects on learning performance in children, sleep disturbance, annoyance and cardiovascular health and mental wellbeing.
- Identification of populations most sensitive to noise and vulnerable to non-auditory health effects (findings should inform environmental, planning and health policies).
- Given the prevalence of cardiovascular disease and its associated cost to society further research appears prudent to examine noise as a risk factor (the link between environmental noise and high blood pressure – hypertension – and ischaemic heart disease, as suggested by cross-sectional literature, is by no means conclusive at the moment).
- Evaluation of noise reduction schemes on community health (intervention studies).
- Longitudinal studies, dose–response studies.
- Appropriate attention to study design, sampling and sample sizes, control of confounders, investigation of factors modifying the effects, precise exposure estimation and precise measurement of outcomes.

Table 6. Priority actions for addressing non-auditory health impacts of environmental noise

Issue	Action	Responsibility	Priority
Noise policy	Formally acknowledge there is sufficient evidence to establish a link between noise and health and to warrant further consideration of the issue. Until more noise policy conclusive research is completed the WHO *Guidelines for Community Noise* 1999 can be considered as the primary reference for national environmental noise goals	State and Territory health agencies	High
	Legislative review and review adequacy of existing policy frameworks to address health impacts of environmental noise	enHealth Council/DEST, State and Territory health agencies in consultation with environment, transport and planning agencies and local government	Medium
	National Environmental Health Strategy includes noise matters	enHealth Council	
	Consider opportunities for linking noise with other healthy home initiatives	Relevant agencies, stakeholders and non-government organisations	Low to medium
Noise research	Confirm priority areas for health research from sleep disturbance, annoyance and school performance, cardiovascular effects, and effects on wellbeing	State and Territory Health agencies, enHealth, key researchers, environment and transport agencies	High
	Explore the nature of noise and impacts on sensitive populations (for example, children)	State and Territory Health agencies, enHealth, key researchers, key community stakeholders	High
	Support pilot noise mapping projects to determine community noise environment	Two key sites, key health, environment and transport stakeholders	Medium to low
	Establish and support a collaborative research agenda	enHealth, State and Territory health agencies, CSIRO, capital cities	Medium
	Review adequacy of existing health guidelines in State and Territory legislation	enHealth Council	High

Issue	Action	Responsibility	Priority
Noise action plans	Review existing legislation across all levels of government	enHealth Council, state health, environment and planning agencies	High
	Develop national and state action plans for both long- and short-term to integrate planning and research at all levels of government	enHealth, state health, environment and planning agencies	High
	Adoption of a full collaborative approach among responsible agencies	All	High
	Community education programs at the national level and at individual state levels	Health and environment agencies	Medium to low
	Include recent developments on noise and health in State of Environment Reporting	Environment Australia	Medium
Noise considered in planning	Baseline monitoring of environmental noise levels over time be carried out to ascertain background levels across a broad range of populations and land use areas	Environment and health agencies	Medium
	Planning authorities develop guidelines for noise sensitive developments for layout design and construction	Planning, environment and health agencies in collaboration with local government	Medium
	Greater controls applied where noise is known to have an effect	Regulatory authorities	Medium
	Review option to adopt European Union noise directive maximum emission for key sectors	CSIRO, key sector stakeholders	Medium
Noise reduction	Examine feasible economic and technical incentives for noise source reduction in transportation, industrial and consumer goods	Environment and transport agencies, CSIRO, academics, consumer associations	Medium
	Attention given to adequacy of Building Code to include recommendations for noise insulation from external sources	Australian Building Codes Board, Australian Government	Medium to low
Incorporate noise prevention and controls into planning policies	Produce planning guidance to assist incorporating noise issues into land-use planning	Relevant agencies	Medium/low
	Introduce broader noise related policies into social, mental and child health policies	Relevant agencies	Medium/low

