

Prepared for:



COMMONWEALTH DEPARTMENT OF  
**TRANSPORT AND REGIONAL  
DEVELOPMENT**

GPO Box 594  
Canberra ACT 2601

# Noise

## Volume 2: Health Effects of Aircraft Noise - Literature Review

Proposal for a Second Sydney Airport  
at Badgerys Creek or Holsworthy Military Area

**Technical Paper**

Prepared by

**Soames Job & Associates**

43 Orrmond Street  
Paddington NSW 2021

**PPK**  
Environment & Infrastructure

AN 078 004 798

A NATA Certified Quality Company

PPK House  
PO Box 248  
Concord West NSW 2138

December 1997

Report No. 58H233B PR1465  
ISBN No. 0642280320

## **Explanatory Statement**

This technical paper is not part of the Draft Environmental Impact Statement (EIS) referred to in paragraph 6 of the Administrative Procedures made under the Environment Protection (Impact of Proposals) Act 1974.

The Commonwealth Government is proposing to construct and operate a second major airport for Sydney at Badgerys Creek. This technical paper contains information relating to the Badgerys Creek airport options which was used to assist the preparation of the Draft EIS.

The technical paper also assesses the impacts of developing a major airport at the Holsworthy Military Area. On 3 September 1997, the Government eliminated the Holsworthy Military Area as a potential site for Sydney's second major airport. As a consequence, information in this technical paper relating to the Holsworthy Military Area is presented for information purposes only.

## **Limitations Statement**

This technical paper has been prepared in accordance with the scope of work set out in the contract between Rust PPK Pty Ltd and the Commonwealth Department of Transport and Regional Development (DoTRD) and completed by PPK Environment and Infrastructure Pty Ltd (PPK). In preparing this technical paper, PPK has relied upon data, surveys, analyses, designs, plans and other information provided by DoTRD and other individuals and organisations, most of which are referenced in this technical paper. Except as otherwise stated in this technical paper, PPK has not verified the accuracy or completeness of such data, surveys, analyses, designs, plans and other information.

This technical paper has been prepared for the exclusive use of DoTRD. PPK will not be liable to any party other than DoTRD and assumes no responsibility for any loss or damage suffered by any other party arising from matters dealt with in this technical paper, including, without limitation, matters arising from any negligent act or omission of PPK or for any loss or damage suffered by any other party in reliance upon the matters dealt with and opinions and conclusions expressed in this technical paper.

## **Acknowledgments**

Data used to develop the figures contained in this document have been obtained and reproduced by permission of the Australian Bureau of Statistics, NSW Department of Land and Water Conservation, NSW National Parks and Wildlife Service (issued 14 January 1997), NSW Department of Urban Affairs and Planning and Sydney Water. The document is predominantly based on 1996 and 1997 data.

To ensure clarity on some of the figures, names of some suburbs have been deleted from inner western, eastern, south-eastern and north-eastern areas of Sydney. On other figures, only 'Primary' and 'Secondary' centres identified by the Department of Urban Affairs and Planning's Metropolitan Strategy, in addition to Camden, Fairfield and Sutherland, have been shown.

## **Copyright**

© Commonwealth of Australia 1997

This work is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without written permission from the Australian Government Publishing Service. Requests and inquiries concerning reproduction and rights should be directed to the Manager, Commonwealth Information Service, GPO Box 84, Canberra, ACT 2601.

# CONTENTS

	Page Number
<b>1 METHODOLOGY</b>	<b>1-1</b>
1.1 AIMS AND SCOPE OF WORK	1-1
1.2 LITERATURE SEARCH	1-1
1.2.1 SOURCE MATERIALS	1-2
1.2.2 OBTAINING MATERIALS	1-2
1.3 METHODOLOGY ADOPTED FOR THIS STUDY	1-3
<b>2 SUMMARY OF LITERATURE REVIEW</b>	<b>2-1</b>
2.1 REVIEW METHODS	2-1
2.1.1 DEFINITIONS AND MEASUREMENT OF VARIABLES	2-1
2.2 RESEARCH METHODOLOGY	2-1
2.3 EFFECTS OF NOISE ON PEOPLE	2-4
2.3.1 AUDITORY HEALTH	2-4
2.3.2 BALANCE AND VISUAL EFFECTS	2-4
2.3.3 STARTLE AND ORIENTING RESPONSES	2-4
2.3.4 CARDIOVASCULAR EFFECTS	2-5
2.3.5 ENDOCRINE AND IMMUNOLOGICAL EFFECTS	2-5
2.3.6 SLEEP DISTURBANCE	2-5
2.3.7 IMPAIRMENT OF VOICE COMMUNICATION	2-6
2.3.8 INTERFERENCE WITH TASKS	2-6
2.3.9 REACTION TO NOISE	2-6
2.3.10 PSYCHOLOGICAL HEALTH	2-6
2.4 COMMENT ON ADAPTATION AND HABITUATION	2-7
<b>3 NOISE DEFINITIONS</b>	<b>3-1</b>
3.1 INTRODUCTION	3-1
3.1.1 DEFINITIONS OF KEY TERMS	3-1



3.2 IMPORTANT CHARACTERISTICS OF SOUND AND AIRCRAFT SOUND	3-3
3.2.1 SOUND INTENSITY, SOUND PRESSURE LEVEL, AND PERCEPTION OF LOUDNESS AND NOISINESS	3-4
3.2.2 SOUND FREQUENCY AND PERCEPTION OF PITCH	3-4
3.2.3 TIME PATTERN	3-5
3.2.4 AIRCRAFT SOUND	3-5
3.2.5 RELEVANCE OF NOISE SOURCE TO NOISE OUTCOME	3-7
4 MEASURING HEALTH IMPACTS	4-1
4.1 MEASURING INDEPENDENT AND DEPENDANT VARIABLES	4-1
4.1.1 SOUND EXPOSURE ASSESSMENTS	4-1
4.1.2 HEALTH	4-4
4.1.3 PERFORMANCE	4-6
4.1.4 REACTION	4-7
4.2 STUDY TYPE	4-8
4.2.1 FIELD (COMMUNITY) STUDIES: RESIDENTIAL AND OCCUPATIONAL STUDIES	4-8
4.2.2 LABORATORY STUDIES	4-9
4.3 STUDY DESIGN	4-9
4.3.1 CROSS-SECTIONAL DESIGNS	4-9
4.3.2 LONGITUDINAL DESIGNS	4-10
4.4 MEDIATING OR MODIFYING VARIABLES	4-11
4.4.1 MEDIATING VARIABLES	4-11
4.4.2 MODERATING VARIABLES	4-12
4.5 CONFOUNDING VARIABLES	4-12
5 POTENTIAL NOISE IMPACTS	5-1
5.1 IMPACT OF SOUND ON AUDITORY HEALTH	5-1
5.1.1 AURAL DISCOMFORT AND PAIN	5-1
5.1.2 DEFINITIONS OF HEARING LEVEL, NOISE INDUCED HEARING LOSS AND HEARING IMPAIRMENT	5-2
5.1.3 MECHANISMS OF NOISE-INDUCED HEARING LOSS	5-4

5.1.4 NOISE-INDUCED TEMPORARY THRESHOLD SHIFT	5-6
5.1.5 NOISE-INDUCED PERMANENT THRESHOLD SHIFT	5-7
5.1.6 NOISE-INDUCED HEARING LOSS (IMPAIRMENT) AND NOISE EXPOSURE	5-10
5.1.7 MODERATORS OF THE EFFECTS OF NOISE ON HEARING LOSS (IMPAIRMENT)	5-12
5.1.8 COMPLICATIONS OF HEARING IMPAIRMENT	5-15
5.1.9 COMMENTS ON RECENT SYDNEY AIRPORT STUDIES	5-16
 5.2 IMPACTS OF SOUND ON NON-AUDITORY PHYSIOLOGICAL HEALTH	 5-17
5.2.1 EFFECTS ON THE SENSE OF BALANCE	5-18
5.2.2 VISUAL EFFECTS	5-18
5.2.3 STARTLE REFLEX AND ORIENTING RESPONSE	5-19
5.2.4 FIGHT/FLIGHT AND STRESS RESPONSES	5-19
5.2.5 CARDIOVASCULAR EFFECTS	5-20
5.2.6 PSYCHOENDOCRINE AND IMMUNOLOGICAL EFFECTS	5-31
5.2.7 BODILY FATIGUE	5-35
5.2.8 MORTALITY	5-35
5.2.9 PERINATAL HEALTH	5-36
5.2.10 GENERAL PHYSICAL HEALTH	5-38
5.2.11 ASSESSMENT OF THE CAUSAL ROLE OF NOISE IN HEALTH EFFECTS	5-42
5.2.12 INDIRECT EFFECTS OF NOISE ON NON-AUDITORY PHYSIOLOGICAL HEALTH	5-44
 5.3 IMPACT OF NOISE ON PERFORMANCE AND ACTIVITY	 5-45
5.3.1 SLEEP DISTURBANCE	5-45
5.3.2 INTERFERENCE WITH SPEECH AND COMMUNICATION	5-64
5.3.3 INTERFERENCE WITH GENERAL TASKS	5-71
 5.4 REACTION TO SOUND EXPOSURE	 5-82
5.4.1 SOUND, LOUDNESS, NOISINESS AND REACTION	5-82
5.4.2 RELEVANT SOUND INDICES	5-83
5.4.3 DOSE-RESPONSE RELATIONSHIP	5-84
5.4.4 BEHAVIOURAL REACTIONS TO NOISE	5-93
5.4.5 MODERATING VARIABLES OF THE IMPACT OF NOISE ON ANNOYANCE AND DISSATISFACTION	5-97
5.4.6 INDIRECT EFFECTS OF SOUND EXPOSURE ON ANNOYANCE	5-118
5.4.7 COMMENTS FROM RECENT SYDNEY AIRPORT STUDIES	5-119
 5.5 IMPACT OF NOISE ON PSYCHOLOGICAL HEALTH	 5-122
5.5.1 METHODOLOGICAL CONCERNS WITH RELEVANT STUDIES	5-122
5.5.2 THE IMPACT OF NOISE ON PSYCHOLOGICAL HEALTH	5-123

5.5.3 MODERATORS	5-124
5.5.4 INDIRECT EFFECTS OF NOISE ON PSYCHOLOGICAL HEALTH	5-125
5.5.5 COMMENTS FROM RECENT SYDNEY AIRPORT STUDIES	5-125
5.6 ADAPTATION/HABITUATION TO NOISE EXPOSURE	5-126
5.7 COMBINED EFFECTS OF AIRCRAFT NOISE AND OTHER STRESSORS	5-128
<b>6 VULNERABLE GROUPS AND LAND USES</b>	<b>6-1</b>
6.1 SUMMARY OF VULNERABLE GROUPS	6-1
6.1.1 AUDITORY HEALTH	6-1
6.1.2 NON-AUDITORY PHYSIOLOGICAL HEALTH	6-2
6.1.3 PERFORMANCE AND ACTIVITY	6-3
6.1.4 REACTION TO NOISE EXPOSURE	6-4
6.1.5 PSYCHOLOGICAL HEALTH	6-5
6.1.6 COMMENTS FROM RECENT SYDNEY AIRPORT STUDIES	6-5
6.2 SENSITIVE LAND USES AND RECOMMENDED SOUND PARAMETERS	6-7
6.2.1 AUDITORY HEALTH	6-7
6.2.2 PERFORMANCE AND ACTIVITY	6-8
6.2.3 REACTION	6-9
6.2.4 COMMENTS FROM RECENT SYDNEY AIRPORT STUDIES	6-9
6.3 RESEARCH NEEDS	6-10
6.3.1 OVERVIEW	6-10
6.3.2 RESEARCH NEEDS	6-11
<b>REFERENCES</b>	<b>R-1</b>

## LIST OF FIGURES

	Page No.
Figure 3.1 Sound Pressure Level in dBA as a Function of Frequency for Various Aircraft Types, Measured Outside on the Ground Directly Under the Flight Path at Sydney (Kingsford Smith) Airport	3-6
Figure 5.1 Percentage of Workers with Hearing Impairment (Average Hearing Loss Greater than 25 dBA at 1, 2 and 3 kHz) as a Function of Age for Exposure to Occupational Noise	5-9
Figure 5.2 Average Hearing Loss (dB) as a Function of Frequency (Hz) for Different Durations of Exposure	5-11

Figure 5.3	Percentage of Respondents Aroused or Awakened as a Function of Noise Exposure (SEL) for Laboratory Studies	5-53
Figure 5.4	Percentage of Respondents Aroused or Awakened as a Function of Noise Exposure (SEL) for Field Studies	5-54
Figure 5.5	Background Noise Level (dBA) at which Speech Intelligibility is Satisfactory as a Function of Speaker-Listener Distance for Relaxed Normal Voice and Raised Voice Conversation Outdoors	5-68
Figure 5.6	Normal Voice Sentence Intelligibility as a Function of Background Noise Level (dBA) in a Typical Living Room	5-70
Figure 5.7	Percentage of Respondents Reporting Activity Disturbance as a Function of Exposure to Aircraft Noise (NEF3)	5-78
Figure 5.8	Percentage of Respondents "Moderately Affected" or "Seriously Affected" as a Function of Exposure to Aircraft Noise (NEF3) for Clustered Data	5-87
Figure 5.9	Percentage of Respondents "Highly Annoyed" as a Function of Exposure to General Transportation Noise (dBA Ldn) According to the Least Squares Quadratic Fit and the Third-Order Polynomial Fit	5-88
Figure 5.10	Percentage of Respondents "Highly Annoyed" as a Function of Exposure to Aircraft Noise (NEF3) for Clustered Data	5-89
Figure 5.11	Percentage of Respondents "Highly Annoyed" as a Function of Exposure to General Transportation Noise (dBA Ldn) According to a Cubic Function (Schultz, 1978), an Exponential Error Function (Fidell et al, 1991), a Logistic Function (Federal, 1992) Fit to the Same Data (Fiddell et al, 1989)	5-91
Figure 5.12	Percentage of Respondents Rating Their Annoyance as at Least 4 on the Opinion Thermometer (0 = No Annoyance, 10 = Very Much Annoyance) as a Function of Exposure to Aircraft Noise (NEF3)	5-92
Figure 5.13	General Reaction Score as a Function of Exposure to Aircraft Noise (NEF3) for Respondents with High (at Least 7), Medium (from 3 to 7), or Low (Less than 3) Scores on a Scale Assessing Negative Attitudes Toward the Noise or its Source	5-112
Figure 5.14	General Reaction Score as a Function of Exposure to Aircraft Noise (NEF3) for Respondents with High (at Least 8), Medium (from 4 to 8), or Low (Less than 4) Scores on a Scale Assessing Fear of an Aircraft Crashing	5-113
Figure 5.15	General Reaction Score as a Function of Exposure to Aircraft Noise (NEF3) for Respondents with High (at Least 8), Medium (from 4 to 8), or Low (Less than 4) Scores on a Scale Assessing Noise Sensitivity	5-116

## 1

**METHODOLOGY****1.1 AIMS AND SCOPE OF WORK**

The aims of this study are to:

- collate, summarise and critically examine Australian and international literature and research addressing the human health effects of aircraft noise;
- identify issues relevant to the Second Sydney Airport proposal arising from the third runway project at Sydney Airport and the subsequent Senate Select Committee inquiry into aircraft noise in Sydney;
- identify health variables that can be scientifically justified as being adversely affected by aircraft noise; and
- discuss the susceptibility of various sectors of the population to the health effects identified.

The scope of work for assessing the impacts of aircraft noise on human health has four main components, namely:

- a comprehensive Australian and international literature review;
- a review of available data and research undertaken since the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) including submissions to the *Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995); and
- an assessment of the potential health impacts of aircraft noise based on the findings of the previous two tasks. This has only been undertaken for those health variables that demonstrate scientific evidence of a dose-response relationship.

Health effects addressed in this study include impacts on auditory health (hearing damage/loss); impacts on non-auditory health (effects on balance, vision, mortality and other physiological and physical effects); impacts on performance and activity (sleep disturbance, communication disturbance); community reaction (annoyance and dissatisfaction); and the impacts on psychological health (stress, other mental health effects). The adaptation of humans to noise exposure and the cumulative or combined effects of aircraft noise and other stressors are also addressed.

**1.2 LITERATURE SEARCH**

A comprehensive literature review has been undertaken as the basis for this study. The findings of this review are provided in *Chapters 4, 5 and 6* and the methods used described below.

### 1.2.1 SOURCE MATERIALS

A variety of source materials have been used to undertake the literature review.

Information about the effects of noise on human health, performance and reaction was obtained from a variety of books, government reports and articles. Relevant articles came from two main sources: journals and conference proceedings.

Laboratory, community and occupational studies with longitudinal or cross-sectional designs and using observational, survey or epidemiological techniques were all considered. Thus, the relative advantages and disadvantages of these different types of study, design and approach have been considered in assessing the reported findings. Very little data from laboratory studies with animals was considered, due to potential species differences and the focus of the review on the impacts of noise on humans.

Studies of the impacts of aircraft noise were given greatest attention, since the potential effects of noise from this source are the primary concern of this study and noise from different sources tends to produce different effects. However, data pertaining to non-aircraft noise were included where it was considered that these data may provide an insight into the potential effects of aircraft noise.

In order to ensure relevance of reviewed findings to Australian conditions, data from the most extensive study of the effects of aircraft noise in Australia to date (Hede and Bullen, 1982a) and from the continuing study of the impacts of aircraft at Sydney Airport, in particular the third runway (Carter, Job, Taylor, Peploe, and Morrell, 1996a; Carter, Job, Peploe, Taylor, and Morrell, 1996b; Job et al. 1996a; Job, Topple, Carter, Peploe, Taylor and Morrell, 1996b, 1996c; Job, Topple, Hatfield, Carter, Peploe, and Taylor, 1996d; Taylor, Morrell, Carter, Peploe, and Job, 1996), are reported where appropriate.

### 1.2.2 OBTAINING MATERIALS

Materials were obtained by numerous methods, namely:

- relevant articles, reports and books held by the author were reviewed;
- *Falling on Deaf Ears. The Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) and the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) were considered. A recent publication of the review of the health effects of noise that was conducted for the EIS (Morrell, Taylor, and Lyle, in press) was also considered;
- on the database Psychinfo (1984-1996) at Fisher Library, Sydney University, the following key word searches were performed:
  - aircraft + noise + health (limited to English)- yielded seven records;

- aircraft + noise + performance (limited to English)- yielded four records; and
- aircraft + noise + reaction (limited to English)- yielded 0 records.

All abstracts were reviewed for relevant information, and relevant papers were obtained for full examination;

- on the database Medline (1992-1996) at Fisher Library, Sydney University, the following key word searches were performed:
  - aircraft + noise + health (limited to English)- yielded five records;
  - aircraft + noise + performance (limited to English)- yielded two records; and
  - aircraft + noise + reaction (limited to English)- yielded two records.

All abstracts were reviewed for relevant information, and relevant papers were obtained for full examination;

- issues of the *Journal of the Acoustical Society of America* and the *Journal of Sound and Vibration* from the years 1995 through 1997 were perused to extract recent relevant articles;
- further relevant reports or articles were extracted from citations in the literature reviewed;
- data reported from the ongoing studies of the third runway at Sydney Airport (Carter et al., 1996a, 1996b; Job et al, 1996a, 1996b, 1996c, 1996d; Taylor et al., 1996) were specifically considered; and
- contacts were made with appropriate specialists (in Australia, Sweden, the Netherlands, Austria, the UK and the USA), for suggestions of relevant materials.

### 1.3 METHODOLOGY ADOPTED FOR THIS STUDY

The first stage of this study was to undertake a comprehensive literature review using a variety of source materials including data from ongoing studies of Sydney Airport and in particular the third runway. The methods used for this review are described in the previous section.

There are a number of potential health impacts of aircraft noise, but the research to date does not provide sufficient information to predict the likely impacts of this noise on particular vulnerable groups. It does, however, show that there are some more general impacts which can reasonably be predicted. These may be summarised as follows:

- sleep disturbance, which may be predicted using the Sleep Disturbance Index;

- impairment of voice communication, which may be predicted by the number of external noise events in the order of 65 dBA to 70 dBA and above; and
- reaction, which may be predicted by the ANEC measure. In this case, it is important to recognise that exposure to new noise or changes to noise exposure are likely to elicit greater reaction.

The noise modelling undertaken for this Technical Paper has structured its methodology in part to predict these types of impacts. The assessment of these impacts is documented in *Volume 1*.

In addition, there is also some evidence that exposure to aircraft noise can have a number of other potential impacts, but it is not possible to measure or reliably predict these impacts.



## 2

**SUMMARY OF LITERATURE REVIEW****2.1 REVIEW METHODS**

The extensive literature on effects of noise on humans was accessed through the holdings of the first author, electronic literature searches, direct searches of relevant journals and conference proceedings, citations in the reference lists of articles obtained, and contacts with Australian and international experts. In addition, the report of the Senate Select Committee on Aircraft Noise *"Falling on Deaf Ears"* (Senate Select Committee on Aircraft Noise, 1995), the review of noise effects for the Draft EIS for the Third Runway at Sydney (Kingsford Smith) Airport (Kinhill, 1990), and published data from the ongoing study of the effects of the third runway at Sydney Airport were explicitly reviewed.

**2.1.1 DEFINITIONS AND MEASUREMENT OF VARIABLES**

For this review, *noise* was defined as unwanted sound. The measurement of sound for the prediction of human reaction is complex, and many characteristics of the sound events may be relevant: loudness (and the weighting scale employed in its assessment), frequency or pitch, duration of the sound event, rise time of the event, peak level of the sound, tonality, emergence from the background sound level, and time of day. Further complexity arises from the relevance of non-physical features of the noise to its impact on humans (in particular, the perceived controllability of the noise, and whether it is viewed as a signal for danger).

*Health* was defined according to the World Health Organisation definition, *Not merely the absence of disease or infirmity but... a positive state of physical, mental and social well-being*. Health has been assessed in many ways in the noise effects literature: interview or questionnaire, direct assessment of endocrine, immunological, cardiovascular and other biological functions, hospital admissions, use of other medical services, and use of medications.

*Reaction* refers to the negative feelings which may occur in relation to the noise, including annoyance and dissatisfaction. Additional aspects of reaction have also been extensively researched, such as disposition to complain, symptoms attributed to the noise (such as headaches, nervousness), and disturbance of living activities (such as concentrating, relaxing, sleeping, conversation, listening to music). Within the World Health Organisation definition reaction is appropriately viewed as pertinent to health itself.

**2.2 RESEARCH METHODOLOGY**

An extensive variety of methodologies have been employed in researching the effects of noise, and aircraft noise in particular, on people. This has

included laboratory studies of reported reaction to various noise events, of task performance under noise versus no noise, of sleep disturbance from noise, of temporary hearing loss, and of various biological effects of noise (such as endocrine function related to stress, immune function, and cardiovascular effects). Field studies of the effects of environmental noise in both residential and occupational settings have been extensive and have included assessment of hearing loss, reaction (annoyance, etc.), activity disturbance, sleep disturbance, symptoms, mental health effects, hospital admissions, medication use, general practitioner visits, and assessment of various physiological functions, such as blood pressure.

Nonetheless, this extensive body of research is littered with methodologically flawed studies. Flaws in laboratory studies include confounding of the noise with other factors, unjustified generalisation from selected samples of subjects to the general population, and poor measures of effects. These problems are not insurmountable with rigorous methodology. Nonetheless, the issue of generalisability of results from the artificial laboratory setting to the real world of the person sleeping in their own bed or relaxing in their own lounge room, remains an issue.

In field studies problems include: inadequate assessment of effects through untried or unreliable questionnaires; biased sampling of residents through collection of subjects from newspaper advertisements or other procedures which do not ensure representative sampling nor appropriately address the problems of volunteer bias; inadequate consideration of the possibility of people who live in high noise areas being different in a variety of ways from the average less noise exposed population (for example, socio-economic status; access to health care facilities; or those in high noise exposure being tough survivor population); inadequate or even absent measurement of noise exposure. Rigorous field study methodology and efforts to obtain random sampling and minimum refusal rates can overcome many concerns. Nonetheless, without carefully considered matching on a variety of possible confounding variables, or longitudinal studies (ideally of changes in noise exposure), the possible confounding of noise exposure with many other human or environmental factors remains an issue.

A small number of studies employ a mixed methodology of assessing the effects of noise events deliberately created for the research, in the person's otherwise normal home setting. In this way, noise exposure can be assessed somewhat independently of the naturally occurring noise exposure and its attendant confounding of resident self-selection. However, even these studies are imperfect due to the inevitable interference created by the measurement process, the subjects awareness of measurement, and the possibilities that the noises are artificial and/or novel.

Further concerns arise in terms of the generalisability of results. Although many international results may be reasonably applied to the Australian situation, certain factors may be expected to vary (for example, the warmer climate may allow less temperature, and so also noise, insulated dwellings, more open windows and more outdoor living in Sydney than in colder climates). Thus, the ensuing review represents a synthesis of research conducted with the potential weaknesses and applicability of the research in mind.

In addition, due to a number of features of the literature and noise research itself, it is difficult to set firm limits to noise exposure levels. Firstly, for many of the potential effects of interest a cut point in terms of noise exposure above which certain effects will occur whereas below that cut point the effects will not occur, cannot be identified. On the contrary, as identified in many of the figures included in the review, it is typically and perhaps even uniformly the case that (within limits such as increases from extremely low or high levels) there is a steady increase in a pervasive array of effects with increasing noise. In short, the effects of noise are generally continuous variables (there are degrees of annoyance, degrees of distress, degrees of change in mental health, not dichotomous changes from healthy to unhealthy) and the population incidence of effects is most likely to be a probability function reflecting variations in individual susceptibility. Thus, the setting of limits for unacceptable noise becomes a political and social exercise (rather than a scientific one) in which some level of effect on people must be determined to be acceptable and any more effect determined to be unacceptable. Such setting of levels is appropriately beyond the scope of a scientific review of the literature. Furthermore, the relevant literature often contains different estimates of the severity of various effects, and of the probability of an effect occurring at various noise exposure levels. Finally, the appropriate location of noise measurement (inside or outside the residence) is uncertain: it may be appropriate on logical grounds to assess noise in proportion to individual time exposure inside and outside when considering hearing loss, whereas reaction (annoyance, etc.) may be more closely related to outside levels, and sleep disturbance to inside levels. However, even these claims are uncertain. Thus, only rarely can an accurate function for noise exposure and a specified effect be determined. Thus, such data are rarely offered in this summary, which identifies the likely effects of noise with comment on the consistency with which the effect has been identified. Possible vulnerable sectors of the population for these effects are also identified.