Issue	Action	Responsibility	Priority
Improve capacity of health care providers to educate and respond to noise issues	Assess skills, knowledge, attitudes and behaviours of health care providers on noise	enHealth, State and Territory and local government health agencies, professional associations	Medium/low
	Develop educational materials for inclusion in environmental health program training	enHealth, State and Territory and local government health agencies, professional associations	Low
Limited community awareness and understanding of noise health impacts, control and prevention options	Identify scope for immediate action – noise prevention, control and hearing protection, consumer choice	Key health, consumer, environment and planning stakeholders	High to low
Limited joint activities of health, environment and transport agencies and organisations on environmental health issues, including noise	Consult and identify two shared environmental health goals at national and local level for work	Key stakeholders (may be issue dependent)	Medium to high
Insufficient information on noise environment for decision-making	Review pilot noise mapping projects and their wider application in Australia for environment, transport, planning and health services	Key stakeholders, academics	Medium to low

Project terms of reference

1. Review up-to-date national and international information on the non-auditory health effects of both occasional and routine exposure to environmental noise (principally from transport and industrial sources). Primary focus to be a systematic literature review.

2. Consider the potential extent and level of non-auditory impact of both occasional and routine exposure to environmental noise in Australia (that is, ignoring the auditory effects and the occupational health and safety aspects).

3. Identify world best practice in the management of environmental noise (regulation, amelioration etc).

4. Make recommendations on the management of environmental noise in Australia. In particular, recommend means to incorporate noise concerns into planning and broader development issues, including building design, and how to incorporate noise management into Health Impact Assessment.

5. Identify further research requirements and make recommendations on how these could be progressed.

6. Oversight the development of a report/s on the above matters for the enHealth Council and routinely provide advice on progress.

International noise control policy frameworks

	Austria	Denmark	France	Germany	Switzerland	Netherlands
Aircraft	Statutory order on noise emissions from aircraft (ZLZV) 1992 Aircraft Noise Act being prepared	Two statutory orders govern airports and airfields, noise may not exceed 55 dB(A) (DEN level)	Noise Abatement Law of 31 December 1992	Aircraft noise law of 1974. 62 dB(A) for all regions, shipping traffic limit – 50 dB(A) day-time and 40 dB(A) night. Where aircraft noise exceeds 75 dB(A), no residential building allowed	Environmental law (1983) and noise abatement (1986). No night flights. Airport and helicopter Lmax in dBA Zone I/II/III/IV Plan Value 70/75/80/85 impact thresholds 75/80/85/90 alarm levels 85/90/90/95 (see below)	Aviation Act 1978 – aircraft noise, zoning around airports, 1982
Road traffic noise	Decree on Noise Control on Federal Roads 1983, noise impact of roads 1993, motor vehicle law	Since 1992–93, a total of DK 35 million (~£3 million) invested in noise barrier and sound proofing homes	Noise Abatement Law of 31 December 1992, new roads built close to existing buildings regulated by the Law on Impact Studies of July 1976, 65 dB(A)	59 dB(A) during day; 49 dB(A) at night for new or modified roads	Zonal noise limits same for road, rail and industrial traffic Zone I/II/III/IV Plan Value 50/55/60/65 impact thresholds 55/60/65/70 alarm levels 65/70/75/80	Mandatory road traffic noise legislation in 1982, zoning close to new roads – 1982
Rail	SchLV BGBl. Nr. 1414/1993, SchIV BGBl. Nr. 415/1993 – statutory orders on noise emissions and impact from rolling stock	Noise limit – 60 dB(A) $L_{aeq, 24hr}$ for railway. Rail noise may not exceed 85 L_{amax}, Since 1987 noise barriers and subsidise noise insulation for dwellings in residential areas exposed to levels exceeding 65 dB(A)	Noise Abatement Law of 31 December 1992, noise guidelines require sound protection measures where levels exceed 65 and should further reduce noise to 62 dB(A) and 60 dB(A) for new high-speed infrastructures and trains respectively	Ordinance from June 1990		Treatment of noise around existing railways – 1986, zoning around railway lines – 1987 Railways Decree of 1987, minor changes in 1989, substantial changes in 1993

	Austria	Denmark	France	Germany	Switzerland	Netherlands
Industrial noise	Trade Law (GewO) and the Trade Law EC Directive (GewO R1. 79/113/EWG) machinery emissions	Statutory order 1994–2000 on industrial noise	French by-law of 20 August 1985 authorised industry noise levels , Industry Pollution Law 1976, new legislation On noise from industrial plants adopted January 1997	Federal Clean Air Act of 1974, 55 dB(A), day; and 40 dB(A), night	Zonal noise limits same for road, rail and industrial traffic Zone I/II/III/IV Plan Value 50/55/60/65 impact thresholds 55/60/ 65/70 alarm levels 65/70/ 75/80	Zoning close to industrial areas – 1982
Building code noise insulation		Noise insulation provisions for road, rail and air traffic. Subsidy for insulation for dwellings exposed to LA_{eq} levels greater than 65 dB(A) near Copenhagen airport	Noise Abatement Law of 31 December 1992			Home insulation – 1983 (internal noise must not exceed 37 dB due to road or industry noise)
Planning	1986 ÖAL Guideline No 3, 1990 ÖNORM S 5021, 1994 Env Impact Statement law	Law No. 388 of 6 June 1991 describes the planning system in new residential housing may not be built where road traffic noise exceeds 55 dB(A)			Zonal noise limits same for road, rail and industrial traffic Zone I/II/III/IV Plan Value 50/55/60/65 impact thresholds 55/60/ 65/70 alarm levels 65/70/ 75/80	
Other		Neighbourhood, recreation noise and public buildings/ schools noise – Noise Abatement Law of 1992			Shooting ranges. No night time shooting. Zone I/II/ III/IV Plan Value 50/55/ 60/65 impact thresholds 55/60/65/70 alarm levels 65/70/75/80	

	Spain	European Union	United Kingdom	Portugal	Italy	United States
Aircraft	Royal decree 1302/1986 for environmental impact evaluation applicable to residential buildings built before 1996 affected by Madrid Airport enlargement	Civil Aviation Organisation, Annex 16 – international aviation noise standards Council Regulation, 925/1999 aircraft recertification	Civil Aviation Act, Air Navigation (Noise Certification) Order 1990 – noise certification Airports Act 1986 noise monitoring at airports No noise limits	General regulations on noise 251/87 updated by Decreto-Lei No 292/89 do not stipulate transport mode levels but exterior and interior noise levels	Decree of the Ministry of Environment 31 October 1997 Methodology for the measurement of noise around airports, part of environmental noise pollution n447, 26 October 1995	Noise Control Act of 1972, Aviation Safety and Noise Abatement Act of 1979, Airport and Airway Improvement Act of 1982, Airport Noise and Capacity Act 1990 Federal Interagency Committee on Aviation Noise founded in 1993
Road traffic noise			Individual vehicles – EC directive; no limits but Noise Insulation Regulations 1973, 1974 and 1988 of Land Compensation Act provide for home insulation from new or altered roads, exceeding or predicted to exceed, 68 dB L A10,18h 1 metre from façade	General regulations on noise 251/87 updated by Decreto-Lei No 292/89 do not stipulate transport mode levels but exterior and interior noise levels		FHWA Office of Motor Carrier Safety enforce Noise Control Act of 1972, Federal Aid Highway Act of 1970, 23 CFR 772, fund highway noise abatement