Factors which moderate (ameliorate or potentiate) the risk of negative consequences of noise exposure have received inadequate research attention. Further, where such data are available, their meaning is often ambiguous due to the correlational nature of the data. Nonetheless, consideration of the existing evidence is worthwhile in terms of targeting noise mitigation measures toward critical groups, designing interventions to reduce their risks, or, if the opportunity arises, siting noise sources to avoid vulnerable groups. Both features of the noise and of the exposed individual moderate the impacts of the noise. Person factors will be the focus of the following section, since the features of aircraft noise are regarded as a given for scientific purposes (that is, for extrapolation from previous studies of aircraft noise).

Despite the methodological problems, the possibility of a noise being causal in many supposed health effects is supported by a number of arguments: longitudinal studies show changing patterns of health with noise exposure; laboratory studies show acute effects consistent with the purported long term consequences; surveys do not appear to have more noise sensitive people in the high noise areas which would have created a bias; and logical mechanisms exist by which noise could produce many health effects.

## **2.3 EFFECTS OF NOISE ON PEOPLE**

Vulnerable groups have been identified for a range of potential outcomes of aircraft noise, as briefly summarised below. However, a non-specific vulnerability has been hypothesised for people with reduced adaptability or reserve capacity such as the sick, people with impaired sleeping functions, those who are more sensitive to noise, or those who are subject to other environmental pressures. Likely vulnerable groups will be considered for each effect of noise.

### **2.3.1 AUDITORY HEALTH**

Sounds may be uncomfortable at levels of 80-100 dB, while the threshold for aural pain is around 110-130 dB, with large individual differences in sensitivity. Thus, residents close to airports may experience discomfort but are not likely to experience pain. Susceptible people such as those with certain abnormalities including inflammation, or hearing aids not adjusted to limit the sound pressure level, may experience discomfort or pain at lower levels than those quoted above.

Evidence for permanent hearing loss resulting from typical exposures to aircraft noise is inconclusive and there is no relationship between aircraft sound levels and the hearing ability of residents, including children. While a recommended limit of an 8 hour continuous equivalent level of 75 dBA is unlikely to be exceeded by aircraft noise in residential setting around airports, aircraft noise could contribute to permanent hearing loss when combined with other residential, recreational or occupational noise exposures or with ototoxic drugs or chemicals (which are not uncommon).

### **2.3.2 BALANCE AND VISUAL EFFECTS**

Balance effects are unlikely at residential noise exposure levels except in people with unilateral vestibular system damage. Visual effects are unlikely.

### **2.3.3 STARTLE AND ORIENTING RESPONSES**

People are only likely to be startled by aircraft noise when they fear that noise. Unlike other noise effects, an individual's likelihood to startle reduces as he or she becomes accustomed to the noise events. People who are more sensitive to noise are more likely to be startled.

Sonic booms from aircraft can startle people. Sonic booms are caused by a very small number of aircraft capable of going faster than the speed of sound such as Defence aircraft and the Concord. Very few of these aircraft would use the Second Sydney Airport and they are restricted to sub-sonic speeds over the Sydney region.

### **2.3.4 CARDIOVASCULAR EFFECTS**

Noise may evoke a number of reflexive responses through the autonomic nervous system. Repetition of these responses may result in permanent changes such as hypertension and coronary heart disease. Noise produces acute vasoconstriction, increased blood pressure and increased heart rate. In children vasoconstriction may occur with aircraft noise of 70 dBA.

Noise generally causes an acute increase in blood pressure. Community studies of aircraft noise suggest elevated blood pressure in children, and possible elevations and greater antihypertensive medication use in adults, exposed to aircraft noise. Claims of other cardiovascular effects of aircraft noise generally are limited by poor methodology.

Type A personalities are more susceptible to cardiovascular effects, as may be women, those with a family history of hypertension, people with additional exposure to non-aircraft noise (workers in noisy industries) and those who perceive aircraft noise to be uncontrollable or to be a signal for danger.

### **2.3.5 ENDOCRINE AND IMMUNOLOGICAL EFFECTS**

Noise causes increases in endocrine hormones such as catecholamines, which influence the cardiovascular and immunological systems. Noise is a stressor, and stressors depress immunological functioning. However, effects of noise on immunity, other than through sleep loss are inconsistent.

Suggestions of increased mortality are based on poorly controlled investigations. Similarly, effects of noise on perinatal health have not been determined in unconfounded investigations.

### **2.3.6 SLEEP DISTURBANCE**

The prominent and well established effects of noise (including aircraft) include various disturbances to sleep. Negative effects on sleep caused by intermittent noise may occur at 45 dBA indoor maximum sounds pressure level, or at lower levels (40 dBA) in quiet background conditions.

It has been proposed that shift workers might be more at risk of aircraft-noise-induced sleep disturbances than the general population, because they sleep during the day, when there may be more aircraft noise events and sleep tends to be lighter. However, data are insufficient to identify whether shift workers are at increased risk of noise-induced sleep disturbance over and above their exposure to noise when they are trying to sleep during the day.

The probability of EEG responses and awakening as a result of noise increases with age, whereas children are more likely than adults to demonstrate a heart rate response for a given sound pressure level. Women are probably more sensitive to noise-induced sleep disturbance than men. Finally, evidence suggests that neuroticism and noise sensitivity may increase susceptibility to sleep disturbance.

### **2.3.7 IMPAIRMENT OF VOICE COMMUNICATION**

Interference with voice communication is a critical effect of noise in residences, hospitals, schools, pre-schools, and places of worship. The degree of interference is influenced by the voice effort. Relaxed voice at a two metres distance is 100 percent intelligible with background sound pressure levels of around 40 dBA. Lower levels may be desirable in classrooms where communication must occur over greater distances.

Noise-induced impairment of speech intelligibility may be particularly prevalent amongst certain groups; including the hearing impaired, the elderly, young children and people for whom the language being spoken is not their first. For the latter groups, a 5 to 10 dB larger signal-to-noise ratio is needed for good speech intelligibility.

### **2.3.8 INTERFERENCE WITH TASKS**

Noise may improve or impair task performance. It may improve the performance of people who are tired (low arousal), by raising their arousal to a more optimal level. In contrast, noise has been found generally to impair cognition and reading in children, especially those in higher school years. Noise-sensitivity increases the probability that noise exposure will interfere with task performance, and reduce productivity.

### **2.3.9 REACTION TO NOISE**

Around major airports a majority of the population will perceive noise as disturbing at least some daily activities. Although large individual variation in reaction exists, dose-response curves are available. The most relevant of these are provided by the two major Australian studies of aircraft noise (Hede and Bullen, 1982; and Bullen, Job and Burgess, 1985). These studies show reasonable agreement and suggest that 10 percent of residences would be seriously affected by the noise at levels around 19 NEF3 (Noise Exposure Forecast 3).

The likelihood of a negative reaction to aircraft noise is increased in people who have a negative attitude to noise source (aircraft, the airport or airport authorities), in individuals who are fearful of the health and/or safety impacts of aircraft noise, in noise-sensitive individuals, and in those who view the noise as uncontrollable. Australian data suggest that older residents are less likely than younger residents to report negative reactions to the noise, although the effect of age is quite small.

### **2.3.10 PSYCHOLOGICAL HEALTH**

Evidence for effects of noise on psychological health is not consistent and is methodologically difficult to obtain, but suggests that aircraft noise may be harmful to mental health.

Individuals with latent mental illness are more likely to demonstrate psychiatric morbidity as a result of exposure to noise. Noise-sensitivity has

also been found to be a risk factor for noise-induced psychiatric morbidity but may itself be a marker of depression. Individuals who perceive the noise as uncontrollable may be at increased risk of "learned helplessness" and depression.

## **2.4 COMMENT ON ADAPTATION AND HABITUATION**

While adaptation to noise might be expected to occur, evidence suggests that only some responses to noise adapt with time. The orienting response and some sleep disturbances apparently adapt. However, many sleep effects and reaction (annoyance, etc.) do not appear to adapt. Apparently paradoxically, changes in noise exposure produce "over-reaction": residents show greater change in reaction than would be predicted from the new noise exposure. Thus, the introduction of a new noise generally results in an increase in reaction which is greater than reaction to the new noise level if ongoing. It has been estimated that a correction of around +8 dB should be allowed for new noise sources (that is, an increase to 70 dB will be reacted to as though the new level was 78 dB). This greater reaction to new sources can be explained in terms other than adaptation or habituation, and can continue for years. The effects cited above and the noise levels identified for the production of these effects are from ongoing noise sources. Thus, these are the levels of reaction to which the exposed population may return after many years, not levels from which any adaptation should be expected. Initial reaction to the noise should be greater than the levels cited in the above sections due to the newness of the noise.

## 3

**NOISE DEFINITIONS****3.1 INTRODUCTION**

Noise pollution is regarded as a major problem associated with aircraft operations in the vicinity of airports. But what precisely are the effects of aircraft noise on residents in these areas? Are certain individuals particularly at risk? What can be done to minimise potential risks? A large body of literature has considered the impact of noise exposure on human health, performance and reaction to the noise. The review of this literature undertaken for this study focuses on the influence of aircraft noise, though data regarding noise from non-aircraft sources has also been considered where appropriate to provide more general information about the effects of noise on humans.

**3.1.1 DEFINITIONS OF KEY TERMS**

Assessment of the impacts of aircraft noise on health, performance and reaction requires clear definition of these terms.

*Sound and Noise*

In physical terms, sound is a mechanical disturbance which travels as a wave in air. In psychological terms, sound is "a sensory perception ...evoked by physiological processes in the auditory brain" (Berglund and Lindvall, 1995, p3) resulting from the acoustic wave entering the ear. "Noise" refers to a class of sounds which are subjectively experienced in a particular manner.

The definition of noise as "unwanted sound" (Berglund and Lindvall, 1995, p15) will be accepted for the purposes of the present review. It is important to realise that this definition of noise involves a psychological attitude towards the noise - that it is "unwanted". Thus high level sound will not always equate with "noise". For example, a person who chooses to listen to music at high volume is unlikely to regard it as noise, whereas their neighbours may consider the sound to be noise. In contrast, even the soft dripping of a tap could be regarded as noise by someone who is trying to sleep. The distinction between noise and high levels of sound is an important one, since several health and reaction outcomes may be determined by the perception of the sound as noise, rather than by the sound exposure level per se. The commonly applied operational definition of noise as "audible acoustic energy that adversely affects, or may affect, the physiological and psychological well-being of individuals or populations" (Berglund and Lindvall, 1995, p4) is rejected as it begs the question to be addressed by this study.

Noise in the community may issue from a wide range of sources, including aircraft, road traffic, railways, industrial and commercial premises, construction machines, radios and televisions, air conditioning units and domestic pets. Aircraft noise refers to any noise resulting from aircraft



operations, including stationary engine running, taxiing, take-off, landing and fly-overs.

### *Health*

Health has been defined by the World Health Organisation as "Not merely the absence of disease or infirmity but a positive state of physical, mental and social well-being" (World Health Organisation, 1994, p1). Health thus refers both to physiological and psychological wellbeing and the present review will consider the impact of noise on physiological health outcomes such as coronary heart disease and psychological health outcomes including depression. It is, however, important to recognise that physiological and psychological health outcomes may not always be independent. Thus, noise may have a direct effect on blood pressure, but it may also have an indirect effect mediated by the psychological outcome of annoyance where annoyance then causes changes in blood pressure. It is equally conceivable that the noise may produce annoyance indirectly in virtue of having negative consequences for physiological health.

Physiological health outcomes which have received the most attention in noise research have been auditory effects, such as aural pain, tinnitus and hearing loss, and cardiovascular effects such as acute or chronic increases in vasoconstriction, blood pressure and heart rate as well as cardiovascular illness. Impacts on the sense of balance, vision, bodily fatigue, psychoendocrine and immune function, mortality, perinatal health and general health have also been considered.

The definition of mental health (and illness) is not uniform throughout the relevant literature and is often unclear. Whether an individual is considered to be mentally ill is based on a range of somewhat arbitrary criteria, which differ from study to study. For example, classification as ill may depend on treatment adoption, the presence of symptoms, indicators of negative mood and wellbeing, low functional effectiveness and role performance or absence of signs of positive mental health such as coping skills (Kasel and Rosenfield, 1980). Freeman (1984) defined mental health as the absence of identifiable psychiatric disorder according to current norms. Virtually all of these criteria have been employed in studies of the impacts of noise on mental health, although the first three are most common. The symptoms which have been examined in noise research include anxiety, depression, emotional stress, nervous complaints, nausea, headaches, instability, argumentativeness, sexual impotency, changes in general mood and anxiety, and social conflicts, to more general psychiatric categories like neurosis, psychosis and hysteria, or even more general outcomes such as mental hospital admission.

The World Health Organisation (1947) definition of health draws any short term undesirable impact of noise into the realm of health effects. Thus both acute and chronic health outcomes of exposure to aircraft noise have been considered in this study.

### *Performance*

The term performance will be used to refer to the ability to carry out basic activities and tasks. Thus, this study considers the extent to which noise

influences individuals' capacity to carry out such tasks and activities and the manner in which they do so. Disturbance of activities which are potentially critical for physiological and psychological wellbeing- sleep, voice communication and recreational activities- will receive particular attention. Activity disturbances which may have substantial societal impact such as interference with childrens' learning and cognition, and with productivity- will also be a focus.

### *Reaction, Annoyance and Percent "Highly Annoyed"*

Reaction refers to an evaluative cognitive, emotional or evaluative response to the noise. It has typically been defined inexhaustibly in terms of annoyance with the noise.

The term annoyance is used differently by noise researchers, and its meaning is discussed by several authors (Altena, 1987, 1990; Lindvall and Radford, 1973). It has been defined as "a feeling of displeasure associated with any agent or condition known or believed by an individual or a group to be adversely affecting them" (Lindvall and Radford, 1973 cited in Berglund and Lindvall, 1995, p87). Data indicate that the term annoyance does not include all potential negative reactions to noise. It has been argued that there are many possible reactions to noise besides annoyance, for example, anger, frustration, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, exhaustion or potentially many others (Job, 1993; Job et al., 1996d).

Occasionally reaction has been assessed in terms of noise-induced activity disturbance, complaint disposition, symptoms (headaches, nervousness etc.) and residency decisions.

Community reaction is often expressed on a group basis in terms of the percentage of the population who are "highly annoyed" or "seriously affected" by the noise. This approach permits evaluation of the community noise problem in accordance with international standards that consider noise to be unacceptable if it results in more than 10 percent of the population being "highly annoyed" or "seriously affected" (Bullen, Job, and Burgess, 1985; Hede and Bullen, 1982a, 1982b; Schultz, 1978).

## **3.2 IMPORTANT CHARACTERISTICS OF SOUND AND AIRCRAFT SOUND**

The physical characteristics which are most critical to the perceptual experience of a sound are its sound pressure level (instantaneous, maximum, equivalent), frequency spectrum (weighting functions, tonal components) and time pattern (rise time, amplitude fluctuations, duration, number and time distribution of events). A basic understanding of these parameters and their perceptual counterparts is valuable in considering the impacts of aircraft noise exposure.

### 3.2.1 SOUND INTENSITY, SOUND PRESSURE LEVEL, AND PERCEPTION OF LOUDNESS AND NOISINESS

Sound intensity is the physical magnitude of the sound. Specifically, it is the rate of energy flow per unit area. Sound intensity is proportional to the mean square of sound pressure level (SPL), which is usually expressed in decibels (dB). Instantaneous level refers to the sound level at a particular point in time, maximum level to the greatest sound pressure level reached in a given period of time or for a given sound event, and equivalent to the average sound pressure level in a given period of time (most commonly eight or 24 hours).

Loudness is the perceived magnitude of a sound and is primarily a function of intensity, frequency and duration. For sound at a particular frequency, loudness is proportional to some power of the sound intensity (Berglund and Lindvall, 1995). For example, the loudness of aircraft noise has been found to be a power function of its sound pressure level (Berglund, Berglund, and Lindvall, 1975a). For lower frequency sounds, loudness changes more for a given change in SPL than for higher frequency sounds. Sensitivity typically varies as a function of frequency, such that sounds of equal intensity will be perceived to be differentially loud depending on their frequency. Humans are most sensitive in the middle frequency range from about 1,000–4,000 Hz. The basic unit of loudness is the sone (where 1 sone is the loudness of a 1000Hz pure tone heard at an SPL of 40dB).

Usually sound measurement meters use a filter which weights SPL measurements as a function of frequency approximately in accordance with the frequency response characteristics of the human ear. A, B, and C filters are designed to match the response characteristics of the human ear at low, medium and high loudness, respectively. Loudness levels on the A scale are expressed in dBA, on the B scale as dB(B) etc.

Noisiness, like loudness, is a perceived attribute of a sound, but these two concepts are distinct and people are able to distinguish between them for aircraft noise in a laboratory setting, provided they are carefully defined (Berglund, et al., 1975a, 1976; Hellman, 1982). A loud sound is not always unwanted and is thus not always noise. Neither loudness nor noisiness are directly related to sound pressure level (Zwicker, 1987), but are influenced by other acoustic and non-acoustic factors to different extents. It has been proposed that the concept of noisiness emphasises the emotional, as opposed to cognitive, aspects of human reaction more than does the concept of loudness, but less than does the concept of annoyance (Berglund and Lindvall, 1995). However, the precise psychological processes which underlie ratings of sounds on each of these scales are not well understood.

### 3.2.2 SOUND FREQUENCY AND PERCEPTION OF PITCH

Sound frequency is the number of complete cycles of the sound wave passing a given point in one second and is expressed in Herz (Hz). The physical characteristic of frequency is proportional to the perception of pitch. Sounds with greater frequencies have a higher perceived pitch. The audible

frequency range is approximately 20-20,000 Hz. Loss of hearing with age (presbycusis) generally occurs at higher frequencies (Hinchcliffe, 1959).

Low frequency sound (generally defined as between 20 and 100 Hz: Berglund, Hassmén, and Job, 1996) is particularly concerning because it propagates efficiently and is only minimally attenuated by structures such as walls and ear protection devices. It may cause potentially damaging resonance of the human body. It tends to mask other frequencies more than it is masked by them, increasing its potential to disturb speech. It tends also to cause vibration (Berglund et al., 1996), which is a particular concern in relation to human reaction because of the impact of vibration of objects within people's residences and of vibration of the residence itself.

### 3.2.3 TIME PATTERN

Sound pressure levels of sound events may exhibit different time patterns and different sounds will appear intermittently during days and nights. Acoustically, and this is taken into account by energy equivalent noise measurements. Rise time refers to the time it takes for the sound pressure to reach its maximum level. Sound pressure may also fluctuate substantially across the duration of the event. Rapid fluctuation (rise) of SPL over 2s may result in impulsiveness. The total duration of a sound may also influence its consequences. Other critical features of the time pattern of a sound are the distribution of the sound in a given period and the time of day that it occurs.

### 3.2.4 AIRCRAFT SOUND

Aircraft sound is characterised by intense, short duration, intermittent noise typically superimposed on relatively low background noise. It tends to be both more intense (depending on the distance to the source) and more intermittent than road traffic noise.

It has a large low-frequency component, which relative to other frequency components increases with the distance from the source. Measurements taken at ground level under flight paths at Sydney Airport identify a substantial sound energy component between 10 and 100Hz for a number of aircraft types (Berglund et al, 1996). This is shown in *Figure 3.1*.

This, however, is not unique to aircraft. Urban noise environments commonly include low frequency sound, from road vehicles, industrial machinery, artillery and mining explosions, and air movement machinery including wind turbines, compressors, and indoor ventilation and air conditioning units (Leventhall, 1988; Tempest, 1976).

Sound pressure levels may reach approximately 90 dB LAmax in the vicinity of a major commercial airport, depending on conditions, although lower estimates (between 65-75 dBA) are given by some authors (Andersson and Lindvall, 1988). Sound events of slightly lower intensities occur frequently throughout the day. Sound events are often restricted to day and evening hours, with nighttime curfews imposed. Sound pressure levels typically vary over periods of 10 to 100 seconds.

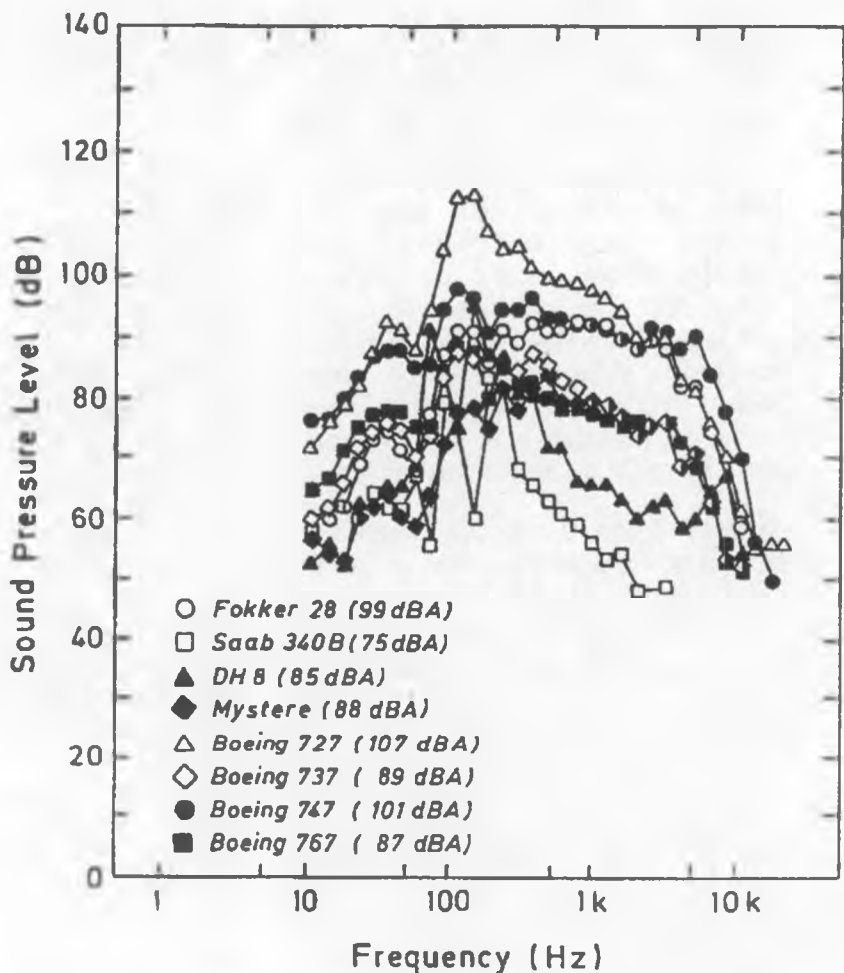


FIGURE 3.1: SOUND PRESSURE LEVEL IN dBA AS A FUNCTION OF FREQUENCY FOR VARIOUS AIRCRAFT TYPES, MEASURED OUTSIDE ON THE GROUND DIRECTLY UNDER THE FLIGHT PATH AT SYDNEY (KINGSFORD SMITH) AIRPORT

Source: Berglund et al (1996).

The nature of aircraft sound characteristics and movements can vary substantially depending on whether operations are commercial, military or recreational in nature. Aircraft flying at speeds greater than the local speed of sound produce sonic booms. Sonic booms are shock wave systems in air, the passage of which causes an initial rise in atmospheric pressure followed by a drop to below normal pressure then a sudden rise back to normal. The sound generated by helicopters differs from that generated by aeroplanes and has been found to relate differently to reaction (Berglund and Lindvall, 1995).

### 3.2.5 RELEVANCE OF NOISE SOURCE TO NOISE OUTCOME

Evidence suggests that health, performance and reaction outcomes vary with the source of the noise (for example, aircraft versus traffic versus occupational versus artillery) (see for example, Berglund, Berglund and Lindvall, 1976; De Jong, Opmeer, and Miedema, 1995; Hall, Birnie, Tayler, and Palmer, 1981; Hede and Bullen, 1982a; Kurra, Maekawa, and Morimoto, 1995; Miedema, 1987; Möhler, 1988; van Kamp, 1990) and the difficulty of estimating these differences has been identified by a number of researchers (Bullen, Hede, and Job, 1994; Fields and Walker, 1982; Rohrmann 1983a, 1983b, 1986). Differences may result from acoustic or non-acoustic features of noise from a particular source. Thus, a noise which is persistent and impulsive is liable to be more detrimental to hearing than one which is neither. Alternatively psychological variables such as attitudes toward the noise source and perceived controllability of the noise may be critical. For example, people may be more annoyed by aircraft than traffic noise, because they consider automotive transport to be important in their lives but might doubt the personal usefulness of air travel (see Job, 1993).

At levels below 50 dB LAmax community noises (for example, pile driver, jack hammer, and typewriter noise) are more annoying than aircraft noise (Berglund et al., 1976). However, aircraft noise tends to be more annoying than road-traffic noise at the same equivalent continuous sound pressure level (Green, 1993; Hall et al., 1981; Taylor, 1993; van Kamp, 1990; but see De Jong et al., 1995), as does railway noise (Miedema, 1987; Mohler, 1988; but see Yano, Yamashita, and Izumi, 1996a).

The parameters of the noise exposure which determine which particular type of noise has the greatest impact on outcome is likely to depend somewhat on the outcome in question.

Similarly, for a particular outcome, different sources may be detrimental for different reasons. Thus, some noises are primarily annoying because of their sound pressure level (for example, aircraft noise), whereas others are primarily annoying because of their temporal pattern (for example, noise from a typewriter) (Berglund, et al., 1976). This should be considered in designing noise abatement interventions.

Different noise sources may also vary in the number of people they influence. For example, community noise can affect small groups or even individuals without affecting near neighbours whereas road traffic and aircraft noise typically influence whole communities. This more even influence might make people more accepting of the noise, or, influenced by the dissatisfaction of their neighbours and group action, less accepting.

## MEASURING HEALTH IMPACTS

### 4.1 MEASURING INDEPENDENT AND DEPENDANT VARIABLES

Consideration of the issue of measurement of key variables is critical in evaluating the findings of studies which have assessed the impact of noise exposure on human health, performance and reaction. Generally, each of the methods which have been used has flaws, but used in combination can provide valuable data. When the findings of studies which have used the various measurement approaches are discussed, the relative merits of these approaches should be kept in mind. Criticisms will not be repeated at the point of presentation of the relevant data.

#### 4.1.1 SOUND EXPOSURE ASSESSMENTS

##### *Choice of Frequency Weighting Scale*

The capacity of the various weighting scales to handle low frequency components of sound deserves careful consideration in the present study, because aircraft sound contains substantial low frequency components.

The A-filter is more appropriate than the B- or C-filter for community exposure to aircraft sound. Although the D-filter was developed to handle aircraft noise (see IEC 537, 1976) it is not in common use and so most relevant data relate to the A-Filter which is addressed here. With the A-filter, the loudness of sound which contains substantial low frequency component is underestimated by up to 9dB within the range 52-70 dBA (Gamberale, Goldstein, Kjellberg, Liska, and Lofstedt, 1982) or 6 phon (where the phon is an equal loudness metric that corresponds to dB sound pressure level units for a pure tone concentrated at 1kHz) for 63 Hz and below (Berglund, 1990; Berglund and Berglund, 1986; see also Kjellberg and Goldstein, 1985; Kuwano, Namba and Miura, 1989). Vercammen (1992) suggested that an additional change be made to the A-weighted spectrum for the 10-160 Hz range with variations between 5 and 10dB compared with the present setting. The inaccuracy of the A-filter at low frequency is perhaps not surprising in that the iso-loudness functions employed in the weighting were actually extrapolations by hand into the low frequencies rather than being based on genuine data for the low frequencies (see Goldstein, 1994). For example, in classic work on the subject both Stevens (1975) and Kryter (1985, 1994) chose to extrapolate the equal-loudness and equal-noisiness contours into the low frequency range despite the absence of empirical data.

Alternative procedures developed for the prediction of (perceived) loudness or annoyance of complex sounds (such as aircraft noise), from various frequency weightings or calculation procedures (for example, Bryan, 1976; Kryter, 1985, 1994; Stevens, 1975; Zwicker and Fastl, 1990) have been less successful for low frequency noise (Berglund et al., 1996; Goldberg and Kjellberg, 1985).

These limitations of relevant filters to accurately predict perceived noisiness or annoyance for individual sound events is well publicised and may form the basis of scepticism regarding the A-filter. Nonetheless, the A-filter provides reasonable correlation between physical measurements of the sound and subjective evaluations of it (for example, Goldstein, 1994; Scharf and Hellman, 1990). The A-filter is also the most commonly employed filter in studies of community reaction to non-impulsive noise, such as aircraft noise. Finally, in consideration of community reaction underestimation of low frequency components of the sound will have little effect on data comparing sounds of similar levels of low frequency, or on estimations of reaction as long as the data employed for estimation have a similar low frequency component to the sounds for which the extrapolation is to be made. This is the case in the present study when aircraft noise data are employed to estimate reaction to aircraft noise. The underrepresentation of the low frequency component in the previous studies actually results in the level of reaction being overestimated for the given noise level. This is counterbalanced by the same under-representation of the low frequency components in the noise for which the extrapolation is made. This convenient state of affairs may only lead to error if the low frequency component of the noise changes significantly. Such a change is not impossible. It may occur if the noise characteristics of the aircraft fleet changes or if the usual policies of different airports dictate that certain airports accommodate more of the types of aircraft which produce more low frequency sound while other airports accommodate more mid to high frequency sound producing craft.

#### *Choice of Noise Metric*

Whilst a number of studies have measured total exposure to acoustic energy, this is an inappropriate measure of noise exposure, in that noise refers only to a particular class of sounds- those which are unwanted. Thus, more appropriate measures of noise include weightings for sound characteristics which could be expected to contribute to undesirability. A broad variety of noise indices which correlate moderately well with the outcomes of interest have been created by combining underlying acoustic and non-acoustic factors such as loudness, total "dose", loudness fluctuation amplitudes, rate of fluctuation, number of events, or noise energy for the relevant source.

The Equivalent Continuous Sound Pressure Level ( $L_{eqT}$ ), defined as "the value of a continuous steady sound that, within a measurement time  $T$ , has the same mean square sound pressure as a (fluctuating) sound under consideration" (International Organisation for Standardisation, 1982), has been adopted by the International Organisation for Standardisation for the measurement of both community noise exposure and hearing damage risk. It is also widely used in assessing the effects of noise on a variety of other outcomes, such as non-auditory physiological and mental health, sleep, communication and activity disturbance, and community reaction. It is however inadequate in several respects. It underrepresents the importance (in terms of perceived noisiness) of sounds with frequencies below 100 Hz, and does not take into account other features of the sound which might be relevant to the subjective effects of interest.



L<sub>A</sub>max, which is the maximum L<sub>AeqT</sub> reached during a given sound event (for example, an aircraft flyover or truck passby), where  $T = 1.0$  s, the time constant on "Slow" setting of the sound level meter, is another commonly used metric. This metric may be most appropriate for impulsive sounds, but for continuous sounds does not take into account the potential importance of sound duration in determining the impact of the sound.

As a consequence of the overwhelming range of noise exposure measures, the results of the many studies which have examined the impact of exposure to noise on human health, performance and reaction are difficult to compare directly. Whilst the various indices provide similar estimations of mean perceived magnitude (Botsford, 1969; Ollerhead, 1973; Young and Peterson, 1969), different indices may vary widely in estimating other psychological as well as physiological outcomes of a sound.

Which index is most accurate will depend on the outcome in question as well as features of the sound, situation and individual. For example, sleep disturbance seems to depend critically on signal to noise ratio and number of noise events, whereas prediction of annoyance depends on consideration of low frequency component, impulsivity and number of noise events.

The present review does not restrict its focus to any particular noise indices, however the relative advantages of the various indices are noted where appropriate.

### *Outside Versus Inside Sound Measurements*

Another important consideration of the measurement of noise exposure is where these measures should be taken, and the attenuation of sound that can be expected from outside to inside.

Firstly, is it adequate to estimate the noise levels of an entire residential area, or should levels be measured at individual homes? The accuracy of taking measurements at individual residences must be weighed against the costs (in time and finances) it entails.

Secondly, are inside or outside measures more relevant to the effects in question? The answer to this question probably depends on the outcome in question. For example, hearing impairments probably depend on both outside and inside levels, whereas sleep disturbance depends largely on noise levels inside the bedroom. However, noise levels inside the bedroom might be quite accurately predicted by noise levels outside if people sleep with their windows open. Reaction (including annoyance, dissatisfaction etc.) bears a complex relationship to inside versus outside noise (see Bullen et al., 1985).

Thirdly, what is the likely magnitude of the difference between outside versus inside levels? That is, how much are buildings likely to attenuate the sound? Three sources address this issue. Finegold, Harris and von Gierke (1994) refer to the US Environmental Protection Authority's "average house noise reduction" as 17 dB for windows open and 27 dB for windows closed. It is questionable whether these two values are applicable to all American, let alone Australian, conditions. Passchier-Vermeer (1993) assumed outdoor/indoor attenuation of 15 dB with single glazed windows and 25 dB

for double glazed windows (presumably with windows closed in both cases). For regulatory purposes she stated that 15 dB was appropriate. However in a later report, Passchier-Vermeer (1994) states that with windows in the "ventilation position" (partly open), for which sound insulation is to be determined according to Netherlands night time aircraft noise regulations, the attenuation is 22 dBA for landings and 20.5 dBA for take-offs. When windows are fully open the attenuation is lessened by 5 dBA. Carter, Ingham and Tran (1992b) reported that average attenuation depends on whether the window was closed or partially open (up 20 cm, which presumably corresponds to the "ventilation position") and on which noise metric is used. With windows partially open the mean attenuation values were 17.05, 17.35, 17.2, 13.39, 17.77 and 17.63 dB for LAeq, LAmx, LApk, LA90, LA10 and LA1, respectively. With windows closed the mean attenuation values were 21.52, 23.08, 21.11, 12.05, 23.72 and 23.72 for these metrics, respectively.

The relevance of these three attenuation guidelines to aircraft noise in particular must be considered. The degree of attenuation is influenced by noise spectrum, with lower frequency noises being attenuated less. The position of the source is also likely to be a source of variation. For example, aircraft noise is often likely to be less attenuated than traffic noise, because it comes from above buildings and in Australia roofs generally provide less insulation than walls. Thus the applicability of the general attenuation values offered by the US EPA to aircraft noise in particular is dubious. The attenuation values reported by Carter et al (1992) were determined for traffic noise and may not be appropriate for aircraft noise. The Netherlands regulatory figures may well be appropriate for aircraft noise and apartment buildings, but not for the single family, single storey dwellings commonly found near airports in Australian cities. Neither the USEPA nor Passchier-Vermeer (1994) considered more than one noise metric, despite the potential of different metrics to produce different attenuation values. Thus, it is recommended that further investigations be made into aircraft noise attenuation under Australian building conditions.

#### **4.1.2 HEALTH**

From a theoretical point of view, an assessment of the causal relationship between noise exposure and non-specific health effects presents difficulties. Increases in blood pressure level, heart disease, gastric ulcers, and other stress-related syndromes have a multifactorial origin. It is difficult to exercise sufficient control over all relevant risk factors in epidemiological studies, particularly as several of the risk factors such as social class, personal habits, and personality characteristics are difficult to define.

A number of approaches to assessing health outcomes have been employed. They can be broadly classified into epidemiological, direct assessment and survey techniques. Though each of these approaches has limitations, considering data derived from all three approaches provides a valid insight into the impact of noise exposure on human health.

### *Epidemiological Techniques*

The epidemiological approach of obtaining data from public records, hospital records and sales records, is an extremely cost effective one which involves minimal compliance from subjects and is not influenced by demand characteristics as surveys may be (see Job and Bullen, 1985). Studies examining the health effects of exposure to aircraft noise have been based on records of deaths. Birth records are also examined to determine birth weight and birth defects. Records of both general and mental hospitals have been examined to evaluate numbers of admissions and the nature of complaints in areas of differing noise exposures. Similarly, numbers of visits to general practitioners, and the reasons for the visit have also been considered. The incidence of a particular illness in a particular area has also been measured by evaluating the use of prescription and non-prescription drugs on the basis of sales in pharmacies in that area.

Despite the similarity of these approaches they are of differential value. All of these indices are plagued by the problem that people will not only be admitted to a hospital, visit the general practitioner or buy medication in their area of residence. Whilst public records of births and deaths provide a relatively complete index of the actual population parameter for these outcomes, hospital admission records are likely to be incomplete. For health outcomes which require immediate medical attention, such as myocardial infarction for example, most occurrences in the population will be reflected in hospital admissions. However, residents suffering from seemingly minor complaints which may result from noise exposure, such as sleep disturbance for example, are unlikely to be admitted to hospital (until the "minor" complaint results in a more serious one). Even records of visits to general practitioners will underestimate the actual frequency of minor complaints such as these. Data gleaned from pharmacy sales has similar flaws. Not only do pharmacy sales not provide a complete index of drug use, but drug use does not provide an accurate index of the population incidence of a particular complaint. For example, not everyone suffering from sleep disturbance will take sleeping pills. Further, people may take sleeping pills even if they are not suffering from sleep disturbance. Data regarding the nature of complaints which have caused a visit to the GP, or admission to hospital, or the severity or type of birth defects tends to be very unreliable, due to the large amount of variance introduced by differing recording techniques from one hospital (or general practitioner) to another. Furthermore, these variations may not be random. For example, use of services within the local area may depend on the quality and quantity of such services, which may vary with the socio-economic status of the area. Socio-economic status may influence treatment in the private versus the public system and thus entry into public records. This would tend to underestimate hospital admissions in higher socio-economic, often lower noise, areas.

### *Survey (Self-Report) Techniques*

Survey techniques overcome these difficulties to some extent and allow assessment of a wide range of health outcomes. Survey techniques involve obtaining information about subjects' physiological and psychological health status via interviews and questionnaires. Thus a respondent can be asked

whether they are suffering from sleep disorder or whether they are depressed. The survey approach allows detection of complaints which are not severe enough to warrant a visit to the doctor. However, some complaints which might be detected by direct measurement may not be sufficiently detectable by the respondent for them to report it. Survey techniques also strike a middle ground between the epidemiological and direct measurement in terms of cost effectiveness and subject compliance. Further, they permit control over (and assessment of) the consistency of measurement techniques in order to minimise unnecessary variance in the data. For example, interview protocols can be standardised. The main disadvantages of survey techniques are those inherent to self-report. The accuracy of the data relies on the accuracy of the subjects report. This may be distorted by demand characteristics or imperfect knowledge or recall, or deliberate distortion. Further, surveys which rely on volunteer sampling may not provide a representative sample of the population making generalisation of the findings to the general population difficult. Similarly, the necessity of excluding certain individuals, for example on the basis of literacy, also undermines the representativeness of the sample.

However, many of the difficulties which are potentially associated with survey techniques may be minimised or avoided by using good sampling, good interview technique and payment of incentives (see Job and Bullen, 1985, 1987).

#### *Direct Assessment (Observational) Techniques*

Direct assessment of particular health outcomes circumvents the problem which plagues the epidemiological approach (and to a lesser extent survey techniques) that the incidence of certain illnesses is underrepresented. For example, the incidence of high blood pressure in a population can be assessed by randomly selecting a representative sample of individuals from that population and directly measuring the blood pressure of these individuals. This approach does not depend on a complaint becoming sufficiently severe to require consultation with a general practitioner, or admission to hospital, before it can be detected. As for the survey (but not the epidemiological) approach, unnecessary variance can be minimised by standardising experimental procedures. A further advantage of this approach to assessing the health outcomes of noise exposure is that it allows measurement during noise exposure in a way the other two methods do not. Unfortunately this approach also has its shortcomings. Firstly, this method is very labour intensive and thus costly. Secondly, it involves a greater degree of compliance from subjects than does the epidemiological approach. Thirdly, it involves the same difficulties with volunteer bias as do survey techniques.

Finally, a number of the putative detrimental health outcomes of noise are not amenable to assessment by this method. For example, depression cannot be assessed in as direct a manner as blood pressure.

#### **4.1.3 PERFORMANCE**

The majority of studies have assessed performance by direct assessment and/or survey techniques.

### *Direct Assessment (Observational) Techniques*

Direct assessment involves observing subjects carrying out the particular task or activity while monitoring their ability to do so, sometimes under noisy conditions. The main disadvantage of this approach is that the assessment procedures may interfere with performance of many tasks or activities (for example, Hawthorne effect (Roethlisberger and Dickson, 1939)). As a particularly pertinent example, direct assessment of sleep disturbance by monitoring individuals' vegetative function during sleep is liable to interfere with normal sleep patterns.

### *Survey (Self-Report) Techniques*

Survey techniques involve asking respondents whether noise interferes with various activities (such as watching television, conversation) or whether they are having trouble sleeping. This allows assessment of a wide variety of activities, some of which may be difficult to assess with direct measurement. However, as noted previously the accuracy of this method depends on the accuracy of the respondents' recall, knowledge, or report.

Data gathered using each of these methods will be considered in the present review.

#### **4.1.4 REACTION**

Reaction is typically measured by survey techniques, which have the advantages and disadvantages outlined above with respect to health surveys.

Consideration of reaction has frequently been restricted to an assessment of community annoyance (Gunn, Petterson, Cornog, Klaus, and Connor, 1975), to the exclusion of the many other reactions residents could potentially have to noise exposure. However, measures of reactions to noise phrased in terms of the degree to which the respondent is "affected by" or "dissatisfied" with the noise provide a demonstrably more global and reliable measure of reaction than more specific measures, such as "annoyance with" the noise (Job et al., 1996d). Furthermore, indices of reaction which are constructed from a number of questions are more reliable than measures based on a single question (Job 1988a, 1991a). There may be two reasons for this. Firstly, the reliability of an index is increased by increasing the number of items used to construct it. Secondly, like single questions phrased in general terms ("affected by" and "dissatisfied"), the indices composed of several items have covered more potential reactions than single questions on "annoyance". Thus, a change in one component of reaction will not alter the score on the index as much as will a change in the one component to which a single item index refers (Job et al., 1996d).

Studies which have considered more than annoyance as a measure of subjective reaction (e.g. Bullen and Hede, 1986; Bullen, Hede, and Job, 1991; Job and Hede, 1989; Job, Bullen, and Burgess, 1991) have produced broadly similar results to those studies examining annoyance only (Berglund and Lindvall, 1995).

This review includes "reaction" data derived from a single question on annoyance as well as data derived from single questions phrased in more general terms and from reaction indices composed of a variety of questions. However, in assessing the results of reviewed studies it should be recognised that the latter two approaches provide more reliable and valid data.

Several other indices of reaction have been considered, including activity disturbance (Borsky, 1980; Bullen and Hede, 1986; Bullen, et al., 1991; Gunn, 1987; Job and Hede, 1989; Job, et al., 1991; Lindvall and Radford, 1973), complaint disposition and changes of residence (Borsky, 1980; Bullen and Hede, 1986; Bullen, et al., 1991; Gunn, 1987; Hede and Bullen, 1982a, 1982b; Job and Hede, 1989; Job, et al., 1991; Lindvall and Radford, 1973). These indices potentially provide the opportunity to assess reaction without the use of self-report, but have typically been addressed in surveys rather than observational studies anyway. Further, these indices are not directly related to reaction, as they may be influenced by a range of other factors. Arvidsson and Lindvall (1978) found that simple measures of physiological arousal (urine catecholamines) are not adequate predictors of self-reported noise annoyance.

De Jong and Miedema (1995) and Job (1995) provide further discussion of survey techniques for measurement of reaction. Consideration of the most appropriate response scales for measuring reaction is provided by Fields (1996b, 1996c), Job (1995) and Khan, Johansson and Sundback (1996).

## **4.2 STUDY TYPE**

The effects of exposure to aircraft noise have been conducted in the field and in the laboratory. Laboratory studies involve noise exposure in the laboratory, whereas field studies involve more naturalistic noise exposure. Field studies may involve some testing in the laboratory. Again, the relative merits of these two basic study types should be considered in evaluating the findings of reviewed studies.

### **4.2.1 FIELD (COMMUNITY) STUDIES: RESIDENTIAL AND OCCUPATIONAL STUDIES**

Generally in field studies, the noise exposure which serves as the main independent variable occurs in the subjects' area of residence (residential studies) or place of work (occupational studies). The value of the ecological validity of such exposure is counterposed by the difficulties of measuring it.

Measurement of dependant variables is generally conducted in the field but may be conducted in the laboratory.

The main disadvantage of field studies is the bias potentially introduced by self-selection. People who choose to live in noisy areas or work in noisy occupations are likely to be people who are tolerant to noise and have not suffered negative impacts on health, performance and reaction (however residence and career choices may be restricted by other factors such as socio-economic status). Furthermore, individuals working in noisy professions

tend to be young males. As these samples are not representative of the general population, it is difficult to draw conclusions concerning the general populations. This difficulty can be overcome to some extent by taking residential behaviour into account or performing studies immediately following changes in noise exposure.

#### **4.2.2 LABORATORY STUDIES**

In laboratory studies subjects are exposed to varying levels of various sounds. This facilitates measurement of more precisely controlled noise levels of a wider range of noise sources than is possible in field studies.

The reverse side of this advantage is the difficulty of assessing the effects of long term noise exposure in humans and the reduced ecological validity. For example, the sleep process and the manner in which noise affects it may be quite different in the unfamiliar laboratory environment than at home. This problem may be addressed in part by allowing the subjects to become familiar with the testing environment before the commencement of testing.

Measurement of dependant variables is typically conducted in the laboratory. This has the advantage of permitting tighter controls on procedure, in particular noise levels during testing, than is possible in the field.

Many laboratory studies employ non-human animals as subjects, raising issues regarding the validity of animal models of effects in humans. While such studies have yielded valuable information they cannot address issues to do with human activity disturbance or dissatisfaction and the levels of noise at which these occur.

### **4.3 STUDY DESIGN**

Several community study designs have been used in an attempt to ascertain the impact of exposure to noise on human health, performance and reaction, some more appropriately than others. They can be broadly classified into cross-sectional and longitudinal designs. Each of these have advantages and disadvantages which should be considered when assessing the findings of studies which have used them.

#### **4.3.1 CROSS-SECTIONAL DESIGNS**

Cross-sectional designs involve comparing groups which are exposed to different levels of noise simultaneously. For example, the health of residents in a low noise area (say, maximum level of less than 50dB) might be compared to the health of residents in a high noise area (say, maximum level greater than 60dBA). The advantages of this design are that it is time and cost effective and that the required populations are readily available. However it has serious limitations, making a finding that health is poorer in high noise areas difficult to interpret.

Firstly, the possibility of finding an effect is possibly reduced by the possibility that the high noise sample represent a "survivor" population.

Where there has been high noise exposure for some time people who are particularly sensitive to noise may have moved out of the area, leaving a group of people who are less vulnerable than average to any detrimental effects of noise exposure. Thus, even if noise exposure does have a negative impact it might not be detected by comparing such a survivor population with residents of a low noise area. However, those remaining in a high noise area may not be those who are less susceptible, rather those who are less aware, or less able to move, which might produce the opposite effect. One means of addressing these concerns is to employ a sample from an area which has just become exposed to high noise levels. However, this approach brings its own difficulties. Such a sample is not as easy to come by and, more importantly, this design potentially confounds the effect of noise exposure per se with the effects of a change in noise exposure. In addition, health effects due to noise may take time to develop and so could be missed in a study of recently introduced noise. If the comparison group is one which has just become exposed to low noise levels the complication of previous exposure levels is introduced. Ideally these effects would be disentangled by employing the two "changed exposure" groups ("changed to high noise" and "changed to low noise") as well as "long term" low and high exposure groups. Alternatively, one might consider the impact of noise exposure on sensitive subgroups of each sample, or control for the effects of residency changes statistically.

Secondly, because the cross-sectional design is essentially correlational, the chain of causality is not clear. Given a correlation between ill health and high noise levels, it seems apparent that poor health is not the cause of high noise levels (although not impossible, in that people who are forced out of work for medical reasons, may have to live in a high noise area for financial reasons), but it is not clear high noise levels cause ill health. For example, ill health could be caused by other factors which are associated with residency in high noise areas, such as low socio-economic status. This concern can be addressed to some degree by controlling (methodologically or statistically) for the effects of such confounding factors. Alternatively, direction of causality may be determined by conducting longitudinal studies.

#### **4.3.2 LONGITUDINAL DESIGNS**

Longitudinal designs avoid many of the problems of cross-sectional designs by facilitating interpretation of causality and restricting inflation of variance and confounding due to individual differences. In longitudinal research the same subjects are tested on more than one occasion. This allows examination of the effects of chronic exposure to noise, without confounding by the characteristics of people who have had long term exposure to noise versus those who have not (for example, socio-economic status). However, exposure prior to the first testing occasion should be considered in order to address the possibility that any effects have already taken place.

Longitudinal designs also provide the opportunity to examine the effects of a change in noise exposure from low to high or high to low. Ideally, subjects are first tested before exposure to high noise levels. They are then re-tested at various intervals following exposure to high level noise. Because the "low noise group" involves the same subjects as the "high noise group", any observed effect is unclouded by confounding factors such as socio-



economic status and noise sensitivity. Thus, a change in health, performance or reaction from the first to later testing occasions can be attributed to noise exposure with relative confidence. The effects of a change in noise exposure can be gauged by testing during a long follow-up period after the change to high noise levels. The occurrence of adaptation can also be evaluated in this manner. Changes in residence can be monitored and considered as a component of reaction.

Although superior to cross-sectional designs, longitudinal designs are not without their problems. Firstly, the results of follow up test may be influenced by previous testing. In order to assess this influence it is advisable to administer test on each occasion to a cohort that has not been tested before. Designs which involve a change in noise derive further benefit from inclusion of a "matched" control group which is repeat tested but not exposed to a change in noise. Secondly, events other than noise exposure changes can confound results if the groups are affected differentially, which may be the case for changes in air pollution etc which accompany the change in noise level. A final difficulty with longitudinal designs is that they may be costly and require much more time.

#### **4.4 MEDIATING OR MODIFYING VARIABLES**

It is unlikely that sound only influences health, performance and reaction directly. Some of its impacts are probably mediated by other effects or moderated by other factors. A mediating variable is one which "transfers" the impact of the sound. Thus, if sound exposure causes sleep disturbance, which in turn causes annoyance, sleep disturbance is said to "mediate" the effect of sound on annoyance. A moderating variable is one which influences (ameliorates or potentiates) the impact of the sound. Thus, if the extent of annoyance produced by a sound depends on a person's age, age is said to "moderate" the impact of the sound.

##### **4.4.1 MEDIATING VARIABLES**

Studies have sometimes assessed mediating variables by assessing the correlation between the mediating variable in question and the outcome it supposedly mediates. However, this approach results in ambiguity as to the causal direction. For example, a correlation between noise-induced sleep disturbance and annoyance could indicate that sleep disturbance mediates the impact of sound on annoyance, that annoyance mediates the impact of sound on sleep disturbance, that sound has direct and independent impacts on sleep disturbance and annoyance or that some third effect mediates the impact of sound on both sleep disturbance and annoyance.

Clearly, it is possible that chains of mediation involve more than one step. Thus one way in which noise impacts on health might be by disturbing immune function, by causing anxiety, by causing sleep disturbance. By recognising "one step" chains of mediation it is possible to infer which more complex chains might exist.

This review presents hypotheses about potential indirect mechanisms of the impact of sound on outcome variables. Only "one step" mediations are discussed, leaving others which remain untested to be inferred. Empirical evidence which addresses these hypotheses is also presented.