	Spain	European Union	United Kingdom	Portugal	Italy	United States
Rail			No railway noise requirements, Noise Insulation (Railway and Other Guided Transport Systems) Regulations 1995 of Land Compensation Act provide for home insulation from new or altered railways exceed 68 dB L A10,18h (0600–2400)or 63 dB L Aeq,6h (2400–0600) predicted or measured 1 metre from the façade	General regulations on noise 251/87 updated by Decreto-Lei No 292/89 do not stipulate transport mode levels but exterior and interior noise levels		FRA enforces Noise Control Act of 1972.
Industrial noise	Series of regional laws/ordinances govern industry, recreational activities and installations $L_{eq\ 1\ minute}$, 40 dB(A) from 8–22 hours, L_{max}, 45 dBA $L_{eq\ 1\ minute}$, 30 dB(A) from 22–8 hours, L_{max}, 35 dB(A) Municipal ordinances in Madrid, Barcelona and Zaragoza	EC Directive of 1996 phased in from 2001 to 2007	No limits, 1974 Control of Pollution Act, nuisance provisions Environmental Protection Act 1990, Pollution Prevention and Control Act 1999	General regulations on noise 251/87 updated by Decreto-Lei No 292/89	EC Directive of 1996 phased in from 2001 to 2007	Noise Control Act of 1972 (construction equipment)

	Spain	European Union	United Kingdom	Portugal	Italy	United States
Building code planning			Town and Country Planning Act 1990, general guidance noise exposure categories (NEC) from aircraft, road, rail and industry for new developments in Planning Policy Guidance Note PPG24: Planning and Noise: 0700–2300/2300–0700 A-<57/<48 B-57–66/48–57 C-66–72/57–66 D->72/>66 Planning permission refused	General regulations on noise 251/87 restricts building of new residential buildings, schools and hospitals in areas classified as 'noisy' L50 <75 dB(A), between 0700–2200 hrs and L50 <65 dB(A) between 2200 and 0700 hrs or 'very noisy' – exceed levels above	Land use planning around airports	Clean Air Act 1970, Title IV, The Airport Noise and Capacity Act of 1990 mandate FAA to participate in noise compatibility planning
Other				Noise from entertainment and shows may not exceed background by 10 dB(A) in three time periods: 0700–2000 2000–2400 0000–0700	Prime Ministerial decree 1997 indoor/outdoor entertainment noise requirements- cannot exceed L_{Aeq} <95 dB(A)	

Glossary

ADR – Australian Design Rules

ANEF – Australian Noise Exposure Forecast System

A-weighted sound pressure level (L_{pA}) – the level of A-weighted sound pressure in decibels given by:

$$L_{pA} = 10 \log_{10}(p_A/p_0)^2$$

where: p_A = the sound pressure in pascals
p_0 = the internationally agreed reference sound pressure of 20 micropascals (20 µPa).

A-weighting – an electronic filter built into a sound measuring device. The A-weighted sound pressure level, in dB(A), has been shown to correlate well with subjective response to sounds and is generally used for occupational and environmental noise assessment.

CSIRO – Commonwealth Scientific and Industrial Research Organisation

Decibels – unit for the measurement of sound and abbreviated as dB

EEG – electroencephalograph

EU – European Union

Frequency – rate of change of sound pressure level with time measured in cycles per second or Hertz (Hz)

ICD-10 – International Classification of Diseases, 10th edition

$L_{Aeq,T}$ - Equivalent sound pressure level over a time period, T. Common time periods include 8 hr (work day) and 24 hour (day and night). Can be used to measure continuing sounds such as road traffic noise, continuing industrial noise and noise from ventilation systems. Given by:

L_{den} – Equivalent sound pressure level over a day–evening–night period

L_{dn} – Equivalent sound pressure level over a day–night period

L_{eqT} – $10 \log10 \{(1/T) \int (p_A^2/p_0^2\, dt)\}$ in dB(A)

Presbycusis – normal age-related hearing loss

REM – rapid eye movement

SEL – Sound exposure level of a particular noise event like an aircraft overflight or truck passing

Sound pressure level – amplitude of pressure changes

Sound pressure amplitude (uPa)	Sound pressure level (dB)
20	0
40	6
80	12
160	18
320	24
640	30
1280	36
2560	42

syscusis – lowering of the threshold of aural discomfort and pain

WHO – World Health Organization

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