#### **4.4.2 MODERATING VARIABLES**

Consideration of moderating variables, such as age, gender, ethnicity, socio-economic status, attitude toward the noise source, and sensitivity has unfortunately been sparse. Noise sensitivity, which has arguably received the most attention, suffers from conceptual and methodological difficulties. Firstly, the application of the concept noise sensitivity tends to be circular. Noise sensitivity has been proposed as a trait susceptibility to noise, but is assessed only in terms hypothesised effect. Secondly, noise sensitivity has typically been measured using self-report techniques and single-item indices, raising serious concerns about the validity of the data. Measurement in terms of reactivity to other stressors perhaps presents a solution to each of these difficulties. For example, subjects classified as being high or low responders to traffic noise have been found to exhibit similarly elevated or reduced reactivity to stressors, including simulated traffic noise, rotten-egg odour and tobacco smoke, in the laboratory (Winneke, Neuf, and Steinheider, 1996).

It is important that the influence of moderating variables be examined. Failure to consider moderating variables is liable to distort results of investigations of the impacts of noise on health, performance and reaction. Further, a sound knowledge of the variables which moderate the impacts of noise is invaluable. It would allow better prediction of the impacts of a given noise and thus would provide the basis for decisions about which populations to target with noise mitigation measures. More importantly, it might direct efforts towards alternative interventions to ameliorate the impacts of noise. For example, if particularly negative impacts of aircraft noise are associated with a negative attitude toward the airport, interventions designed to improve attitudes could be effective in minimising impact of the noise (see Job, 1991b on use of attitude).

#### **4.5 CONFOUNDING VARIABLES**

A correlation between sound exposure and a particular outcome may not indicate any relationship between exposure and the outcome at all, but rather the effects of a third variable. For example, poorer health may be observed in high noise areas not because noise has a negative effect on health, but because people who live in such areas may tend to be of lower socio-economic status, and low socio-economic status is known to be associated with poor health. Confounding variables may also mask a true effect of noise. Widespread failure to adequately control for the effects of potential confounding variables may be one of the reasons for inconsistencies in data regarding the impacts of noise on health, performance and reaction.

The repeated commentary that confounding factors may explain a difference in health between those in high versus low noise areas is frustrating.

However, little can be done about this. It is unfortunate that residents in high noise areas are likely to be closer to industrial zones, have less access to services and have lower socio-economic status than residents in low noise areas. The researcher can do nothing to alter this state of affairs. In research on various factors (especially potentially beneficial ones), long-term effects can be studied in well controlled experiments in which subjects are exposed to the factor and the effects observed. This is not ethically or logistically possible in noise research. First, subjects who are willing to be exposed to long term noise for the sake of science may be difficult to find and are likely to constitute a self-selected, non-representative subset of the population. Second, given the possibility of real harm, no ethics committee would allow such research. These difficulties present a considerable disincentive to conducting noise research. Even where rare opportunities emerge to research potential health effects in "naturally occurring experiments", such as changes to airports (e.g. the opening of the third runway at Sydney airport), research is difficult. For example, it may be hampered by lack of funding or changes in human reaction created by extensive media coverage (Carter et al., 1996a). Thus, the frustration we may feel with the incomplete answers supplied should be tempered with an awareness of the reasons for these limitations.

## POTENTIAL NOISE IMPACTS

### 5.1 IMPACT OF SOUND ON AUDITORY HEALTH

Empirical evidence unambiguously supports the popular assumption that excessive exposure to high intensity noise can result in hearing loss. Individuals living in remote quiet regions demonstrate particularly acute hearing in comparison with members of urban populations of equivalent age (Rosen, Bergman, Plester, El-Mofty, and Satti, 1962), though this may be due to cultural, genetic, dietary or non-noise environmental factors, rather than noise exposure alone. The majority of evidence pertaining to the impact of noise on auditory health derives from industrial surveys, although there is also evidence that motorcycling, snowmobiling, loud music, toys, and fireworks can impact on auditory health (Axelsson, 1991; Axelsson and Jerson, 1985; Dickinson and Hegley, 1989; Fearn and Hanson, 1984; Hellström, 1991; Hellström and Axelsson, 1988; Hellström, Dengerink, and Axelsson, 1992; Ising, Babisch, Gandert, and Scheuermann, 1988; Kryter, 1991; Struwe, Jansen, Schwarze, Nitzche and Notbohm, 1995). Although currently available data suggest that typical exposures to aircraft noise alone are not sufficient to produce hearing loss, noise-induced hearing loss may be observed in the presence of exacerbating factors. Other auditory effects, such as aural pain may result from aircraft noise.

#### 5.1.1 AURAL DISCOMFORT AND PAIN

##### *Discomfort, Aural Pain and Sound Pressure Level*

For individuals with normal hearing, the SPL threshold for physical discomfort, referred to as the uncomfortable loudness level, is around 80-100dB (Spreng, 1975). The threshold for aural pain ranges from 110-130 dB, although individual differences are marked especially for high frequency exposures (von Gierke, Davis, Eldredge, and Harry, 1953). Intense low frequency noise also tends to produce aural pain (von Gierke and Nixon, 1976; see also von Békésy, 1960). Thus, whilst residents in the vicinity of an airport seldom experience exposures intense enough to occasion physical pain, they frequently experience sound pressure levels which are sufficient to produce discomfort.

##### *Noise Moderators*

Individuals with abnormal hearing often demonstrate dysacusis, "a lowering of the threshold of aural discomfort and pain" (Berglund and Lindvall, 1995, p46), so may suffer pain at sound pressure levels which are common in the vicinity of the airport. For example, in cases of inflammation, pain may be caused in the eardrum or middle ear by sound pressure levels of about 80-90 dB.

With regard to the issue of aural pain, particular consideration must be given to hearing-aid users, who frequently report discomfort with exposure to

sudden loud sounds, loud music, and even raised voices. Hearing aids may transmit some components of aircraft sound at a higher volume than other sounds, thus contributing to increased discomfort and disturbance (Vipac Engineers and Scientists Ltd., 1990). However, it is possible to set hearing aids to automatically limit sound pressure level output (Gabrielsson, Johansson, Johnsson, Lindblad, and Persson, 1974).

Thus, if exposure to aircraft noise produces hearing impairment, it may further contribute to the experience of aural pain at the SPLs common in the vicinity of the airport.

Kinhill (1990) recognised that hearing aid wearers may experience some discomfort or pain as a result of exposure to aircraft noise. This suggestion was supported by the submission of one hearing aid user to the Senate Select Committee on Aircraft Noise in Sydney (1990) that he found he was forced to turn his hearing aid off and felt this resulted in various safety risks.

Kinhill (1990) however, did not suggest that individuals with impaired hearing or ear infections may suffer discomfort or pain as a result of diacusis, nor that even individuals with normal hearing are likely to experience some discomfort given the strong low frequency component of aircraft noise.

#### **5.1.2 DEFINITIONS OF HEARING LEVEL, NOISE INDUCED HEARING LOSS AND HEARING IMPAIRMENT**

Discussion of the effects of noise exposure on hearing requires definition of the terms hearing level, hearing loss, and hearing impairment.

##### *Hearing Level*

"Hearing level" is a physical unit used to describe the output of an audiometer. Many audiological outcomes can be measured in terms of hearing level, such as hearing threshold, uncomfortable loudness level, and acoustic reflex threshold. When auditory thresholds are expressed in hearing level, they are termed hearing threshold levels." (Berglund and Lindvall, 1995, p30).

##### *Hearing Loss and Threshold Shift*

Hearing loss usually refers to an upward shift of hearing threshold level (King, Coles, Lutman, and Robinson, 1992), which may be temporary or permanent. Noise-induced threshold shift is a hearing loss attributable to noise alone. Thus, in order to infer that a threshold shift following noise exposure is in fact noise-induced, the influence of other factors which may have caused the shift must be taken into account.

In particular, the influence of the reduction in hearing sensitivity which typically occurs with age, known as presbycusis (Glorig and Nixon, 1962), must be considered. Unfortunately, there are problems associated with disentangling the effects of noise exposure and ageing per se. Although the general progression of presbycusis has been well-established (for examples see, Gallo and Glorig, 1964; Hinchcliffe, 1959; Spoor, 1967; US NCHS, 1987; Weinstein, 1994), there is substantial individual variation in both the

amount and rate of hearing loss due to ageing. A model relating presbycusis and noise induced permanent threshold shift has been proposed by Corso (1992). However, controversy exists as to the degree to which hearing loss due to the cumulative effects of everyday noise exposure (sociacusis; see Glorig, Grings and Summerfield, 1958) confounds hearing loss due to ageing alone.

### *Hearing Impairment*

Hearing impairment has been defined in terms of hearing level and hearing loss. In both cases the classification depends on exceeding some criterion of severity.

Thus, the criterion for hearing impairment has been defined as "the hearing level at which individuals begin to experience difficulty in leading a normal life, usually in relation to understanding speech" (Berglund and Lindvall, 1995, p30: citing Abel, Krever, and Alberti, 1990; Smoorenburg, 1992). Hearing of other acoustic signals, such as door bells, telephones, or electronic signals, may also be impaired.

Alternatively, a hearing loss which is greater than a particular standard is classified as hearing impairment. These standards have supposedly been set according to the requirements for adequate speech communication. According to the international standard (ISO 1989, 1990), an individual with a hearing loss of at least 25 dB averaged over the frequencies 0.5, 1, and 2 kHz is classified as hearing impaired. However higher frequency signals (up to 4kHz) are critical to speech intelligibility and music perception under nonoptimal conditions such as the presence of high level background noise or signal distortion (Abel et al., 1990; Acton, 1970; Aniansson, 1974; Ceypek and Kuzniarz, 1974; Harris, 1965; King et al., 1992; Kryter, Williams, and Green, 1962; Niemeyer, 1967). This shortcoming of the ISO criterion is particularly pertinent for noise-induced hearing losses, as these most commonly occur at 2kHz and above. Thus, losses at 3 kHz should also be included in the classification of hearing impairment. Inclusion of losses at frequencies of 4 and 6 kHz would produce a criterion which is particularly sensitive to early hearing impairment. Standards in various countries do take higher frequencies into account. In Australia, hearing disability is classified as beginning when there is a hearing loss of at least 20dB at any of 0.5, 1, 1.5, 2, or, 3 kHz, a hearing loss of 25 dB at 4kHz, of 30 dB at 6kHz or of 35 dB at 8kHz (Macrae, 1988). Table 5.1 presents a range of hearing loss criteria adopted by various US organisations (Ishii, 1993a). In the United Kingdom, the standard is an average hearing loss of 30 dB at 1, 2, and 3 kHz, and in Poland, 30 dB at 1, 2, and 4 kHz (after age correction).

Thus, the classification of hearing impairment depends on the, often arbitrary, choice of a criterion. Since even small hearing losses can disturb voice communication (Smoorenburg, 1992), the use of such a criterion may result in hearing loss which actually causes impairment not being classified as "hearing impairment". Further, the size of the hearing loss is not the only determinant of impairment. Alterations in the loudness-growth function (recruitment) can result in reduced speech intelligibility (Hellman and Meiselman, 1990). Finally, speech intelligibility may not be the most appropriate guide to impairment, because it does not necessarily indicate

whether a hearing loss is sufficient to interfere with daily life. Because speech involves a multiplicity of cues, hearing losses which are sufficient to interfere with other activities may not reduce speech intelligibility when listening conditions are optimal. To avoid these difficulties, in some countries the use of a criterion other than impairment itself is rejected (King et al., 1992).

TABLE 5.1: AMERICAN HEARING LOSS CRITERIA

Source	Frequency Fence (kHz) <sup>1</sup>	Average (dB)
American Academy of Ophthalmology and Otolaryngology <sup>2</sup> (1961)	0.5, 1, 2	25
American Academy of Otolaryngology <sup>3</sup> (1990)	0.5, 1, 2, 3	25
National Institute of Occupational Safety and Health (Kryter, Williams and DM Green, 1962; JD Harris, 1965)	1, 2, 3	25
Occupational Safety and Health Act (US Department of Labour, 1983)	2, 3, 4	10

- Notes: 1. The level above which hearing impairment occurs.  
2. American Academy of Ophthalmology and Otolaryngology and AMA (pre-1971) were the same.  
3. American Academy of Ophthalmology and Otolaryngology's hearing section separated to AAO (post-1979), AMA (post-1971), and ANSI-1969.
- Source: Ishill (1993)a.

The degree of noise-induced hearing impairment that could be expected in a community is important for determination of "acceptable" noise levels. "Damage-risk has been defined as the percentage of a population with a given amount of hearing impairment, after corrections have been made for those persons who would "normally" incur losses from causes other than noise exposure (ISO 1989, 1990). " (Berglund and Lindvall, 1995, p39-40).

5.1.3 MECHANISMS OF NOISE-INDUCED HEARING LOSS

Current knowledge of the effects of noise on the physiology of the auditory system has largely been gleaned from laboratory studies with humans and nonhuman animals (for examples see CHABA, 1988; Katz, 1994). Data suggest that noise can cause changes to the metabolism of the cochlea, which are at least partially reversible, and can cause permanent mechanical damage to the auditory system.

*Normal Auditory Process*

In the normal auditory process, sound vibrations in the air cause vibrations of the eardrum, which are transmitted by the three small bones of the middle ear (the malleus, incus and stapes) to the organ of Corti, the sensory organ of the cochlea (inner ear). As a consequence waves travel along the basilar membrane, causing the hair cells with which it is covered to bend. This produces nerve impulses which are transmitted to the auditory brain to cause the perception of sound. The maximum stimulation of the hair cells occurs

at the point of greatest displacement of the basilar membrane. The location of this point is determined by the frequency of the sound causing the displacement. The higher the frequency, the closer is the point of maximum displacement to the base of the cochlea, where the basilar membrane is narrowest. The lower the frequency the further is the point of maximum displacement towards the point at which the basilar membrane is widest, its apex.

The otoacoustic reflex provides some protection against damage by high intensity sounds. In response to sounds above 75-90dBA, sudden contraction of the stapedius muscle changes the movement of the stapes, reducing conduction of sound energy to the cochlear by approximately 15-20 dB at low and middle frequencies (Møller, 1961). The degree of protection afforded by this reflex depends on the intensity, frequency and time pattern of the sound. Sounds with a rapid rise time (impulsive sounds) can penetrate the ear before the muscle contraction occurs, because the response time of the aural reflex is of the order of 100-300 ms. This may in part explain greater community reaction to impulsive noise, than non-impulsive noise (Job, et al., 1991). Further, since the reflex action weakens with time it provides little protection against damage by prolonged steady sounds. This is particularly the case for frequencies above 3 kHz, for which the muscle contraction is momentary, whereas for lower frequencies it continues for a considerable time (Johansson, Kylin, and Langfy, 1967). The efficacy of the acoustic reflex also demonstrates substantial individual variation. It has been demonstrated that patients with unilateral stapedius muscle paralysis experience a significantly greater temporary loss in auditory sensitivity in the affected than in the unaffected ear (Zakrisson, 1975). Contradictory findings have been found in animal studies, in which the stapedius muscle was severed (Ferris, 1966; Steffen, Nixon, and Glorig, 1963).

The cochlea might also be protected from damage by high intensity noise by pathological changes to the middle ear, although it has also been proposed that the such changes could increase the possibility of noise-induced damage. Whilst there have been reports of lower noise induced hearing loss in damaged than in normal ears (Johansson, 1952), it has been argued that bone conduction becomes more effective with middle ear pathology, rendering the otoacoustic reflex less effective (Dieroff, 1964; Mills and Lilly, 1971; Mounier-Kuhn, Gaillard, Martin, and Bonnefoy, 1960; Ward, 1962).

#### *Metabolic Consequences of Noise Exposure*

It is thought that cochlear blood flow may be altered by noise exposure, resulting in changes to local temperature and cell metabolism. These changes may result in damage to local proteins (Berglund and Lindvall, 1995).

Ward (1960) hypothesised that insufficient cell metabolism as a result of noise exposure might produce both the temporary and permanent noise-induced hearing deficits.



### *Mechanical and Sensorineural Damage*

Intense or explosive sounds, such as blasts, can rupture the eardrum or cause immediate damage to the structures of the middle and inner ear. Prolonged exposure to noise can also produce morphological changes in the auditory system. Initially, the stereocilia (receptor cells) of the inner and outer hair cells in the cochlea are found to fuse and bend (Axelsson and Lidén, 1985). The hair cells of the inner ear may be destroyed, with an associated loss in auditory sensitivity. The severity of noise-induced hearing loss depends on both the degree and location of damage in the organ of Corti, which, in turn, depend on the intensity and frequency of the sound exposure. The number of hair cells damaged or destroyed increases with increasing intensity and duration of noise. Many hair cells can be lost from basilar region which is receptive to low frequency stimulation without significant loss in low frequency sensitivity. Whereas loss of hair cells from the basilar regions which are responsive to high frequency stimulation results in significant losses of high frequency sensitivity (Hamernik, Ahroon, and Hsueh, 1991; Miller, Rosthenberg, and Eldredge, 1971; see also Katz, 1994). This is thought to be due to there being a greater portion of the basilar membrane receptive to low frequency than to high frequency stimulation.

Whilst several putative mechanisms have been proposed to account for the destruction of the Corti organ (for reviews see Ward, 1973, 1991), and numerous animal experiments have been conducted, it is not yet known how the damage occurs. One tentative theory is that mechanical stresses destroy the hair cells (Hamernik, Turrentine, Roberto, Salvi, and Henderson, 1984).

Permanent hearing losses are generally due to sensorineural damage (to the inner ear) and can thus be detected in both air and bone conduction audiograms.

#### **5.1.4 NOISE-INDUCED TEMPORARY THRESHOLD SHIFT**

A substantial reduction in audiometric thresholds, sometimes accompanied by tinnitus, often results from brief exposure to high intensity noise, but disappears some time after return to a quiet environment. This transient loss in auditory sensitivity is referred to as a noise-induced temporary threshold shift (NITTS) and is measured by comparing pre- and (repeated) post-exposure audiograms.

NITTS has been examined in laboratory studies with a number of animal species (including humans), using a wide variety of noise exposure patterns. The following general observations (see Clark, 1991; Danielson, Henderson, Gratton, Bianchi, and Salvi, 1991) should be treated with caution since many of the relevant studies used nonhuman animals as subjects:

- there is considerable individual variation in susceptibility to NITTS, the rate at which it approaches asymptote, and the rate of recovery from it;
- NITTS can be experienced by individuals who have a previously existing permanent noise-induced threshold shift;

- in humans the greatest NITTS occurs at frequencies slightly above the dominant frequency of the noise stimulus;
- generally, the extent of the temporary hearing loss is predicted by the equal energy rule. That is, the size of the NITTS is determined by the total sound energy (the product of sound intensity and duration) which enters the ear, for steady noise. The equal energy rule overestimates the NITTS for sounds with frequencies lower than 2kHz and underestimates the NITTS above 2kHz (Yamamoto, Shoji, and Takagi, 1968). The NITTS from interrupted noise is also overestimated by the equal energy rule (Ward, 1970);
- typically, NITTS from impulse noise increases more rapidly than NITTS from steady noise (Ward, Selters, and Glorig, 1961) and recovers more slowly (Cohen, Kylin, and LaBenz, 1966); and
- recovery from NITTS occurs as an exponential function of time over a period of hours to weeks, depending on the severity of the hearing shift, and thus on individual susceptibility, and the type of exposure. Thus, in order to infer a permanent threshold shift sufficient recovery time must be allowed. Further, recovery of sensitivity as assessed by audiogram should not be taken to indicate that recovery has occurred as there may be injuries which are not measurable psychophysically (Bohne, 1976).

If recovery is not complete before the next noise exposure, there is a possibility that some of the loss will become permanent. Indeed, efforts have been made to use information on NITTS to predict sound pressure levels that might cause permanent threshold shifts and to predict individual susceptibility to permanent noise-induced hearing loss.

### 5.1.5 NOISE-INDUCED PERMANENT THRESHOLD SHIFT

Noise exposure has been found to lead to permanent hearing losses, referred to as noise-induced permanent threshold shifts (NIPTS) which, because they are sensorineural, can be detected both in air and bone conduction audiograms. However, evidence for NIPTS resulting from typical exposures to aircraft noise is inconclusive (Berglund and Lindvall, 1995).

NIPTS is believed to occur gradually over a period of years. However some data suggest that abrupt hearing losses are also possible. Evidence for sudden changes in sensitivity may, however, be misleading. Early damage may not be easily detected due to failure to interfere with speech (Berglund and Lindvall, 1995).

Few studies have examined the effects of exposure to aircraft noise on hearing. Generally, these studies have "found no relation between aircraft noise levels and measures of residents' hearing" (Bradley, 1996, p2542) and furthermore such a relationship would not identify a casual connection. For example, Moch-Sibony (1984) reported that in the vicinity of the Paris airport, children attending a sound-attenuated school performed better on an auditory discrimination task performed under quiet conditions than did children attending a non-sound-attenuated school (matched for social class). From this finding it has been concluded that the children from the non-sound attenuated school were suffering from hearing losses. There are several

difficulties with this conclusion. It is not clear that sufficient time for recovery from NITTS was allowed before testing for NIPTS. Further, it is possible that the poorer performance of the children from the noisy school was due to learning deficits under noisy conditions rather than a problem with their hearing during the test in quiet conditions. Other studies have found that the hearing of children exposed to aircraft noise did not differ significantly from the hearing of non-exposed children (Andres, Kerrigan, and Bird, 1975; Fisch, 1981).

Carter, MacSween, Bultear, Gray and Ferris (1975) studied the effects of exposure to general noise (including aircraft, road traffic, railway and industrial noise) on the hearing of 10-12 year old Sydney children. Children who had lived in noisy areas of Sydney for five to 12 years were compared to those who had lived in quiet areas for a comparable period. No differences in the hearing threshold level for pure tones from 500 to 6,000 Hz were found.

Most studies of NIPTS have been cross-sectional occupational studies, using workers in noisy industries (heavy industry, shipyards, textile plants, jet-cell test rooms, foundries, transportation, and forestry) as subjects (for example, Atherley, Noble, and Sugden, 1967; Bauer, Korpert, Neuberger, Raber, and Schwetz, 1991; Baughn, 1973; Burns, 1973; Burns and Robinson, 1970; King, 1941; Passchier-Vermeer, 1974; Robinson, 1971; Stone, Freeman, and Craig, 1971; Sulkowski, 1974; Talbott et al., 1996; see also Katz, 1994). Frequently, audiograms were compared with so-called "normal" thresholds in order to control for the influence of presbycusis and selection procedures were adopted to control for previous noise exposure or pre-existing otological abnormalities. Generally in these studies (see Berglund and Lindvall, 1995):

- workers with daily exposure to noise above approximately 85dB over several years demonstrate NIPTS. For example, Cohen, Anticaglia, and Jones (1970) concluded that SPLs of at least 85-88dBA could be harmful to the ear, on the basis of comparing control subjects' hearing levels with those of subjects exposed to sounds of a variety of intensities and durations. Two occupational studies also report risks from exposures above 85-90 dBA (Martin, Gibson, and Lockington, 1975; Roth, 1970). Talbott et al. (1996) studied hearing levels of workers who had worked in noisy industry for at least 15 years. Workers who had worn hearing protection devices for at least 75% the time during their employment were compared with those who wore hearing protection devices no more than 25% of the time. They report that workers who had worn hearing protection had significantly better hearing than those in the second group, "although they were more exposed". However, the exact functional exposure when the hearing protection devices were worn was not estimated. Rey (1974) found that amongst metal workers exposed to SPLs from 95dBA 60% suffered hearing impairment according to the ISO criterion (controlling for duration of exposure, age and health). *Figure 5.1* compares the percentages of workers with hearing impairment (average hearing loss greater than 25 dBA, at frequencies of 1, 2, and 3 kHz) as a function of age for unexposed groups and for groups exposed to sound pressure levels of occupational noise of 85, 90, and 95 dBA (Lampert and Henderson, 1973);

- there is considerable individual variability in vulnerability to NIPTS;
- individual variability in audiometric thresholds is greater in noise exposed than in non-noise exposed populations; and
- NIPTS occurs mainly for high frequency sounds with a maximum around 4kHz.

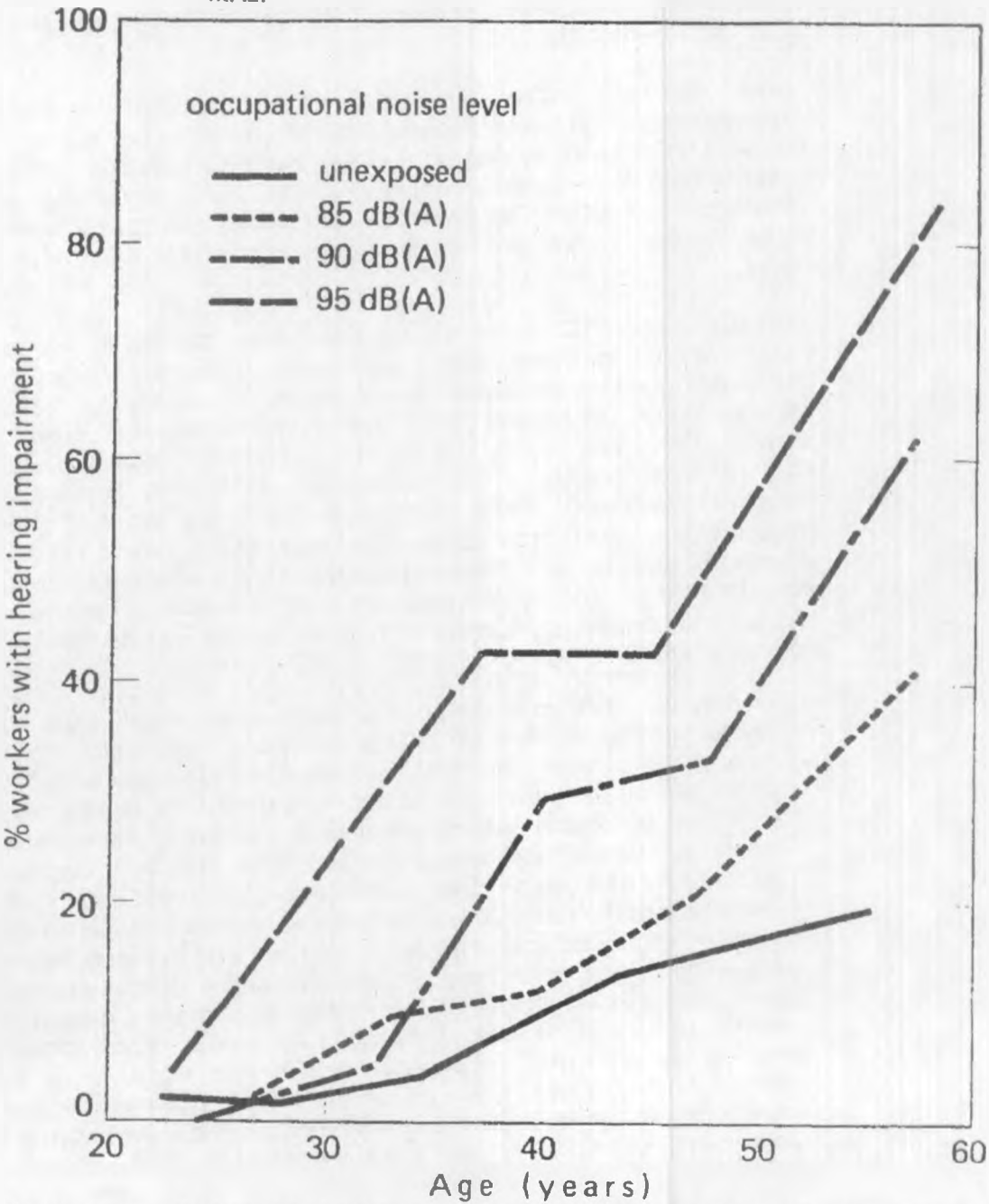


FIGURE 5.1: PERCENTAGE OF WORKERS WITH HEARING IMPAIRMENT (AVERAGE HEARING, LOSS GREATER THAN 25 DBA AT 1, 2, AND 3 KHZ) AS A FUNCTION OF AGE FOR EXPOSURE TO OCCUPATIONAL NOISE

Source: US National Institute for Occupational Safety and Health (Lampert and Henderson, 1973).

In many of occupational studies sufficient recovery of NITTS due to occupational exposure may not have been allowed.

The findings from studies of occupational noise exposure cannot necessarily be extrapolated to aircraft noise exposure, because it is not clear that the exposure patterns for these different noise sources are comparable. In particular, exposure to aircraft noise tends to be substantially more intermittent, potentially allowing recovery from NITTS between exposures and thus reducing the possibility of NIPTS (Kryter, Ward, Miller, and Eldredge, 1966). The protective effect of intermittent exposure against NIPTS is suggested by the finding that hearing losses in musicians are not as large as suspected (Royster, Royster, and Killion, 1991), perhaps because there are usually long intervals between exposures (Axelsson and Lindgren, 1978).

#### **5.1.6 NOISE-INDUCED HEARING LOSS (IMPAIRMENT) AND NOISE EXPOSURE**

The rate and degree of NIPTS is related to sound energy dose (the product of sound intensity and duration) and *Figure 5.2* shows the progression of noise-induced hearing loss observed in workers with increasing duration of exposure to intense noise levels (Johansson, 1952; see also Abel and Haythornthwaite, 1984). The influence of other factors including individual differences in vulnerability make prediction of NIPTS (and thus the establishment of "safe" noise levels) difficult. NIPTS is not reliably predicted by the perceived loudness of a noise, the discomfort it causes, or the extent to which it interferes with human activity.

Several theories have been proposed to predict the NIPTS will result from a particular noise exposure. According to the Equal Temporary Effects Rule "the NIPTS due to long-term, daily, steady-state noise exposure is equal to the average NITTS produced by the same daily noise in healthy young ears" (Ward, Glorig, and Sklar, 1958, 1959, cited in Berglund and Lindvall, 1995, p37). The relationship between temporary and permanent threshold shifts is suggested by the finding that "[a]udiograms of persons exhibiting temporary hearing loss in laboratory studies tend to be similar to those of persons exposed to comparable noise over a period of several years (Nixon and Glorig, 1961, cited in Berglund and Lindvall, 1995, p34).

The Equal Energy (or 3dB) Rule proposes that the extent of the NIPTS is determined by the total daily "dose" of sound energy (the product of intensity and duration). The rule predicts that for each halving of duration a 3dBA increase in SPL will cause equivalent damage (Burns and Robinson, 1970; Martin, 1976; US EPA, 1974b; Ward and Nelson, 1971). Whilst the equal energy rule is thought to provide a good estimate of the accumulated physical damage caused by interrupted noise (Burns and Robinson, 1970), it may underestimate the damage caused by very intense, short duration, and impulsive sounds.

A number of theories, related to the 3dB rule, are thought to provide better risk estimation for certain noise exposure patterns. For example, the 4dB Rule allegedly provides a more protective risk estimate for high frequency sounds (US Air Force, 1989), the 5dB Rule is purported to better compensate for intermittent sounds (Walsh-Healey Public Contracts Act, 1969) and the 6dB Rule is more conservative still. The nomenclature of these rules identifies the increase in sound intensity which would produce equivalent damage for each halving of duration.

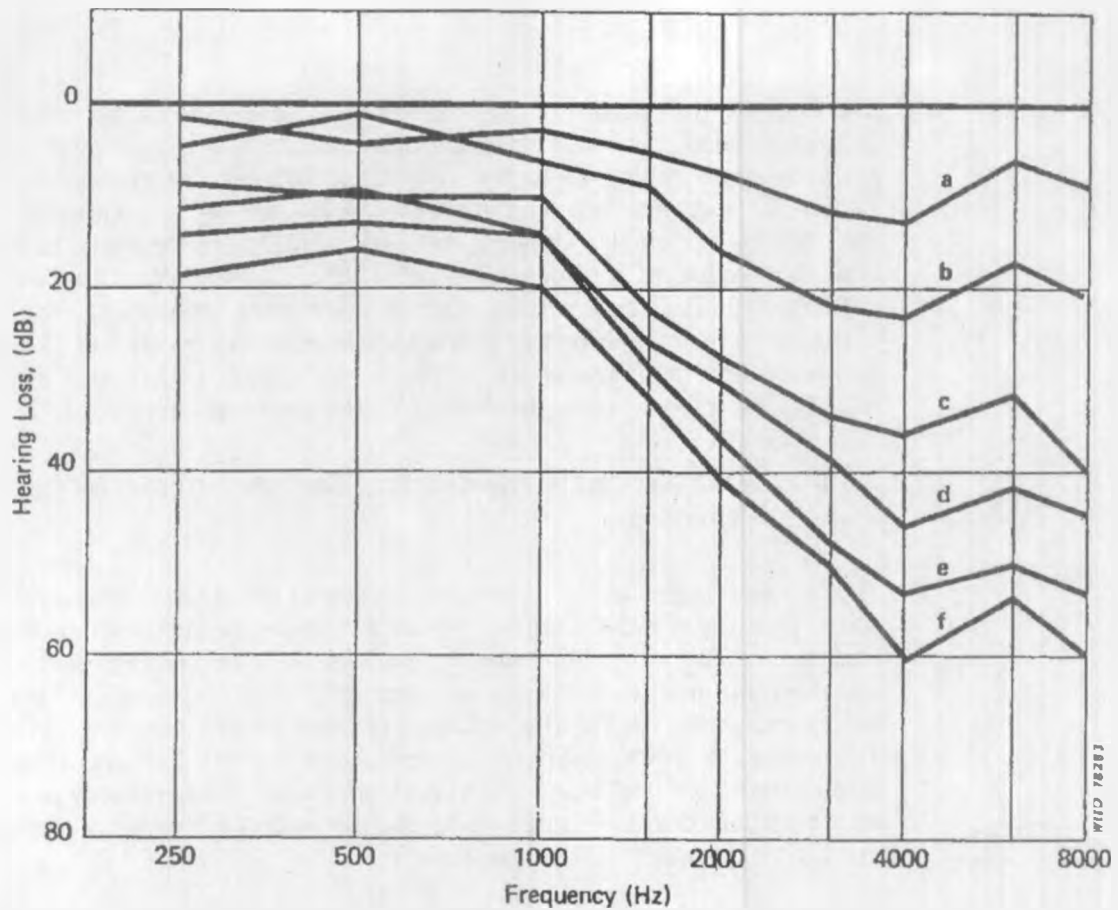


FIGURE 5.2 AVERAGE HEARING LOSS (dB) AS A FUNCTION OF FREQUENCY (Hz) FOR DIFFERENT DURATIONS OF EXPOSURE (A = LESS THAN 1 YEAR, B = FROM 1 TO 5 YEARS, C = FROM 6 TO 10 YEARS, D = FROM 11 TO 20 YEARS, E = FROM 21 TO 30 YEARS, F = MORE THAN 30 YEARS).

Source: Johansson, 1952

On the basis of data available from occupational and community studies Berglund and Lindvall (1995) summarise: "Lifetime exposures to 90 dB LAeq is judged to cause clearly noise induced hearing loss, but as levels reduce below 90 dBA it becomes increasingly difficult to disentangle noise exposure from other causes such as ageing. The chances of showing an effect at 80 dB LAeq that is statistically significant are very small, although some individuals probably are affected, an 8-h continuous equivalent level of 75 dBA might be identified as the limit for protection against significant NIPTS." (p39). Since maximum intensity in residential airports around commercial airports are on average approximately 65-75 dB (Andersson and Lindvall, 1988) (though some noise events may be of greater intensity), hearing impairment due to aircraft noise exposure alone is unlikely. However, there are factors which may potentate the impact of aircraft noise exposure on hearing.

### 5.1.7 MODERATORS OF THE EFFECTS OF NOISE ON HEARING LOSS (IMPAIRMENT)

#### *Characteristics of the Sound*

Several parameters of the sound influence the level of risk. In particular peak sound pressure, duration, rise and decay times, type of wave form, repetition rate, spectrum, and number of impulses (Buchta, 1993; Rice, 1991; Rice and Robinson, 1995; Vos, 1990). Hearing is at risk from sounds with SPLs which are in excess of 140dB for more than 5ms, regardless of rise time, spectrum, or the presence of oscillatory transients. If duration is shorter, peak SPLs up to 165dB may be tolerated, but SPLs above 165dB are likely to damage the cochlear regardless of duration (Acton, 1967; Burns and Robinson, 1970). Whilst noise events seldom reach this intensity in the vicinity of an airport, aircraft noise has a low frequency component which may be damaging.

#### *Low Frequency Sound and Infrasound*

Low frequency sounds (less than 200Hz), may present particular risks to hearing. NITTS due to low frequency sounds is similar to that of higher-frequency sounds, but may take longer to recover than is the case for higher frequency sounds (von Gierke and Nixon, 1976). Extreme pressure produced by very low frequency sounds may cause aural pain, damage to the ear drum and cochlea (von Gierke and Nixon, 1976).

Sounds just below the limit of human hearing (less than 20 Hz) may become painful at sound pressure levels as low as 30-40dBA (Berglund and Lindvall, 1995). Such extremely intense infrasounds may cause a reaction similar to the stress reaction (see Section 5.4) and pulsating auditory sensations (Berglund and Lindvall, 1995). The whole body vibration which may result for infrasound may interact with high noise exposure to produce hearing losses (Manninen, 1990, 1993).

#### *Impulsive Sound*

Relevant data on the effects of exposure to impulsive noise, mostly from studies of gunfire (for example, Coles, Garinther, Hodge, and Rice, 1968) but also from a few studies of industrial noise (Ceypek and Kuzniarz, 1974; Dieroff, 1961b, 1974), suggests that it poses a particular threat to human hearing. Sounds with impulsive content may cause more hearing loss than noise without impulses when both have the same LAeq.

Very short exposures are able to harm the cochlea for two main reasons. Firstly, because the response time of the aural reflex is of the order of 100-300 ms, it does not provide protection against noises which reach dangerous levels in a shorter period (Coles et al., 1968; Coles and Rice, 1970). Secondly, according to von Békésy's hydrodynamic theory of hearing, the shock waves of very short noise impulses may greatly stimulate the base of the cochlea. Thus, NIPTS due to pure impulse noise occurs predominantly at high frequencies such that its detection requires testing at 4 kHz



Interestingly, presentation of impulsive sound with steady-state sound for 30 minutes resulted in a lower NITTS than the sum of the NITTS resulting from the two sources presented alone (Kundi, Weninger, Stidl, and Haider, 1984).

Since, the mode of effect of impulsive noise differs slightly from that of steady noise, criteria employed to predict the extent of hearing loss due to steady noise, are not appropriate for estimating the risk from impulsive noise. For example, support for the application of the equal energy rule (Martin, 1976; Rice and Martin, 1973) has been undermined by results of more recent studies (Neuberger, Schwetz, Raber, Korpert, and Bauer, 1990; Schwetz, Raber, Neuberger, Korpert, and Bauer, 1992). The higher risk posed by impulsive noise has been accounted for with a "penalty factor" of 2 to 8 dB, though the appropriate penalty remains uncertain.

### *Situational Variables*

Aircraft noise may cause hearing loss (impairment) if combined with exposure to non-aircraft noise or ototoxic agents (agents which damage hearing), which occurs relatively frequently.

"The adverse effects of noise on hearing may be enhanced by a variety of ototoxic drugs and environmental chemicals. Theoretically, the potential of noise-induced hearing loss by chemical agents may mean that noise exposures which would otherwise not disrupt hearing may become damaging due to the presence of such a co-factor. The practical significance of such interaction effects is difficult to assess due to the paucity of dose-effect curves in combined exposure studies" (Berglund and Lindvall, 1995, p42).

### *Exposure to Non-Aircraft Noise*

It is important that the potential impact of noise exposure from aircraft not be considered in isolation. Concurrent exposure to noise from non-aircraft sources (for example, occupational, road traffic, aircraft noise, and noise from leisure activities) should also be considered for several reasons. Firstly, the extent of hearing loss varies as a function of total noise exposure. Secondly, it is possible that the effects of aircraft noise are potentiated by additional noise exposure. Or, similarly, that exposure to aircraft noise increases the probability that exposure to other noise sources will impair hearing. For example, the ISO (1990) recommendation that the risk of hearing impairment is minimal for an equivalent continuous sound level during 8-h work at 80 dBA, may underestimate the risk due to the assumption of recovery during nonworking hours. Kryter (1970) found that only those airport area residents with occupational exposure to noise showed hearing deficits at 4000 Hz.

### *Exposure to Ototoxic Drugs*

Several therapeutic agents have significant ototoxic potential and laboratory evidence suggests their use may potentate the effects of noise exposure. For example, aminoglycoside antibiotics and cis-platin (an anti-tumor agent) may produce NIPTS, loop diuretics have been associated with NITTS, and chronic, high-dose aspirin (salicylate) therapy most commonly produces temporary tinnitus rather than a primary shift in auditory thresholds.



Combined exposure to sound and aminoglycoside antibiotics in the laboratory has been shown to potentate cochlear hair cell loss and resultant NIPTS which would be expected for exposure to the source alone (for example, Brown, Brummett, Fox, and Bendrick, 1980; Collins, 1988; Dodson, Bannister, and Douek, 1982; Vernon, Brown, Meikle, and Brummett, 1978).

Potential of cochlear damage and dysfunction has also been reported in animals co-administered cis-platin and octave band noise at 85 dB continuously for 5 days (Gratton, Salvi, Kamen, and Saunders, 1990).

No data are available on the interactive effects of loop diuretics and noise exposure, and evidence for the disruption of auditory function during aspirin therapy is inconsistent. Whilst high doses (3.9 grams over two days) have been found to potentate NIPTS in humans, lower doses did not produce this effect (McFadden and Plattsmier, 1983). Laboratory experiments with non-human animals have not supported interactive effects of noise and aspirin. One study comparing chinchillas receiving combined exposure to noise and salicylate with those receiving exposure to noise alone detected no differences in cochlear structure and function (Salvi, Boettcher, Spongr, and Bancroft, 1991).

#### *Exposure to Ototoxic Chemicals*

Several agents used in occupational settings, asphyxiants, organic solvents, and metals, may be ototoxic. Some of the organic solvents are also used within households in glues, stain removers, and paints, and are sometimes abused because of their psychopharmacological properties (for example, toluene). Chemical asphyxiants which have been shown to disrupt hearing in laboratory animals include carbon monoxide, cyanide (Konishi and Kelsey, 1968), and hypoxic hypoxia (Nuttall, 1984).

Combined exposure to very high carbon monoxide levels and noise can potentate destruction of outer hair cells in the cochlea and NIPTS (Fechter, Young, and Carlisle, 1988; Young, Upchurch, Kaufman, and Fechter, 1987). This finding is corroborated by the finding from an epidemiological investigation that amongst noise exposed workers, smokers had a higher rate of hearing loss compared to non-smokers, controlling statistically for age (Prince and Matanoski, 1991). Carbon monoxide is one constituent of cigarette smoke and smokers have elevated carboxyhemoglobin levels.

Organic solvents known to be ototoxic by themselves include toluene (which is in glues and spray paints) (Ehyai and Freemon, 1983; Pryor, Dickinson, Howd, and Rebert, 1983; Sullivan, Rarey, and Conolly, 1989), styrene (Muijser, Hoogendijk, and Hooisma, 1988; Pryor, Rebert, and Howd, 1987), carbon disulfide (Rebert, and Becker, 1986; Sulkowski, 1979), n-butanol, and trichloroethylene (a dry cleaning agent) (Velazquez, Escobar, and Almaraz, 1969). Evidence for an ototoxic interaction between solvents and noise is inconsistent. Factory workers exposed to noise and high levels of toluene (Morata, Dunn, Kretschmer, Lemasters, and Santos, 1991) or carbon disulfide (Morata, 1989) demonstrated greater hearing loss than those exposed to ototoxic chemicals alone. Similarly, rats exposed sequentially to toluene (1,000 ppm, 16 hours/day for 5 days/week for two weeks) and frequency modulated noise of 100 dB LAeq for 10 hours/day for four weeks

showed greater NIPTS than did rats exposed to noise or toluene separately (Johnson, Juntunen, Nylen, Borg, and Hoglund, 1988). In contrast, Fechter (1993) found no potential of noise-induced hearing loss among laboratory animals acutely exposed to high doses of styrene.

Heavy metals such as lead, arsenic, and mercury (Haider, Kundi, Groll-Knapp, and Koller, 1990) have been shown to potentiate noise induced hearing loss. Because areas with high volumes of road traffic may have high concentrations of carbon monoxide and lead in the air, residents in these areas may be particularly at risk for noise-induced hearing loss.

### *Individual Differences and Demographic Variables*

Substantial individual differences in susceptibility to noise-induced hearing loss have been demonstrated in occupational studies. Workers exposed to the same noise environment may demonstrate quite different audiograms, with some showing negligible NIPTS.

Individual difference factors which are hypothesised to underlie these differences include fatigue of the acoustic reflex, middle and inner ear structure, the functional status of the autonomic system, and possibly latent vitamin B deficiency (Berglund and Lindvall, 1995). Hearing impairment has been found to increase vulnerability to aural pain (Berglund and Lindvall, 1995). Effects of combinations between noise and head injury and/or ear disease have been quantified in multivariate analyses by Neuberger, Körpert, Raber, Schwetz, and Bauer (1992).

Of the demographic variables which have been examined, only socio-economic status seems to be related to the risk of hearing loss. Males and females have been found to have equal susceptibility to hearing loss (Fletcher, 1972). The suggestion that vulnerability to NIPTS (Kryter, 1960) is positively related to age has not received clear empirical support (Kup, 1965). Some studies suggest that amongst people of working age there is no such relationship (Davis, 1973; Schneider, Mutchler, Hoyle, Ode, and Holder, 1970), whereas other studies suggest that there is some support for the observation that age and noise exposure can have a synergistic effect (Moscicki, Elkins, Baum, and McNamara, 1985).

### **5.1.8 COMPLICATIONS OF HEARING IMPAIRMENT**

Hearing impairment caused by exposure to noise is liable to be accompanied by complaints which are often associated with hearing impairment, such as tinnitus, loudness recruitment, and paracusis.

Sufferers of hearing impairment often experience tinnitus (ringing in the ears) defined as "the illusory sensation of sound not brought about by simultaneously applied acoustical signals" (Lutman and Haggard, 1983). The sounds which are heard may be caused by blood flow through inner ear structures or may be emitted by the inner ear itself. In a field study carried out by Tarnopolsky, Watkins and Hand (1980) acute as well as chronic tinnitus (ringing in ears) was frequently reported among subjects exposed to aircraft noise exceeding 45 NNI compared to subjects exposed to aircraft noise up to 45 NNI.

Sensorineural disorders, particularly noise-induced hearing losses, are often associated with loudness recruitment. Recruitment refers to an abnormality in loudness perception in which the absolute hearing threshold is elevated and the rate of growth of loudness with sound intensity is more rapid than normal. The shape of the psychophysical function may vary considerably between individuals with recruitment (Hallpike, 1967; Hallpike and Hood, 1959).

Paracusis, or sound distortion, may occur in conjunction with serious losses of auditory sensitivity. For example, a sound may be heard as having a pitch which is inappropriate for its frequency.

These complications of hearing impairment may further contribute to disturbance of voice communication or to other reactions to aircraft noise.

#### 5.1.9 COMMENTS ON RECENT SYDNEY AIRPORT STUDIES

According to Kinhill (1990), international standards state that habitual exposure to an eight hour continuous level of 90dBA each day should not cause significant hearing damage. However, it is argued that "[t]o protect 97% of the population from any measurable hearing loss owing to continuous exposure would require an LAeq (twenty-four hours) of less than 70dBA" (Kinhill, 1990 p22.3). This study does not identify that such standards are based largely on occupational studies and that because aircraft noise is intermittent extrapolation of this risk is uncertain. This application of 70 dBA is based on long term exposure in adults and so extrapolation to children is also uncertain. Nor is it recognised that the risks associated with aircraft noise exposure are likely to be increased due to its low frequency component and may be increased by concurrent exposure to ototoxic agents and/or other environmental noises. However, three studies were cited which found no association between exposure to aircraft noise and hearing loss in children.

Potential complications of hearing loss, such as tinnitus and recruitment, are not addressed in the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990).

The Senate Select Committee on Aircraft Noise in Sydney (Senate Select Committee on Aircraft Noise in Sydney, 1995) reported submissions which seem to suggest that Kinhill (1990) underplayed the potential for a negative impacts of aircraft noise on aural health. For example, a group of workers who had been working in a noise-affected environment for an extended period of time reported to the Senate Select Committee that they had begun to notice hearing losses since the opening the third runway caused increases in noise levels at their workplace. Dr Aline Smith claimed she has encountered cases of "tinnitus or ringing in the ears, and chronic ear problems made worse" as a result of aircraft noise. The complaints hotline and general practice survey run by Doctors Educating About Flyovers (DEAF) received reports of tinnitus and other hearing problems. It must be acknowledged, however, that these "studies" involved self-selected samples of individuals who rang or were in a doctors surgery because of having a problem and can not be considered to constitute a representative sample of the population. Further, the limitations of self-reported data must also be

recognised in this context. Reports to the complaints hotline, to the doctor or to the Senate Select Committee should be interpreted cautiously since dissatisfaction with the change in noise levels may cause such problems to be noticed or reported, rather than the increased noise levels causing hearing problems. Without appropriate longitudinal studies and control groups it cannot be assumed that reported hearing problems are (or are not) caused by aircraft noise.

In a submission to the Senate Select Committee, the Australian Medical Association commented that the conclusion of the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) that "[a]uditory effects of noise have been well described but are not considered of importance in relation to domestic exposure to aircraft" was only supported by one study. However, this study cited three studies which found no effect of domestic exposures. Further, on the basis of occupational studies of daily continuous eight hour exposure to very high noise levels, it seems unlikely that exposure to aircraft noise alone would produce hearing deficits. Nonetheless, generalisations from exposure to occupational sound to exposure to aircraft sound cannot be made with certainty. The Australian Medical Association nominated a study by Ising et al. as evidence for aircraft noise induced hearing impairment, but recognise that this study examined the effects of exposure to noise from military aircraft, which fly much lower and produce much more intense sound on the ground than commercial aircraft. The Australian Medical Association did not identify whether the observed hearing losses were temporary or permanent. The Australian Medical Association also suggested that "noise effects are cumulative and there is increasing evidence that young people are suffering NIHL [Noise Induced Hearing Loss] at much younger ages than their forebears" (Senate Select Committee on Aircraft Noise in Sydney, 1995, p145). In relation to this claim it is critical to recognise that it is very difficult to disentangle the influence of noise on hearing from the influence of other factors such as air pollution, let alone to identify the influence of aircraft noise alone. Such naive analyses of the evidence are often misleading.

The Senate Select Committee reported that in a study of 200 hearing-impaired and 200 normal-hearing school aged children (Green, Pasternack, and Shore, 1982b), a positive, but statistically nonsignificant, association between aircraft noise exposure and high frequency hearing loss was found. Any effect of aircraft noise on hearing which was not detected with a sample of this size, is likely to be a small one, or maybe the result of chance differences between the relevant groups, as indicated by statistical non-significance. Alternatively, this result may reflect a genuine effect in a sub-population of greater susceptibility, washed out by the other, unaffected subjects.

## 5.2 IMPACTS OF SOUND ON NON-AUDITORY PHYSIOLOGICAL HEALTH

Exposure to noise may result in a variety of biological responses. Examination of such effects has mostly been restricted to short-term studies on animals and human subjects. However, it has been postulated that if

provoked continuously such responses would ultimately lead to the development of clinically recognisable physical or mental ill health in human beings. Furthermore, community studies, some of them longitudinal, have supported this hypothesis.

### 5.2.1 EFFECTS ON THE SENSE OF BALANCE

#### *Noise and the Sense of Balance*

Available data suggest that balance problems are only likely to result from exposure to aircraft noise for people whose auditory systems are differentially sensitive to stimulation.

The ear not only houses the auditory system. It also contains the sense organs of the vestibular system, which are responsible for balance. Thus nonoptimal stimulation of the vestibular system by high levels of noise may disrupt balance equilibrium.

This hypothesis has been insufficiently researched and available data are inconsistent. Subjects in the laboratory and in the field have complained of nystagmus (involuntary, rapid horizontal eye movements), vertigo (dizziness), and balance problems after exposure to very intense level noise (Berglund and Lindvall, 1995). However, levels upwards of 130dB were required to produce such effects in personnel working on jet engines (Dickson and Chadwick, 1955; see also Parker, 1976). Lower SPLs (95-120 dB) may also disturb the sense of balance, provided the two ears receive unequal stimulation (Harris, 1974; Nixon, Harris and von Gierke, 1966). Such levels are unlikely to occur in residential areas around airports.

#### *Noise Moderators*

Individuals suffering with unilateral deafferentation (disconnection of nerve tissue) of the vestibular system are at increased risk of aircraft-noise-induced balance problems.

### 5.2.2 VISUAL EFFECTS

#### *Noise and Visual Effects*

Data regarding the visual effects of noise are inconsistent, but it seems unlikely that aircraft noise is sufficiently intense to influence vision.

Workers exposed to sound pressure levels of 110-124 dB have been found to demonstrate a lasting narrowing of the visual field and reduced colour vision (Benkö, 1959, 1962). However, the effect of noise on colour perception was not observed in later studies (Kitte and Dieroff, 1971).

### 5.2.3 STARTLE REFLEX AND ORIENTING RESPONSE

#### *Noise and the Startle and Orienting Responses*

Whilst certain noises produce startle, aircraft noise (except for sonic booms) is unlikely to do so unless it is feared. It is not known whether ongoing repetition of acute startle reflex and orienting reaction has a negative impact on human health. However, the startle reflex is one response to noise which habituates. Thus, ongoing repetition may not be likely.

Certain noises, especially impulsive noises, may cause a startle reflex (Molinie, 1916), which involves contraction of the flexor muscles of the limbs and spine and of the orbital muscles (eye blink). Detection of the startle reflex and orienting response involves behavioural observation and/or electrophysiological measurement of muscle tension/activity (Davis, Buchwald, and Frankmann, 1955; Galambos, Rosenberg, and Glogig, 1953).

It is thought that the startle occurs in preparation for avoidance of a dangerous situation, the potential of which is signalled by the sound. The startle reflex may be followed by an orienting reflex, which causes turning of the head and eyes a sudden sound in order to identify its source (Thackray, 1972), or by a fright reaction. The fright reaction may increase the effects of noise on the circulatory system and may cause changes in skin conductance via alterations in perspiration (Klosterkötter, 1974; Niveson, 1992).

Startle reactions may result even from low intensity sound, provided the sound is sufficiently sudden or somehow indicates danger. Sonic booms can elicit startle, which increases with the intensity of the boom (Rylander, Sørensen, Andrae, Chatelier, Espmark, Larsson, and Thackray, 1974). For meaningless noises orienting responses may be elicited only at the beginning of a series of signals. Habituation then occurs, in inverse proportion to intensity, and there may be a masking effect of background noise.

Thus, the likelihood of startle to aircraft is extremely limited. The intensity of aircraft noise in the vicinity of an airport is not sufficient to sustain occurrence of the orienting response. Nor is the onset of aircraft noise sudden enough to cause startle. It is, then, only if aircraft noise signals a potential danger that it is likely to cause startle. Whilst this may be true for individuals who fear the crash of the aircraft, this fear may habituate so that repetition of the startle reaction is not sustained. Nonetheless, community surveys show that significant numbers of individuals fear aircraft noise of aircraft crashes in their area (for example, Hede and Bullen, 1982a).

More sensitive subjects react to noise with greater startle and arousal (Stansfeld, 1992; Stansfeld and Shine, 1993)

### 5.2.4 FIGHT/FLIGHT AND STRESS RESPONSES

#### *Noise and the Fight/Flight and Stress Responses*

Exposure to sound, particularly unknown or unwanted sound, may evoke a number of reflexive responses mediated by the autonomic nervous system,

which regulates the alternating rhythms of sleep-arousal, endocrine secretion, and other functions (Bergamini, Bergamasco, Benna, Covacich, and Gilli, 1976). The fight/flight response involves mechanisms which shunt blood from interior organs to skeletal and heart muscle, activate lipid metabolism to mobilise energy, and increases in contractility of the heart and fluid retention by the kidneys to raise blood pressure. The non-specific stress response, which is mediated by the pituitary adrenal-cortical system, involves reduction of the inflammatory response, fluid retention by the kidneys, and release of free fatty acids as an energy source. Thus, changes in the noise environment could activate physiological changes leading to cardiovascular effects, such as increased vasoconstriction, blood pressure, heart rate (Andr n, 1982), as well as catecholamine and corticosteroid secretion. The lower the frequency of a noise, the more likely it is to provoke a defensive reaction (measured using finger pulse amplitude, skin conductance and so forth)(Meyer-Falke, Lanzendorfer, and Jansen, 1995).

These responses are generally transient, with the physiological system returning to the preexposure state within a short time of sound termination. There is not conclusive evidence of habituation of these reflex responses for fluctuating noise (for example, Vallet et al., 1983a, 1983b). Greater habituation has been observed in the stress response to low frequency sounds, with eventual diminution to minimal response (Meyer-Falke et al., 1995).

However, repetition and persistence of these reactions may result in permanent change, such as hypertension and coronary heart disease (Carter, Crawford, Kelly and Hunyor, 1993). For example, it has been hypothesised that noise may increase resting blood pressure because repeated stimulation causes the lumen of peripheral or renal arterioles, and later the large arteries or veins, to narrow due to proliferation of smooth muscle cells. Further, catecholamines secreted by the adrenal medulla during the stress response can cause acceleration of atherosclerosis in the major arteries by increasing platelet adhesiveness and low density cholesterol. The corticosteroids secreted by the adrenal cortex as part of the non-specific stress response may have immunosuppressive effects.

Selye (1956) suggested that stress could have a negative impact on health especially if it is chronic, interferes with daily activities or is annoying.

### 5.2.5 CARDIOVASCULAR EFFECTS

The literature on acute and chronic cardiovascular effects of noise in waking subjects is examined in this section (see Thompson, 1995, 1996 for a review). Cardiovascular effects during sleep are examined in Section 5.3.

#### *Acute Cardiovascular Effects*

Laboratory studies of humans and nonhuman animals, show that exposure to noise can result in vasoconstriction and increases in blood pressure and heart rate (Jansen, 1969; Klein and Gr bl, 1969; Kryter, 1985; Lehmann and Tamm, 1956) and that these effects are potentiated by the demands of concurrently performed tasks (Carter and Beh, 1989; Hanson, Sceellekens, Veldman, and Mulder, 1993). However, some studies report findings which

are inconsistent with these (Etholm and Egenberg, 1964; Klein and Gröbl, 1969). The clinical significance of these effects is unclear, but cannot be dismissed.

#### *Vasoconstriction*

Community and laboratory studies suggest that exposure to noise at intensities typical of aircraft noise is sufficient to produce peripheral vasoconstriction.

Peripheral vasoconstriction generally refers to precapillary vasoconstriction at the finger tips in studies examining the effects of noise exposure. It is measured in terms of percentage reduction in mean blood volume (BV) or size of blood volume changes (pulse volume or PV).

Community exposure to aircraft noise at 70 dBA has been found to produce vasoconstriction at the finger tips in children (Hunter, 1971; cited in Carter et al, 1993). The response was greater in children with reading difficulties than in normal children.

Laboratory studies reveal acute vasoconstriction during exposure to meaningless noise at levels as low as 60-70 dB (Davis et al., 1955; Kryter and Poza, 1980), with the response occurring within several seconds of noise onset. For example, Griefahn et al (1991; cited in Carter et al, 1993) report that subjects exposed to forty-nine 62-80dBA impulsive noises each lasting 19 seconds experienced strong vasoconstriction, which was linearly related to maximum levels. The intensity of the response to bursts of pink noise increased with maximum level, bandwidth and centre frequency of the noise from 250 to 4,000 Hz, and was greater for lower rise times (Osada, 1991; cited in Carter et al, 1993). However, studies which employ impulsive noise may not be directly applicable to aircraft noise.

Data suggest that partial habituation may occur to some stimuli, although the response did not habituate to short bursts of noise (Jansen, 1969). Fruhstorfer and Hensel (1980) found no habituation to daily 12-second bursts of 100 dBA white noise presented at five minute intervals, whereas Ginsberg and Furedy (1974) reported habituation to short bursts of pure tones at 80 dB. Thus, the occurrence of habituation may depend on sound level and bandwidth.

Examination of individual differences in responsivity of noise-induced vasoconstriction has been restricted to the discovery that Type A and Type B personalities differ in this respect (Hunter, 1971; Ickes et al., 1979; both cited in Carter et al, 1993)

Available data is insufficient to assess whether noise-induced vasoconstriction persists or whether its frequent repetition has long-term effects, such as blood pressure elevation. Peripheral vasoconstriction is controlled by the sympathetic nervous system. However, its correlation with vasoconstriction at other sites responsive to the sympathetic nervous system, such as renal arterioles, is unknown. Whilst Griefahn et al. (1991) report that vasoconstriction was accompanied by a moderate but significant acceleration of heart rate, vasoconstriction has also been observed in the absence of a change in heart rate or blood pressure.



### *Elevations in Blood Pressure*

Although evidence from numerous laboratory studies suggests that exposure to noise produces acute elevations in blood pressure, especially during simultaneous task performance, extrapolation to aircraft noise exposure is tenuous.

Laboratory studies examining the effects of noise on the diastolic blood pressure of subjects at rest, carrying out a simple intellectual task, or engaging in very light exercise, have detected noise-induced increases in blood pressure relatively consistently. Increases in diastolic blood pressure have been reported at noise exposures below 85 dBA (Andrén, Hansson, Björkman, and Jonsson 1980; Andrén, Hansson, Björkman, Jonsson, and Borg, 1979; Mosskov and Ettema, 1977a, 1977b; Pulles, Biesiot, and Stewart, 1990; Rövekamp, 1983, Study I; Von Eiff et al., 1981), and above 90dBA (Andrén, Hanson and Björkman, 1981; Andrén Lindstedt, Björkman, Borg, and Hansson, 1982; Cartwright and Thompson, 1975; Lehmann, 1955, 1959; Lehmann and Tamm, 1956; Michalak, Ising and Rebentisch, 1990; Van Dijk, Souman and De Vries, 1983). Diastolic blood pressure elevations have been found following exposure for less than 30 minutes (Andrén et al., 1979, 1980, 1982; Michalak, et al., 1990; Mosskov and Ettema, 1977a; Von Eiff et al., 1981) and following longer exposure periods (Cartwright and Thompson, 1975; Lehmann and Tamm, 1956; Mosskov and Ettema, 1977a; Van Dijk, et al., 1983). In contrast, Etholm and Egenberg (1964) observed no change in pulmonary artery pressure in ten subjects to 90dB white noise for 29 min. However their sample may not have been large enough to detect an effect or may not have included relevantly sensitive individuals. Arguelles, Martinez, Pucciarelli, and Disisto (1970) found that amongst subjects exposed to a 90 dB 2.0 kHz tone for 30 minutes only hypertensives showed increases in blood pressure. Similarly, Ising (1983) found that amongst individuals exposed to recorded traffic noise played back at 60-65dB LAmax for up to 12 hours, some demonstrated blood pressure elevation while others demonstrated decreases in blood pressure. "In regression analysis, poor general condition and pain were associated with decreased blood pressure whereas a hypertensive disposition was associated with increased blood pressure" (Berglund and Lindvall, 1995, p70). It should be noted that these studies do not speak to the causal question; it is not clear whether already hypertensive types react in this way to noise, or whether reacting in this way to noise combined with noise exposure creates hypertensive types, or whether neither of these accounts is accurate.

Findings regarding the effects of noise on systolic blood pressure have been less consistent than findings regarding diastolic blood pressure. Whilst several studies have reported an increase in systolic blood pressure (Michalak et al., 1990; Rövekamp, 1983, study I; Von Eiff et al., 1981), others have reported a decrease (Cartwright and Thompson, 1975; Ponomarenko, 1966; Terentyev, Sheludykov, and Sciridova, 1969) and others no change (Andrén et al., 1979, 1980, 1982; Mosskov and Ettema, 1977b; Rövekamp, 1983, study II; Van Dijk et al., 1983).

Exposure to noise has also been observed to produce increases in mean blood pressure (Andrén et al., 1979, 1980, 1981, 1982; Van Dijk et al.,

1983), and decreases in pulse pressure during noise exposure (Lehmann and Tamm, 1956; Mosskov and Ettema, 1977a, 1977b; Ponomarenko, 1966).

Laboratory studies of subjects engaged in physical work suggest that noise causes very small noise-induced elevation of blood pressure (Van Dijk et al., 1983). In contrast, Sanden and Axelsson (1981) found no effects of noise on blood pressure. However, the work the subject was required to perform was more demanding and noise effects may have been masked by cardiovascular response to increased tissue demands.

Results of laboratory studies in which subjects were to carry out more complex intellectual tasks during noise exposure generally provide evidence of noise-induced elevations in blood pressure. Increased diastolic blood pressure was observed in young adults carrying out a vigilance task accompanied by bursts of narrow band noise at 92 dBA separated by one minute, on average (Carter and Beh, 1989). Taffala, Evans and Chen (1988) found additional increases in both diastolic and systolic blood pressure associated with a mental arithmetic task, when subjects were exposed to intermittent noise and instructed to put maximum effort into the task. Similarly, Hanson et al. (1993) report that exposure to noise had a significant effect on systolic blood pressure during the performance of effortful tasks, and suggest that individuals alter their state to maintain performance. Ray, Brady and Emurian (1984) found that 10 minutes of 93 dBA intermittent pink noise caused an increase in mean blood pressure beyond that associated with performing a battery of computer controlled tasks. However, Linden (1987) found no increase in blood pressure with 5-minute exposure to continuous noise during performance of mental arithmetic. Thus, most studies report a significant effect. This combined effect has important potential implications for noise exposure during learning and study (see Section 5.3.3).

Laboratory studies of animals have also revealed that acute exposure to intense noise can cause a persistent increase in blood pressure (for example, Rosencrans, Watzman and Buckley, 1966). However, absence of noise has also been shown to cause hypertension in rats (Lockett and Marwood, 1973) and lifetime exposure has failed to reveal any effects on blood pressure in rats (Borg and Moller, 1978).

Given the paucity of studies of aircraft noise, either in the laboratory or in the field, the conclusion that exposure to aircraft noise may cause elevation in blood pressure levels can be drawn tentatively.

#### *Elevations in Heart Rate*

Evidence regarding the impact of noise exposure on acute heart rate elevations is somewhat inconsistent. Whether heart rate is accelerated seems to depend on the pattern of noise exposure, individual differences and whether a task is performed concurrently.

A community study of children exposed to aircraft noise at about 70 dBA while carrying out a reaction time task revealed an increase in heart rate (Hunter, 1971).

However, most laboratory studies have found no effect of noise on heart rate despite the wide range of noise types, levels and durations examined (Andrén et al., 1979, 1980; Cartwright and Thompson, 1975; di Cantogno, Dallerba, Teagno and Cocola, 1976; Etholm and Egenberg, 1964; Finkelman, Zeitlin, Romoff, Friend, and Brown, 1979; Kryter and Poza, 1980; cited in Carter et al, 1993; Lehmann and Tamm, 1956; Mosskov and Ettema, 1977b; Ponomarenko, 1966; Sanden and Axelsson, 1981; Van Dijk, et al., 1983). For example, Etholm and Egenberg (1964) found no change in heart rate in subjects exposed to 90dB white noise for 29 minutes. In contrast, Griefahn et al. (1991) detected a moderate but significant acceleration of heart rate in subjects exposed to 49 impulsive noise of 19 second duration at 62-80 dBA. Klein and Gröbl (1969) found both increases and decreases in heart rate with a ten second exposure to 92-96 dB noise, using a sample of 40 subjects (see also Rövekamp, 1983).

Results have also varied when subjects were to perform more demanding or prolonged intellectual tasks during exposure. Ray et al. (1984) reported no effect, whereas increased heart rate was associated with varying noise (Linden, 1987) and unpredictable bursts of narrow band noise during a vigilance task (Carter and Beh, 1989). Hanson et al. (1993) also detected significant heart rate acceleration as a result of exposure to noise during the performance of effortful tasks.

Whilst one community study provides evidence for aircraft-noise-induced heart rate elevations, most laboratory studies demonstrate effects of noise on heart rate only if effortful tasks are being performed during the noise exposure. This difference may be partially due to more negative reaction to community than to laboratory noise. Negative reactions may mediate the stress response. Generally, it has been concluded that any increase in heart rate which does result from aircraft noise exposure is so small as not to pose any long-term threat (Berglund and Lindvall, 1995).

#### *Cardiac Output, Stroke Volume and Sinus Arrhythmia*

Laboratory studies, which have examined the effects of noise exposure on cardiac output, stroke volume and cardiac arrhythmia have produced inconsistent findings. Further, the relevance to aircraft noise in the community is dubious.

Whilst exposure to meaningless noise has been found to produce a reduction in cardiac output (Andrén et al., 1979, 1980; Jansen, 1969; Lehmann, 1955, 1959; Lehmann and Tamm, 1956), failure to detect any change in cardiac output or stroke volume in subjects exposed to 90dB white noise for 29 minutes has also been reported (Etholm and Egenberg, 1964). However the sample size of the later study may have been insufficient. Carter and Beh (1989) found that exposure to intermittent noise during vigilance task performance in the laboratory resulted in reduction of the 0.1 Hz component of sinus arrhythmia, indicating distress.

#### *Chronic Cardiovascular Effects*

Studies examining chronic cardiovascular effects have mainly used small, selective samples, not controlled for other relevant risk factors (for example, age, alcohol and tobacco use, body mass index, family history) and paid

inadequate attention to dimensions of the noise other than its sound pressure level (for example, frequency spectrum). It may be instructive to consider whether factors such as alcohol and tobacco are influenced by noise exposure, such that they may operate as mediators as well as confounders.

#### *Vasoconstriction*

One community study has considered the effects of long term exposure to aircraft noise on the extent of vasoconstriction which occurs in response to an acute exposure to noise. Residents in high noise areas showed no greater vasoconstriction than those in low noise areas (Deutsche Forschungsgemeinschaft, 1974).

In contrast, occupational studies in a variety of industries have provided evidence of increased vasoconstriction in workers having experienced long-term exposure to continuous noise in excess of 85 dBA. However, these studies were poorly controlled for the effects of a variety of other risk factors for vasoconstriction (see Berglund and Lindvall, 1995).

#### *Elevations in Blood Pressure*

A review of the few available community studies suggests a weak to moderate effect of aircraft noise on blood pressure in both children and adults. Findings from occupational and laboratory studies corroborate this conclusion.

In a study of 262 children attending school around Los Angeles Airport, Cohen, Evans, Stokols, and Krantz (1986) found blood pressure to be significantly higher in children attending noise affected schools than in children attending quiet schools. Differences were greatest during the first two years of aircraft noise exposure but persisted in attenuated form thereafter. However, the longitudinal data may have been distorted by high attrition rate. Interestingly, the children who did not return at the noisy school were primarily from families with a history of hypertension, raising the possibility that hypertensive effects were underestimated. Similarly, blood pressure elevations in children have been associated with exposure to intense (above 115 dBA) noise in the vicinity of military aircraft installations (see Ising et al, 1980; cited in Carter et al, 1993). Nine to 13 year old girls living within an intense noise zone demonstrated increases in systolic and diastolic blood pressure, as did boys when hereditary predisposition to hypertension was controlled. However, boys living in another district with comparable levels of aircraft noise did not display this effect.

Studies addressing the relationship between aircraft noise exposure and hypertension in adults have produced inconsistent but suggestive findings. No relationship was detected by Pulles et al. (1990) however no statistical details were reported. In contrast, Knipschild and coworkers (Knipschild, 1977a, 1977b; Knipschild and Oudshoorn, 1977) reported that residents in the vicinity of (Amsterdam) Schiphol Airport demonstrated a higher blood pressure than residents in a low noise area, with the data suggesting a possible dose-response relationship (see also Karagodina, Soldatkina, Vinokur, and Klimukhin, 1969). However, a low response rate (approximately 42%) and the probable failure to control for body weight, smoking or socio-economic status undermine confidence in this conclusion.

A follow up found that a change from low to high noise exposure caused an increase in the purchase of antihypertensive medication. In the quiet control community medication use remained stable. Based on such data Knipschild (1978) concluded that noise exposure levels of 65-75 dB  $L_{Aeq}$  were sufficient to produce blood pressure elevation.

Cross-sectional community studies of traffic noise have shown only weak associations of traffic noise with hypertension. For example, Otten, Schulte, and von Eiff, 1990) found that individuals living in a noisy area (63-78dB  $L_{Aeq}$ ) had a similar mean blood pressure to those living in a less noisy area ( $L_{eq}$  less than 55dBA) despite rating the noise as less tolerable. Use of antihypertensive medication was associated with perceived tolerability rather than blood pressure. In the Caerphilly and Speedwell Heart Disease Studies (Babisch and Gallacher, 1990; Babisch, Elwood, and Ising, 1993; Babisch, Gallacher, Elwood, and Ising, 1988) association of traffic noise and blood pressure was found to be stronger in subjects with exposure to workplace noise, supporting the contention that the effects of a specific noise source cannot be regarded in isolation.

Occupational studies in a variety of industries have provided evidence of increased blood pressure. However, recent studies which have included adequate controls for risk factors such as smoking, fat consumption and family history, have shown only a weak correlation of blood pressure with noise exposure. These studies have used exposure times varying from 1 to 30 years, often in the face of the claim that a minimum of 20 years is necessary before the relationship of noise exposure to blood pressure would become apparent. However, other researchers have suggested that effects on blood pressure would be discernible after five years (Berglund and Lindvall, 1995). Whilst Theorell (1990) reported that noise-induced elevation of blood pressure occurred mainly among workers with a family history of hypertension, Zhao, Zhang, Selin, and Spear (1991) found a dose-response relationship between noise exposure (levels ranged from 75-104 dBA) and hypertension, even when family history was statistically controlled. Amendments for age, working years, salt intake, and family history were also made in a multiple logistic regression. The odds of hypertension were found to increase by 1.2 for each 5dBA increase. Although the sample was large ( $N > 1,000$ ) it was restricted to women, who may have a higher susceptibility to high blood pressure. Talbott et al. (1996) report a study of male workers in which noise exposure was significantly related both to diastolic and to systolic blood pressure in multiple regression analyses in which age, body mass index, alcohol consumption (drinks/week), current hypertension, and use of hearing protection were also entered.

Animal studies support the contention that extended exposure to noise can lead to increases in blood pressure. In a study which is supposed to be most applicable to humans (Peterson, Augenstein, Tanis, and Augenstein, 1981; see also Peterson, 1984) exposed rhesus monkeys to 85-90 dB work place noise over periods of up to nine months. Compared to controls, exposed animals showed increases in systolic and diastolic blood pressure of 23-28% and changes in the diurnal rhythm of the blood pressure that persisted for a month after exposure ceased. These levels of exposure were insufficient to produce hearing loss. In later studies, these researchers have found that daily

exposure is related to the magnitude of blood pressure elevation (see Berglund and Lindvall, 1995).

#### *Elevations in Heart Rate*

It has been shown that the heart response to noise exposure varies with noise source, being stronger for traffic noise than pile-driver noise, gunfire and intermittent pink noise (Parrot, Petiot, Lobreau, and Smolik, 1992). The only study of aircraft noise uncovered (Deutsche Forschungsgemeinschaft, 1974) demonstrated no effect of exposure to aircraft noise, however other evidence suggests the possibility that it could lead to elevations in blood pressure.

Residents in high noise areas showed no greater elevation in heart rate or muscular activity in response to the same acute test noise exposure than those in low noise areas (Deutsche Forschungsgemeinschaft, 1974). However, this result indicates only that any effect of noise on heart rate does not increase or decrease with chronic noise exposure. Alternatively, any habituation in this response in the home does not generalise to the test setting.

Several occupational studies have shown long-term exposure to continuous noise in excess of 85 dBA to be associated with elevated heart rate, though other risk factors for heart rate elevation have often been poorly controlled (see Berglund and Lindvall, 1995).

Experiments with primates (rhesus monkeys), demonstrate that exposure to 85-90 dB noise over periods of up to 9 months can result in changes of the diurnal rhythm of the heart rate and "pauses" in heart beat (Peterson et al., 1981, 1984).

#### *General Cardiovascular Health*

The impact of exposure to aircraft noise on general cardiovascular health has been neglected in favour of studies of specific outcomes such as vasoconstriction, blood pressure and heart rate, but community studies of traffic noise and occupational studies suggest that there is a weak negative impact of noise exposure on cardiovascular health.

A general practice survey (Knipschild, 1977a) examined the association between noise exposure and contact with a general practitioner for cardiovascular complaints. A contact rate of 9% was found in a high noise area compared to 6% in an intermediate area and 5% in a low noise area. On the basis of these data, Knipschild (1977a) inferred a dose-response relationship. However, the results may have been biased by a failure to control for differences in socio-economic status, access to general practice services, or diagnostic criteria employed by various general practitioners, either statistically or by subject selection. In a community survey of cardiovascular health (Knipschild, 1977b) exposure to high level aircraft noise was associated with pathological heart shape, cardiovascular drug use, and medical treatment for heart problems. Knipschild regarded these data as strong suggestive evidence that aircraft noise is a causal factor in cases of cardiovascular disease. This conclusion must be viewed sceptically because bias may have been introduced by the low response rate and by failure to



adjust for potential confounders such as smoking, socio-economic status and body weight.

Potential confounding also undermines mortality studies which report increased risk of mortality from stroke (Meecham and Shaw, 1979), from arteriosclerosis and from heart disease in general (Environmental Impact Statements, 1979) as a result of exposure to aircraft noise. Age, sex and socio-economic status - each an important risk factor for the outcomes of interest - are not adjusted for in these studies.

The large (N>6,000) and prospective Caerphilly and Speedwell Heart Disease Studies (Babisch and Gallacher, 1990; Babisch et al., 1993; Babisch et al., 1988) involved initial assessment of risk factors of ischemic heart disease and measurement of 6 to 22 hour Leq traffic noise exposures at each subject's residence. With only 5-10% of subjects exposed to noise exposures which were likely to be clinically significant, no dose-response relationship found using 5dB intervals. Relative risk for Ischemic Heart Disease of low (<60 dB) versus high (66-70 dB) noise exposure was only 1.1. Because the sample in these studies was comprised only of men, the results may only be considered relevant to men.

The Berlin traffic noise case-control community study (Babisch, Issing, Kruppa, and Wiens, 1994; Ising, Babisch, Kruppa, Lindthammer, and Wiens, 1996) examined the influence of traffic noise on the risk of myocardial infarction. "Cases" were men who were successfully treated Berlin hospitals for acute myocardial infarction and controls were matched for age and gender, but not socio-economic status (which was statistically controlled). Subjects were interviewed about potential confounding variables and subjective work noise. Initial analysis revealed a barely significant increase in risk in the most highly noise exposed group (Babisch et al., 1994).

Long term exposure to continuous workplace noise is associated with a higher incidence of circulatory problems/beat irregularities (Jansen, 1962). However, again confounding factors cannot be ruled out. Ising et al. (1996) reanalysed data from the Berlin traffic noise study using subjective work noise as the exposure variable controlling for potential confounding variables (current smoking, body mass index, age, socio-economic status, education, marital status, residential area, shift work). Work noise was rated as being comparable to the noise from 1) a refrigerator, 2) a typewriter, 3) an electric lawnmower, 4) an electric drill, or 5) a pneumatic drill. Because the relative risks of myocardial infarction were virtually identical for the first two classes of work noise these were combined. The risk of myocardial infarction was found to increase significantly and monotonously with class of subjective work noise exposure. However, the nature of this relationship should be interpreted cautiously given the unusual rating scale used. The authors concluded that with social class controlled, 27% of all myocardial infarctions in the source population were attributable to subjective work noise, making this variable the second most important risk factor after smoking. It is important that the observed relationships are for perceived, rather than actual noise exposure, raising the possibility that the observed effect is mediated by a psychological mechanism.

### *Moderators of the Effects of Noise on Cardiovascular Function*

The extent of the cardiovascular response to noise exposure may be moderated by a range of factors besides sound pressure level, which has been shown to predict blood pressure change only for subgroups of workers (Aro, 1984). It has been shown that a combination of noise and other factors may have more of an effect on physiological functions than noise itself (Manninen, 1983).

For example, noise-induced elevations in blood pressure may depend critically on the rate of onset of the noise. Røvekamp (1983, study I) found that synthetic impulse noise produced greater increases in blood pressure than aircraft, traffic and railway noise. Rise time was also found to be an important factor in blood pressure response of elderly people to the noise of low-flying military aircraft (Michalak et al., 1990).

Blood pressure responses to noise may be influenced by age. Subjects in studies showing increased diastolic blood pressure have tended to be young. However, subjects of the three studies in which noise-induced increases in systolic blood pressure were observed spanned a wider age range or were older. Thus, Røvekamp (1983, Study I) employed eight people between 20 and 30 years old and seven people between 40 to 66 years old, as "normal" subjects. Subjects used by Von Eiff et al. (1981) ranged from 20 to 59 years old, and Michalak et al. (1990) employed only elderly subjects.

Several studies have shown greater cardiovascular response to noise (including aircraft noise) in women (Berglund and Lindvall, 1995).

Individual differences in susceptibility to cardiovascular reactions to noise may have some genetic basis (or basis in shared environmental conditions—such as attitudes, diet and so forth). Amongst individuals with normal blood pressure, those having at least one hypertonic family member demonstrate a greater elevation in both diastolic and systolic blood pressure when exposed to noise than those without a family history of hypertension (Theorell, 1990; von Eiff et al., 1981).

Cardiovascular response to noise may also be moderated by noise sensitivity. Subjects who describe themselves as noise-sensitive (feel threatened by noise, were influenced physically or mentally in a serious way, or were annoyed, aggressive or rebellious) react with larger increases in vasoconstriction, blood pressure and heart rate than their "normal" counterparts when exposed to noise from road traffic, aircraft, impulse noise and railway noise at 75 dB  $L_{Aeq}$  while carrying out a simple task (Røvekamp, 1983; see also Stansfeld, 1992). However, Ohrström et al. (1988) found no significant correlations between measures of discomfort thresholds for noise, heat, cold and light and heart rate reaction to noise, suggesting that there was no general factor of physiological sensitivity in these data.

Psychophysiological responses to noise have also been found to increase if the noise is perceived as uncontrollable (Babisch, Fromme, Beyer, and Ising, 1996; Lundberg and Frankenhaeuser, 1978).



Melamed, Harari and Green (1993) found that Type A behaviour was related to increases in diastolic blood pressure and heart rate in workers exposed to sound pressure levels greater than 80 dBA (see also Di Nisi and Muzet, 1989). Type A and Type B personalities also differ in responsivity of noise-induced vasoconstriction (Ickes et al, 1979; Hunter, 1971; both cited in Carter et al, 1993), although it should be noted that the underlying critical factors of Type A personality have transpired not to be those initially described.

The physiological bases for differential reactivity have not yet been elucidated.

### *Indirect Effects of Noise on Cardiovascular Function*

The physiological responses to noise may be mediated by mechanisms other than the direct effect of repeated or sustained elicitation of the stress response described above.

Evidence suggests that noise-induced stress increases the excretion of magnesium, potentially causing serum magnesium deficiency (particularly in individuals with insufficient dietary magnesium intake)(Altura, 1979; Dyckner and Wester, 1983; Ising, 1981), and associated vasoconstriction, vasospasm and ischemia. In turn, these complaints may result in hypertension and coronary heart disease. Indeed the concentration of intracellular magnesium has been found to correlate negatively with long-term increases in blood pressure (Ising, Bertschat, Ibe, Stoboy, Goossen, and Hengst, 1986; Ising, Havestadt, and Neus, 1985), supporting recent data that serum magnesium deficiency can potentate the effects of chronic noise exposure on blood pressure (Altura, 1991, 1993) and in combination with noise exposure has been found to lead to changes in cardiac structure in animals (Gunther et al., 1978).

Noise-induced changes in serum concentrations of cholesterol and triglycerides [may also contribute to increased risk of cardiovascular illness (Ising et al., 1996).

The disturbance and dissatisfaction created by noise exposure in daily life may mediate the stress response. For example, frustration caused by not being able to sleep may produce and increase in blood pressure. Consistent with this hypothesis, Ising and Rebentisch (1993b) reported that subjects experiencing noise-induced sleep disturbances, were more likely to suffer angina pectoris (relative risk: 1.86) and hypertension (relative risk: 2.32) than those not reporting disturbances. Peripheral vasoconstriction following naturalistic exposure to community noise has been found to be greater in children with reading difficulties than in normal children (Hunter, 1971; cited in Carter et al, 1993). Noise reaction has been related to blood pressure (in adults: Lercher and Kofler, 1993; in children: Schmeck and Poustka, 1993). Self-reported annoyance has been found to be associated with hypertension for moderate but not high traffic noise levels in a cross-sectional epidemiological study (Neus, Ruddel and Schulte, 1983), though hypertension was not related with noise exposure itself. However, the suggested causal connection is not definitively established by this research.

### *Comments from Recent Sydney Airport Studies*

According to Kinhill (1990) the findings relating to the impact of aircraft noise on blood pressure elevations are inconsistent. However, they cite only three studies in relation to this claim and do not indicate whether these studies examined aircraft noise nor whether the cardiovascular effects considered were acute or chronic. Kryter's (1985) finding that exposure to traffic noise is correlated with blood pressure in children is cited later. Cardiovascular effects other than blood pressure elevations were not considered. The review of the relevant literature above indicates that a very extensive body of data is at least suggestive of some impact of aircraft noise on cardiovascular effects including vasoconstriction, elevations in diastolic and systolic blood pressure, elevations in heart rate and general cardiovascular health. Evidence is available for both acute and chronic effects.

The *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) suggests that some submissions are consistent with an impact of aircraft noise on cardiovascular health. For example, DEAF report that many respondents have complained of a negative impact of noise on blood pressure. However, the methodological difficulties with the DEAF "studies", which were mentioned earlier, render these findings to be of little value. Reference is made in the report to Knipschild's (1977) finding that amongst residents near (Amsterdam) Schiphol Airport, those in high noise areas were more likely to be undergoing treatment for heart trouble and hypertension. The study of schoolchildren performed by Cohen et al. (1986) is also cited, however the claim that a "follow-up study of the same schools failed to yield longitudinal blood pressure effects due to the high percentage of children with blood pressure leaving the noisy schools" is dubious. It is not certain that biased attrition was the only cause of a failure to find a longitudinal effect. Further, it was children with a family history of hypertension, rather than children with high blood pressure themselves, who left the high noise schools.

#### **5.2.6 PSYCHOENDOCRINE AND IMMUNOLOGICAL EFFECTS**

Noise exposure may produce psychoendocrine and immunological effects associated with the fight/flight and stress responses.

##### *Psychoendocrine Effects*

Very few community studies have examined the impact of noise exposure on the psychoendocrine system, however laboratory studies in animals and humans have found short-term noise exposure to lead to supranormal levels of endocrine hormones, such as catecholamines (including adrenaline and noradrenaline) and cortisol (for example, Cantrell, 1974; Carter, Crawford, Kelly, and Hunyor, 1993; Cavatorta, et al., 1987; Welch and Welch, 1970). Elevation of psychoendocrine activity may have adverse health consequences.

### *Noise and Catecholamines*

Secretion of catecholamines, principally adrenaline and noradrenaline, reflects sympathetic nervous system activity. Thus, catecholamines are thought to be involved with stress/anxiety, mediating cardiovascular effects including elevation of heart rate and blood pressure. Thus, increased catecholamine levels may underlie noise-induced increases in heart rate and blood pressure and sustained elevations may cause damage to arterial linings, cardiac arrhythmias, platelet aggregation, and increased lipid metabolism may occur.

One recent cross-sectional community study of the impact of aircraft noise on psychoendocrine function in children (Evans, Hygge, and Bullinger, 1995; Hygge, Evans, and Bullinger, 1993) detected significantly higher levels of overnight urinary adrenaline and noradrenaline in children chronically exposed to aircraft noise than in a control group (matched on relevant socio-economic variables).

Ising (1983) reported increased urinary noradrenaline excretion in policemen exposed to 60 dB LAeq of recorded traffic noise in the field. In an experimental study carried out in the workplace, Levi (1966) found no effect of noise at work on excretion of catecholamines.

Laboratory studies indicate that exposure to noise can produce elevated levels of catecholamines under certain conditions. No effect of noise on catecholamine solution was found by Follenius, Brandenberger, Lecornu, Simeoni, and Reinherdt, (1980), using regular intermittent pink noise at 90 dBA and 30-second on/off periods, or by Andr  n et al. (1979, 1980, 1982). However, subjects exposed to a 90 dB 2.0 kHz tone for 30 minutes demonstrated elevated levels of adrenaline and noradrenaline (Arguelles et al., 1970). Only hypertensives showed concomitant increases in blood pressure. di Cantogno et al. (1976) found that amongst subjects exposed to continuous road traffic noise at 70 dB LAeq for 10 minutes, urinary catecholamine levels were elevated only in one group, labelled dysmetabolics. Osada et al. (1972) observed increased urinary excretions of noradrenaline after exposure for two or six hours for several days to noise levels of 40, 50, and 60 dBA (see also Slob, Wink, and Radder, 1973). Ising et al (1980; cited in Carter et al, 1993) found that noise enhanced secretion of adrenaline and noradrenalin, but only when subjects performed an unfamiliar task concurrently. Elevated catecholamine levels are also observed in the laboratory when subjects perform cognitive tasks during noise exposure (Arvidsson and Lindvall, 1978; Frankenhaeuser and Lundberg, 1977; Lundberg and Frankenhaeuser, 1978), and appear to result from effort to maintain optimum task performance under noise. Brandenberger, Follenius, Wittersheim, and Salame (1980) also found a task effect not added to by noise.

Animal studies have revealed increased urinary excretion of adrenaline as an after-response to noise (Ogle and Lockett, 1968).

### *Pituitary Adrenal-Cortical Hormones*

Hyperactivity of the pituitary adrenal-cortical system is involved in the stress response (Selye, 1956). Cortisol, an adrenal hormone, is involved in the operation of the immune system. Cortisol elevations may result in suppressed immune function (Ader and Cohen, 1993).

Human (laboratory) studies of psychoendocrine effects of noise exposure have revealed increased plasma and urinary corticoids, urinary 17-ketogenic steroids and 17-ketosteroids in normal and psychiatric subjects exposed to sounds at 63 or 93 dB for one hour (Arguelles, Ottone, and Chekherdeman, 1962; but see Arguelles et al., 1970). Levels of leukocytes, eosinophils, and basophils, as well as in urinary 17-hydroxycorticosteroid have been found to change after exposure twice a day for 30 min to noise levels of 55, 70, or 85 phon (Tatai et al., 1965, 1967). Increased urinary excretions of 17-hydroxycorticosteroids are also observed after exposure for two or six hours for several days to noise levels of 40, 50, and 60 dBA (Osada et al., 1972). Transient increases in serum cortisol were recorded 15 minutes after onset of 90 dBA continuous noise by Favino, Maugeri, Kauchtschischvili, Robustelli Della Cuna, and Nappi (1973). No effect on plasma cortisol was found following exposure to continuous one-third octave bands of noise (Slob et al., 1973) or to a variety of noises, including one in which 105 dBA broad band noise was cycled in 10-second on/off periods for 30 minutes (Brandenberger, Follenius, and Tremolieres, 1970). However, only two subjects were used in each experiment. Noise was found to produce elevations in cortisol levels in a later study using 99 dBA pink noise and a longer on/off period (Follenius et al., 1980) and in a study in which subjects performed an unfamiliar, but not a familiar, task (Brandenberger et al., 1980). Iwamoto, Ishi, Yoneda, Morie and Harada (1995) report that although plasma cyclic AMP was not observed to increase following laboratory exposure to 90 dBA traffic noise, significant elevations were observed when noise was presented while subjects were performing a calculation task. Performance of the task in the absence of noise did not cause significant elevations of cyclic AMP.

Studies in mice, rats and guinea pigs have demonstrated noise-induced depression of corticosterone output (Henkin and Knigge, 1963), temporary eosinopenia and changes in the adrenal gland (Anthony and Ackermann, 1955), rise in adrenal 11-hydroxy corticosteroid in blood (Horio, Sakamoto, and Matsui, 1972), and increases in plasma corticosterone levels (Rosecrans, Watzman, and Buckley, 1966). However, other studies have failed to reveal effects of noise on adrenocortical activity (Anthony, Ackerman, and Loyd, 1959).

### *Other Psychoendocrine Effects*

Noise exposure has been hypothesised to influence levels of growth hormone, creatinine, uric acid, sodium, potassium, serum cholesterol, triglycerides and total lipids, thyroid hormone, blood sugar, glucose, insulin and plasma renin. The results of studies which attempted to test the effect of noise on levels of these variables in humans have been either negative or difficult to interpret (Carter et al, 1993; but see Melamed, 1995 in relation to cholesterol and triglycerides).

### *Immunological Effects*

The possibility that exposure to noise depresses immune function is based on empirical evidence that noise is a stressor (Schwarze and Jansen, 1990) in conjunction with evidence that various kinds of stress can modulate immune function (Sieber, Rodin, Larson, Ortega, and Cummings, 1992).

Early laboratory studies of humans showed no effect of noise on indices of immunity (for example, Finkle and Poppen, 1948). Atherley, Gibbons, and Powell (1970) estimated the total white cell count, eosinophils, neutrophils and lymphocytes of subjects who has been exposed to noise for seven hours. The results did not fit the pattern of a stress response and no statistical tests of significance were reported.

A recent review of nine relevant animal and human studies published since 1988 suggests that evidence regarding the hypothesis that noise can affect health through modulation of the immune system, is inconclusive (Bly, Goddard, and McLean, 1993). The four (out of nine) studies that were considered to have reliable data, have inconsistent findings. Folch, Ojeda and Esquivel (1991) found that noise stress produced a reversible increase in serum thymulin (a hormone affecting the function of the thymus, an important organ of the immune system) concentration in mice exposed to noise stress. Similarly, Irwin, Segal, Hauger and Smith (1989) showed that after 10 (but not 1 or 4) days of noise exposure natural killer cell activity (which is positively correlated with immune function) in rats was significantly increased. In contrast, Sieber et al. (1992) found small reductions in natural killer cell activity after acute exposure of healthy male human volunteers to uncontrollable, but not controllable, noise. Kugler, Kalveram and Lange (1990) found a 25% reduction of two populations of lymphocyte cells after acute, but not chronic, noise stress.

Potential negative impacts of noise on immunity may be influenced if the noise is perceived as uncontrollable, because learned helplessness is associated with impaired immunity (Visintainer, Volpicelli, and Seligman, 1982).

The putative immunosuppressive effects of noise may also be partially mediated by noise-induced sleep loss (Brown, 1991; Brown, Pang, Husband, and King, 1989; Palmblad et al., 1976; Palmblad, Petrini, Wasserman, and Akerstedt, 1979; Ohrstrom, 1993b). The effects of sleep loss have not been consistently addressed in relevant laboratory studies of acute exposure to noise.

Stressful reactions to the noise, such as annoyance, dissatisfaction, frustration, fear, may also impair immune function. Arvidsson and Lindvall (1978) found no association between annoyance and urinary catecholamine levels in a laboratory experiment, however cortisol levels were not measured.

### 5.2.7 BODILY FATIGUE

#### *Noise and Bodily Fatigue*

According to a basic review by Bartley and Chute (1947) fatigue is considered to be directly perceived, personal and cumulative, and to arise from underlying conflicts. It may appear and disappear very suddenly. Physiological models of fatigue are based on energy expenditure, disturbance of electrolyte homeostasis or accumulation of metabolites when working (MacLaren, Gibsoon, Parry-Billings and Edwards, 1989). Psychologically, motivational factors and other individual characteristics play an important role in perceived effort and fatigue (Gamberale, 1985). It might be predicted that bodily fatigue would result from the strain of noise exposure. A range of environmental and intraindividual conditions may cause symptoms of fatigue.

Subjects exposed to intense infrasound have reported symptoms of extreme fatigue (Mohr, Cole, Guild, and von Gierke, 1965) and a higher incidence of fatigue and irritability is reported amongst workers exposed to intense noise than amongst non-exposed controls (Jansen, 1962). However, no simple relationship was found between noise levels and feelings of fatigue among workers exposed to five sound intensities ranging from 50 to 125 dB (between subjects) (Matsui and Sakamoto, 1971). The precise role of noise as a causal or contributive factor in bodily fatigue has not yet been established.

Individuals who are less able to cope with the strain of noise exposure, such as the elderly and the ill, might be particularly prone to noise-induced bodily fatigue.

Fatigue may be an indirect consequence of noise exposure, which results from noise-induced sleep disturbance.

Overall, the lack of observed effects is not surprising and uninformative. It may be true that noise does not cause fatigue. Alternatively, the concept of bodily fatigue may be sufficiently ill-defined, with understanding and measurement of it varying so much from person to person, as to make effects difficult to detect (Lee, Hicks and Nino-Marcia, 1991).

### 5.2.8 MORTALITY

#### *Noise and Mortality*

The claim that mortality rates are significantly elevated in populations exposed to aircraft noise is based on the findings of two studies, one conducted around Sydney Airport, which did not exclude competing explanations. The association is not maintained when the influence of confounding variables is controlled.

According to Environmental Impact Reports (1979) noise in the environs of Sydney Airport was associated with increased mortality from arteriosclerosis, heart disease in general, congenital abnormalities, and nephritis and

nephrosis for particular age and sex population subgroups. However, the division of the study population into low and high aircraft noise exposure areas may have been inaccurate and no attempt was made to account for confounding variables.

Meecham and Shaw (1979) reported that the mortality rates (deaths per 1,000 population) due to cirrhosis of the liver and stroke were elevated in the high aircraft noise area (greater than 90 dBA) by 100% and 15% respectively, compared to a low aircraft noise area (no exposure details provided). However reanalysis of these data (Frerichs, Beeman, and Coulson, 1980) showed that differences in mortality rates disappeared once adjustment was made for age, sex and race. Using Los Angeles County data as the reference, the standardised mortality ratio (SMR) for overall mortality was 0.99 in the high noise area and 0.95 in the low noise area. The SMR for cerebrovascular disease 0.92 in both the high and low noise areas.

Thus, positive findings have not withstood the scrutiny of reasonably controlled investigations.

#### *Comments from Recent Sydney Airport Studies*

Kinhill (1990) included consideration of the mortality studies discussed above and new results of an epidemiological study of the effects of aircraft noise on mortality in Sydney. Previous mortality studies were criticised for a failure to account for demographic and racial factors. Using morbidity data from 1988-89 Taylor and Lyle (1990) concluded that "[t]here do not appear to be any clear or consistent correlations between mortality and exposure to aircraft noise" (Kinhill, 1990, p24.35). Age was matched across noise regions. Other confounding variables, ethnicity and socio-economic status, were found to correlate with mortality rate. Whilst these effects were statistically controlled in the analysis of noise effects on mortality, this was not made clear in the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990). Furthermore, unsurprisingly the boundaries of local government and post code areas, each of which were used to determine noise exposure do not correspond exactly to noise contours. Direct noise measurements were not made. Taylor and Lyle (1990) recognise a further weakness to their study in that exposure levels are determined on the place of residence at the time of death only.

The *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) cites findings from both Kinhill (1990) and Taylor and Lyle (1990). It is remarked that the latter study was less conclusive. However, these studies suffer from very similar flaws and it is more appropriate to conclude that no currently available data resolve the question of whether aircraft noise causes an increase in mortality rates in Australia.

Further research is required to adjudicate on this issue.

#### **5.2.9 PERINATAL HEALTH**

Perinatal health has been considered as an indicator of general health in research on the effects of noise exposure, however the effects of noise on

perinatal health is an issue worthy of consideration in its own right. Evidence from a number of cross-sectional field studies suggest that aircraft noise may have harmful effects on pregnancy and the foetus (for example, Cohen and Weinstein, 1982; Cohen et al., 1986; Knipschild, Meijer, and Salle, 1981), possibly due to noise-induced alterations in uterine and placental blood flow. However, studies which have been performed to determine whether there is an association between aircraft noise and low birth weight, gestation length and birth defects have serious methodological flaws which render their findings difficult to interpret. As an important example, various studies have suffered through lack of control for maternal smoking behaviour, potentially a serious confounder.

### *Birth Weight*

Five studies have addressed the question of whether aircraft noise is associated with low birth weight, most reporting positive results. For example, Ando and Hattori (1973) reported reduction in birth weight after aircraft operations began in Itami (Japan), relative to low noise areas where there was no noise change. Similarly, Rehm and Jansen (1978) reported a non-significant trend between low birth weight and exposure to aircraft noise (range 5.9% to 6.7% across noise divisions) amongst 1,452 births. Unfortunately, neither of these studies indicate that any allowance was made for important confounders (for example, smoking, socio-economic status) and Rehm and Jansen provide insufficient detail on the selection of subjects. However, data consistent with the results of these two studies were reported by Knipschild et al. (1981). Mothers who resided in high aircraft noise areas during their pregnancies were more likely to have babies weighing less than 3,000 grams, reflecting mainly a difference in the birth weight of females. These results could be considered more reliable had the authors controlled for maternal smoking and had more than 902 of 3,094 eligible births in the study period been included in the analysis. Meyer, Aldrich and Easterly (1989) found lower birth weight to be associated with noise exposure on female infants, with socio-economic status controlled. In a study of 3,292 births, Coblenz, Martel, and Ignazi, (1990) reported that birth weight was generally lower for both sexes in one of two aircraft noise affected areas and among males in another, relative to reference areas without aircraft noise. However, these results may have been biased by inadequate control of maternal smoking, as well as by failure to adjust for socio-economic status, gestation length and other potential confounders. In contrast, another epidemiological study has reported no effect of noise on birth weight (Schell, 1981). The ecological design of each of these studies raises the difficulty that those at lowest risk of having a low birth weight baby (for example, those of high socio-economic status) may have migrated out of areas that became aircraft noise affected.

### *Gestation Length*

Available evidence supports the hypothesis that exposure to aircraft noise results in reductions in gestation period (and thus a higher rate of prematurity), which may contribute to the reductions in birth weight. Prematurity rate is reported to have increased following the commencement of aircraft operations in Itami (Japan) relative to areas which continued to have low noise exposure (Ando and Hattori, 1973). Schell (1981) reported a



corresponding effect of noise on gestation period with maternal age, smoking and socio-economic status controlled. However, sufficient detail on sample selection was not provided. The same methodological concerns as raised in the preceding section apply here also.

### *Birth Defects*

The influence of aircraft noise on the prevalence of birth defects is uncertain. Jones and Tauscher (1978) concluded from a study of over 225,000 birth certificates in Los Angeles county, that babies whose mothers resided under a flight path where noise exceeded 90dBA were significantly more likely to display birth defects than those whose mothers did not. Due to criticism of the accuracy of birth certificates as a measure of the incidence of defects, Edmonds, Layde, and Erikson (1979) conducted a similar study around Atlanta airport using data derived from a comprehensive birth defects surveillance system. These authors did not detect any effect of exposure to aircraft noise.

### *Comments from Recent Sydney Airport Studies*

In Kinhill (1990) data regarding the influence of aircraft noise on perinatal health are considered and methodological faults with the relevant studies are recognised. For example, Ando and Hattori (1973) are criticised for failing to account for prematurity, the age of the mother, or socio-economic status. However, the studies reported in their study would seem at least suggestive of a negative impact of aircraft noise on perinatal health.

The *Report of the Senate Select Committee on Aircraft Noise* (Senate Select Committee on Aircraft Noise in Sydney, 1995) cites the same studies as Kinhill (1990) and claims that "the Draft EIS discounted studies which indicated an association between aircraft noise and perinatal problems... because other factors were not taken into account" (Senate Select Committee on Aircraft Noise in Sydney, 1995, p144). Nonetheless, while the methodological problems of a study can be recognised and its findings consequently deemed inconclusive, the problems do not render the data completely pointless. These results are suggestive of the need for rigorous research on this question. A submission to the Senate Select Committee from the Australian Medical Association also refers to the same studies but in the absence of appropriate methodological criticism the findings of these studies are inappropriately presented as being unambiguous. Nonetheless, in consideration of a precautionary approach to sustainable development, such evidence leaves cause for concern.

## **5.2.10 GENERAL PHYSICAL HEALTH**

### *Noise and General Health*

Investigation of whether exposure to aircraft noise causes a reduction in general health has produced inconsistent findings. Numerous clinical symptoms including nausea, headache, irritability, instability, argumentativeness, reduction in sexual drive, anxiety, nervousness, insomnia, abnormal tiredness, and loss of appetite (Jirkova and Kromarova, 1965) have been attributed to noise exposure.

Few studies have found a simple relationship between aircraft noise with self-reports of general health and visits to the physician for physical symptoms, however health measures have been found to be associated with subjective responses to noise. Grandjean, Graf, Lauber, Meier, and Muller (1973) found no association between aircraft noise exposure level and general symptoms in a study around three Swiss airports. In a study on aircraft noise around a German airport, no signs of disease were found in a thoroughly examined sample of the population exposed to 82-100 dBA aircraft noise (Deutsche Forschungsgemeinschaft, 1974). Similarly, Graeven (1974) using a sample of 552 subjects found no relationship between noise level (NEF) and a symptom checklist measure, although annoyance was found to be strongly related to health problems. An Australian community survey (Hede and Bullen, 1982a) found that subjects in high aircraft noise zones ( $> 25$  NEF) were no more likely to rate their health as "bad" or "very bad" than subjects in lower noise zones. However, the belief that noise has negative effects on health correlated significantly with noise exposure (correlation coefficients ranging from 0.13 to 0.23) as well as general reaction (correlation coefficients ranging from 0.26 to 0.56) (Hede and Bullen, 1982a). Van Kamp (1990) found no relationship between health complaints and aircraft or traffic noise stratum (however, the health complaints she considered included sleep disturbances and psychological problems including depression, which are covered elsewhere in this review). In contrast, Knipschild (1977b) reported that people in high noise areas have more digestive system problems and visits to the general practitioner. However, these findings must be viewed with some scepticism given the brief period of study (one week) and the failure to control for potential confounding variables, such as smoking and socio-economic status. Knipschild and Oudshoorn (1977) found an increase in the purchase of antacids and cardiovascular drugs in a community newly exposed to noise but not in one where there was no change. Again, age, gender and socio-economic status were not controlled. However, the study of an area newly exposed to noise reduces the risk of noise nuisance being caused by lower socio-economic status or of bias by self-selection.

The prevalence of headaches has been found to be higher in high than in low noise areas (Bullen et al., 1981; Jonah, Bradley, and Dawson, 1981). Tarnopolsky, Hand, Barker, and Jenkins (1980), studying the effect noise exposure in the vicinity of Heathrow airport using a 27-symptom checklist discovered that minor accidents and symptoms classified as acute (including irritability, sleep disturbance and burns, cuts and minor accidents) were more prevalent in a high than in a low noise area, whereas the opposite was the case for symptoms classified as chronic (among them headaches, undue tiredness and breathlessness). Monotonic dose-response relationships were not clearly visible. However, in a large study ( $N=6000$ ) also in the vicinity of Heathrow in which potential confounding variables were controlled, Watkins, Tarnopolsky, and Jenkins, (1981) found no relationship of noise exposure with any of a range of indicators of health including drug use, visits to the general practitioner, status as an out- or inpatient, and use of community health services.

In a cross-sectional study conducted around two military airports in The Netherlands, Pulles et al. (1990) discovered a positive correlation (of

unspecified significance) between exposure to aircraft noise and subjective ill-health as measured by a symptom checklist.

In a thorough study (N=82) of the impact of traffic noise on health, Nivison and Endresen (1993) examined the relationship of health factors derived from self-reports on 27 health complaints (severity, when they occurred, medical attention) and sleep patterns (including latency, awakenings, perceived sleep quality) with noise exposure (Leq, Lmax). Potential modifiers such as noise sensitivity, noise annoyance, noise exposure at work, length of residence, other life events, family history, smoking, type A behaviour and trait anxiety, were given careful consideration. Sensitivity and annoyance scales were constructed from two independent sets of highly intercorrelated variables. The results indicated a weak negative relationship of noise exposure with health and sleep complaints. However, noise exposure was not a significant factor in explaining the variance in total health complaints. Health complaints were more closely related to annoyance for men (especially stomach upset, day time fatigue) and sensitivity for women (especially intestinal complaints, cold, flu, nervousness, cardiovascular health, poor sleep quality). Noise sensitivity and anxiety, which were highly correlated, explained 54% of the variance in total health complaints in women.

In a recent cross-sectional community survey examining the impacts of traffic noise (Lercher, 1996), use of analgesics and antacids were significantly associated with sensitivity and annoyance, but not with noise level, though prescriptions generally (including for medications such as sleeping pills) were most strongly associated with noise level.

Whilst occupational studies have generally provided support for a relationship between noise exposure and general health, these findings may not be generalisable to the general population, given the selectivity inherent to occupational studies. Whilst Davis (1958) reported that men working on aircraft carriers did not evidence a higher rate of symptoms if exposed to high noise than if not, this is an occupational group which is likely to be self-selected for high noise tolerance and may even, especially in the 1950s, have been selected for minimal report/admission of signs of weakness such as health problems. Cohen (1976) studied medical records of 500 workers of plants with sound pressure levels above 95 dBA and those of controls matched for age and length of plant experience working with sound pressure levels below 80 dBA. The finding that those working with higher noise had more complaints and diagnosed illnesses has been questioned on the ground that plants with high noise are probably high in other health hazards (Berglund and Lindvall, 1995). However, the actual level of confounding is not known. McDonald and Ronayne (1989) also found that increases in noise level were associated with increases in the frequency of symptoms assessed by a 12 item version of the General Health Questionnaire. Stansfeld (1992) concluded from a review of the relevant literature that individuals working in noisy industries have higher self-rated illness, actual illness and illness-related absenteeism than workers of quieter industries.

### *Moderating Variables*

Intense low frequency noise has been found to cause respiratory impairment (von Gierke and Nixon, 1976; see also von Békèsy, 1960). However, the

levels at which this impairment have been reported are above those experienced by residents near commercial airports.

Several perceived attributes of the noise- controllability (predictability), necessity, and meaningfulness (as a signal of danger) are hypothesised to moderate the physiological effect of high noise exposures. Stressors which are perceived as uncontrollable have been found to be appraised as more threatening and to potentate negative effects on health. For example, Pulles et al. (1990) found that differences in subjective health complaints between noise exposed and nonexposed groups depended on the perceived controllability of the noise rather than its intensity. Atherley et al. (1970) compared the effects of exposure to white noise with a negative meaning, with the effects of equally intense noise with no such meaning. Only meaningful noise increased complaints such as tiredness and irritability, galvanic skin responses, and circulating lymphocytes and neutrophils, and reduced adrenocortical response (urinary 17-ketosteroids).

According to Rehm (1983) individual responses to noise may be more highly correlated with symptoms of ill-health than with the noise itself, a finding which is consistent with an underlying sensitivity factor. Sensitivity to noise has been found to relate to impaired health (Niveson, 1992; Nivison and Endresen, 1993). While the causal sequence of sensitivity causing increased reactivity to noise and thus more health effects is credible and apparently obvious, it is not the only account available. For example, people may be more sensitive to noise as a result of illness.

#### *Comments from Recent Sydney Airport Studies*

Of the five studies regarding the effect of aircraft on general and mental health cited by Kinhill (1990) (Abbey-Wickrama et al., 1969; Meecham and Smith, 1977; Thompson, 1983; Knipschild, 1977a; Koszarny et al., 1981), two examined only mental hospital admissions (Abbey-Wickrama et al., 1969; Meecham and Smith, 1977) and two cardiovascular health in particular (Thompson, 1983; Knipschild, 1977a). Thus, the conclusion that "[w]hile some studies have reported higher rates of several illnesses in areas affected by aircraft noise, these studies have generally failed to allow for other influences on morbidity in the community" (Kinhill, 1990, p24.32), is justified but of limited relevance to general health effects. The evidence reviewed here is inconclusive but suggestive of an influence of aircraft noise on general health.

The *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) also reported the results of an epidemiological study of hospital admissions for the year 1988-89 in Sydney (Taylor and Lyle, 1990). Again, no distinction seems to have been made between general and psychiatric hospital admissions, making the data difficult to interpret in the present context although legitimate for Taylor and Lyle's purposes. The authors concluded that "there do not appear to be any clear or consistent correlations between hospital morbidity and exposure to aircraft noise in Sydney local government and postcode areas". As identified earlier, the validity of these findings is undermined by the concerns regarding the noise level classification.

Whilst the *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) does not make these criticisms of the epidemiological morbidity study included in Kinhill (1990), it does include a number of submissions which appear to suggest that aircraft noise impacts on general health. A wide number of health-related complaints, including tension, anxiety, headaches, respiratory problems, skin disorders, were registered by the hotline and general practice survey run by DEAF. Dr Aline Smith also reported cases of stress and anxiety "requiring more intense therapy through counselling or tranquillisers". Residents of noise affected areas complained of greater use of analgesics, sedatives and antacids. However, the deficiencies in these data must again be identified. The data are based on the self-reports of a self-selected sample and without baseline measurements or a control sample it is difficult to determine whether any illness is caused by, or influenced by, exposure to aircraft noise.

#### 5.2.11 ASSESSMENT OF THE CAUSAL ROLE OF NOISE IN HEALTH EFFECTS

Whilst there is some inconsistency in the relevant literature and much of the available data is correlational in nature, a significant case can be made for the claim that noise harms health, on seven grounds (as outlined by Job, 1996).

First, community studies of changes in noise exposure have revealed associated changes in health status, such as increased prevalence of hypertension and use of cardiovascular disease related medication (Knipschild and Oudshoorn, 1977). Such findings are particularly significant because they are not confounded by the usual self-selection factors (except to the extent of related resident relocations which occur before the investigations).

Second, two lines of evidence are inconsistent with the possibility that the real relationship between noise exposure and health is exaggerated by self-selection biases operating to result in the most noise susceptible people living in high noise areas. Firstly, selection of place of residence is more likely to result in less noise sensitive people living in higher noise areas (even within numerous logistic and financial constraints). Given evidence indicating that people do not adapt to the noise (Weinstein, 1982), noise sensitive people who do move into high noise areas, are presumably more likely to move again because of the noise. Secondly, residents exposed to high levels of noise which are then reduced have consistently been found show a reduction in noise reaction to a lower level than would be expected for the new level of exposure (Brown, Hall, and Kyle-Little, 1985; Raw and Griffiths, 1985; and see Job, 1988b). Similarly, a sudden increase in noise exposure has been found to produce an increase in reaction to a level beyond that expected from the new exposure level (see Raw and Griffiths, 1990; Job, 1988b). These results are inconsistent with the view that those residents who choose to live in high noise areas are particularly sensitive to the noise and people who live in low noise areas are particularly insensitive to the noise. Furthermore, the response criteria for annoyance are higher in people living in high noise areas than in people living in low noise areas (Berglund, Berglund and Lindvall, 1975a; Fidell, Teffeteller, Horonjeff and Green, 1979). Consistent with these arguments, community studies

commonly show near zero to negative correlations between noise exposure and noise sensitivity (for review see Job, 1988a), especially where the noise source is readily apparent when place of residence is chosen (for example, road noise: see Langdon, 1976, who identified a correlation of -0.28 between sensitivity and noise exposure). Whilst McKennell (1978) reported a positive correlation between sensitivity and supersonic aircraft noise exposure, respondents in this survey were unlikely to have selected their place of dwelling with this new, wide distribution, noise source in mind.

Third, longitudinal studies of noise exposure show changing effects on health over time (Babish et al., 1993; Neus et al., 1983; Stansfeld, 1992).

Fourth, laboratory studies have identified short term effects consistent with field observations without the potential complications of a nonrepresentative "survivor" population. Such studies reveal the capacity of noise to produce the relevant effects, at least temporarily. For example, field observations of changed blood pressure in high noise areas (Cohen, Evans, Krantz, and Stokols, 1980; Knipschild, 1977a, 1977b) are corroborated by changes in heart rate and blood pressure during laboratory exposures to noise (Carter and Beh, 1989; Parrot et al., 1992; Vallet, Gagneux, Clairet, Laurens, and Letisserand, 1983b). Exposure to noise in the laboratory also produces startle (Rylander et al., 1974) and elevation of catecholamines and cortisol levels (Cantrell, 1974; Carter et al., 1993; Cavatorta et al., 1987), consistent with observations of startle and stress responses in socio-acoustic investigations (Bullen et al., 1991; Bullen et al., 1985; Wolsink and Sprengers, 1993).

Fifth, evidence supports a range of mechanisms by which noise might cause various health effects.

Sixth, studies which do not detect health effects of noise may suffer a variety of methodological limitations, notably including insufficient statistical power. Small sample sizes, inflation of variance due to measurement error and failure to consider confounding and moderating variables make discovery of existing relationships difficult.

Seventh, some analyses which have controlled for a variety of confounding social factors have uncovered previously identified noise-health relationships (for example, aircraft noise and mental hospital admissions: Kryter, 1990). Thus, while the evidence for health effects of noise is not definitive, a strong case exists.

Although, the above considerations do not prove a causal connection between noise and health effects, the weight of evidence is in favour of such a connection. Further, given the potentially extreme negative consequences of incorrectly dismissing the possibility that noise has a negative impact on health, it seems reasonable to assume that it does while further research aims towards settling the matter. This reasoning is supported by the precautionary principle for a sustainable development.

### 5.2.12 INDIRECT EFFECTS OF NOISE ON NON-AUDITORY PHYSIOLOGICAL HEALTH

Non-auditory physiological health may be adversely affected not only by noise exposure itself, but also by the impacts of noise on other outcomes. For example, any immunosuppressive effects of noise, mediated for example by stress, sleep loss or annoyance, is clearly liable to have negative consequences for health.

Noise exposure increases catecholamine activity (Cantrell, 1974; Cavatorta et al., 1987), which is involved in stress and anxiety, blood pressure and heart rate elevation, and compromised immunity (Ader and Cohen, 1993). Stress also influences plasma cholesterol (Brennan, Job, Watkins, and Maier, 1992) which is probably involved in cardiovascular disease (although possibly not as closely related to life expectancy as previously thought: Atrens, 1994) [see Section 4.6].

Noise which is perceived as uncontrollable (see babisch et al., 1996; Cohen et al., 1986; Evans, 1982; Job, 1993; Lundberg and Frankenhaeuser, 1977) may produce "learned helplessness" (Maier and Seligman, 1976; Seligman, 1991) effects including ulcers (Overmier and Murison, 1989), changes in blood plasma cholesterol (Brennan et al., 1992) and impaired immune system resistance to tumour growth (Visintainer et al., 1982).

It is conceivable that noise-induced sleep disturbance (Carter et al., 1993) could have negative health consequences. The functions of sleep in humans are still the subject of controversy and research. For example, Horne (1990) maintained that there is little evidence in support of the much accepted view that sleep serves a restorative function in humans, whereas Hobson (1989) contended that sleep is necessary for good physiological health. Medical authorities have also argued that sleep disturbance due to aircraft noise can impact on health in otherwise healthy people as well as deleteriously affect the healing process (Hobson, 1969; RPA Hospital Medical Board 1995; Faculty of Medicine, University of Sydney 1995). Mirmiran and Van Someren (1993) suggested that REM sleep in infants may be related to brain restitution, and Carter (1995) has suggested that sleep, especially slow wave sleep, may provide a respite for the cardiovascular system, resensitizing and maintaining set-points in blood pressure control mechanisms. Further, some data obtained from humans and animals suggest that there is an association between sleep and optimal immune function, and that sleep deprivation, particularly loss of slow wave sleep, could affect health through a negative affect on immunity (Brown, Pang, Husband and King, 1989a; Brown Price, King and Husband, 1989b; Brown, Husband and King, 1992; Moldofsky, Lue, Eisen, Keystone, and Gorczynski, 1986, Moldofsky, Lue, Davidson and Gorczynski, 1989; Palmblad et al, 1976; Palmblad et al., 1979; Ohrström, 1993b; Toth and Krueger 1988a, 1988b). However, there are no published data specifically relating noise-induced sleep disturbance to immune function in man or animals.

Self-reported symptoms of ill-health are related to subjective sleep quality (Niveson, 1992). For example, the relationship of noise disturbances during the day and nighttime with self-reported diseases was examined in a cohort study (N=1,006; Ising and Rebentisch, 1993b). Subjects reporting noise-



induced sleep disturbances, were more likely to suffer angina pectoris (relative risk: 1.86) and hypertension (relative risk: 2.32) than those not reporting disturbances. In contrast, daytime noise disturbance was not associated with these complaints. Sleep loss may be associated with stress, with possible causal connections in both directions (see Carter et al., 1993; Sarafino, 1994). The possibility that other reaction modifiers such as attitude to the noise source influence sleep loss is of particular interest. Correlation of these factors in socio-acoustic investigations could simply indicate that those with the most negative attitude report the most sleep loss, or recall the most sleep loss, or that greater sleep loss and/or greater stress induces a more negative attitude. Fatigue, either as a result of noise exposure or noise-induced sleep disturbance, could result in injuries as a consequence of inadequate care being taken.

Injuries may also result from workers failing to hear important warning signals or shouts as a result of noise-induced hearing deficits or noise induced interference with speech intelligibility. Although such mechanisms are little documented in the literature, there is anecdotal evidence for them (Berglund and Lindvall, 1995).

Noise-induced disturbance of voice communication [see Section 5.2] may also result in voice disorders. Voice levels tend to be raised to compensate for noise disturbance (Pearsons, Benett, and Fidell, 1976; Lazarus, 1990), possibly resulting in vocal cord stress and then voice disorders (von Klingholz, Siebert, Schleier, and Thamm, 1978).

Interference of voice communication and social behaviours could disrupt social networks, which may have a negative influence on health (Berkman and Syme, 1979; House, Landis, Umberson, 1988).

Psychological stress may also mediate the impact of noise on health. Noise reaction has been found to be associated with having a nervous stomach (Ohrstrom, 1989), health ratings (Lercher and Widmann, 1993; Rehm, 1983) and use of medication (Lercher, 1996).

### 5.3 IMPACT OF NOISE ON PERFORMANCE AND ACTIVITY

#### 5.3.1 SLEEP DISTURBANCE

Social surveys have revealed that sleep disturbance is regarded as an important effect of environmental noise (Alexandre, 1974; Lambert and Vallet, 1994), although sleep disturbance can occur for reasons other than noise exposure (Langdon and Buller, 1977). Findings pertaining to the effects of noise exposure on sleep, perceived sleep quality and fatigue are inconsistent but suggest some relationship which is subject to noise characteristics, individual differences and general health (for reviews see Berglund, Preis, and Rankin, 1990; Griefahn, 1991; Griefahn, Jansen, and Klosterkotter, 1976; Lukas, 1975; Ohrstrom, 1993b; Suter, 1992; Vallet, 1987). Most studies have focussed on exposure to simulated traffic noise in the laboratory, however evidence suggests that community exposure to



aircraft noise also disturbs sleep. For example, cessation of night flights has been found to reduce sleep disturbance (Berglund and Lindvall, 1995).

### *Normal Sleep Process and Sleep Disturbance*

Recordings of sleep can be obtained by measuring the electrical activity of the brain (electroencephalogram, EEG), together with the electrical activity in the eyes (electrooculogram, EOG) and muscles (electromyogram, EMG). Behavioural and self-report measures are also available (see Carter, 1996a, 1996b; Smith, Oyung, Gregiry, Miller, and Rosekind, 1996).

The normal sleep process involves predictable changes in EEG pattern, which are scored in 'epochs', usually of 20 seconds, 30 seconds, or one minute duration. Prior to sleep, a change from rapid, irregular waves to the regular alpha rhythm can be observed. This is followed by sleep stage 1, which features prolonged reductions in wave amplitude and frequency. Sleep stage 2, is characterised by 1-2 sec bursts of 7-14 Hz waves (spindle waves) dotted with single, slow, relatively large amplitude waves (K-complexes). The following stage 3 includes periods of slow, high amplitude waves (delta waves), with a frequency of approximately 0.3-3 Hz. If the proportion of an epoch occupied by delta waves exceeds 50% it is defined as stage 4 sleep. Following Stage 4 1-REM sleep begins. The 1REM EEG pattern resembles that found during waking, though often with characteristic "saw-tooth" waves. REM sleep is also characterised by rapid and co-ordinated eye movements, which are detected by the EOG, and a marked drop in the amplitude of the EMG signal relative to that of other sleep stages and of waking. Stages 1 and 2 are regarded as light sleep, and stages 3 and 4 deep sleep (Smith et al., 1996). Stages 3 and 4 are also jointly referred to as slow wave sleep. REM sleep is distinguished from the preceding stages which are termed collectively non-REM sleep. For a typically adult one night's sleep involves 4-5 cycles, each containing all stages of sleep and lasting approximately 90 minutes. Overnight the duration of each successive slow wave sleep period usually decreases while REM periods increase (Smith et al., 1996). Interpretation of sleep data must be made cautiously because there is wide variation between individuals as well as across the lifespan.

It has been predicted that exposure to nighttime noise might cause primary sleep disturbance effects such as difficulty in falling asleep, reduced sleep soundness -in terms of alterations of sleep pattern or depth, body movements and awakenings- (see Eberhardt, 1987; Griefahn, 1989, 1990), and vegetative reactions such as increased blood pressure (Muzet and Ehrhart, 1978), increased heart rate (Öhrström, 1989), increased finger pulse amplitude, vasoconstriction, and change in respiration and cardiac arrhythmia (Carter and Hunyor, 1988; Carter, Hunyor, Ingham and Tran, 1994a; Carter, Hunyor, Crawford, Kelly and Smith, 1994b). Nighttime exposures might also induce secondary effects (after effects), which are detectable the day after the noise exposure. These secondary effects include reduced perceived sleep quality, increased fatigue, decreased mood or wellbeing and decreased performance (Öhrström, 1982). The effects of noise on sleep are not necessarily independent. For example, evidence suggests that perceived sleep quality is influenced by the time needed to fall asleep, the number of awakenings during the night and the feeling of tiredness in the morning (Lukas, 1977; Öhrström, 1982).

### *Methodological Concerns*

Several difficulties with assessing the impact of noise on sleep are pertinent. Firstly, community studies may report artificially deflated observed correlations between outdoor noise levels and sleep disturbance. Because higher outdoor noise levels may force people to sleep with the windows closed (Fidell and Jones, 1975; Globus, Friedmann, Cohen, Pearsons, and Fidell, 1974), actual (inside) noise exposures may be lower than recorded (outdoor) noise exposures for high but not low level noises. The correlation between outdoor noise levels and sleep disturbance may be low, for example, because the higher the outdoor noise levels, the more the windows are closed. Carter et al. (1992) measured six noise metrics simultaneously indoors (roughly in the centre of the bedroom) and outdoors (one metre toward the road from the bedroom window) in 20 second intervals overnight at a number of detached, single family dwellings (double-brick and brick-veneer) on Pennant Hills Road, Sydney. The correlation between indoor and outdoor LAeq, LAmx, LApk, LA90, LA10, and LA1 averaged 0.88, 0.80, 0.69, 0.90, 0.90 and 0.84 respectively, when windows slightly (up to 20 cm) open, but only averaged 0.51, 0.43, 0.31, 0.51, 0.57, and 0.49 with window closed. The difference between outside and inside levels was greatest for measures of peak measures and lowest for LA90. In the area studied the main external noise was road traffic and not aircraft noise. As with the correlations, attenuation values were different for the six noise metrics. No consideration was given to the effect of different outdoor noise levels on the size of the correlation. In conclusion, correlations of noise and sleep disturbance should be calculated using indoor noise levels. All field studies of noise and sleep should include continuous (simultaneous) outdoor and indoor noise measurements. Failure to measure indoor noise exposures in one major study of aircraft noise and sleep has presented difficulties in generalising the result to other locations (Horne, Pankhurst, Reyner, Hume, Diamond, 1994).

Secondly, community studies are rare and findings of laboratory studies may be inappropriate for predicting real world responses to given levels and numbers of aircraft noise events for the following reasons:

- a review of 21 laboratory and field studies of the effect of noise on sleep (Pearsons, Barber, Tabachnick, Fidell, 1995) indicated that dose/response curves relating noise levels to probability of awakening, or sleep stage changes differ substantially as a function of whether the data used to derive the curves was gleaned from laboratory or field studies. Curves derived from field data were markedly 'flatter' compared with those using data from laboratory studies. Thus, a given increase in noise exposure produced a smaller increase in response in the field than it would in the laboratory, probably reflecting some habituation in the field, or the combined effect of noise and unfamiliarity in the laboratory;
- the sleep process is likely to be affected by the laboratory environment in ways that are not accounted for by control groups, and these laboratory artifactual effects may interact with noise effects in as yet unknown ways. Much research of noise-induced sleep disturbance has been conducted in the laboratory even though responses to noise in the laboratory, an unfamiliar environment, may be quite different to responses to the same noises when sleeping at home, an environment to

which the sleeper has habituated. This is often referred to as the "first night effect" in laboratory studies but in reality habituation to novel sleeping conditions may take much longer than one night. Whilst such problems may be reduced by having subjects become familiar with sleeping in the laboratory prior to beginning testing, many features of the real world experience are difficult to simulate in the laboratory; and

- the parallel between field and laboratory findings may be further undermined by the common practice of playing recordings of outdoor noise to subjects in laboratories, whereas field study subjects hear the noise after it has been attenuated by the building. Even adjustment for loudness does not overcome the problem that indoor noise is likely to have a greater low frequency noise component (due to differential attenuation of different frequencies by buildings).

Nonetheless, due to its greater practicality laboratory is useful for studying theoretical aspects of noise-induced sleep disturbance, for establishing casual links, for trialing methods to be used in the field, and for investigating certain physiological responses to noise during sleep. However, only field studies can provide the basis for quantitative predictions of the effects of aircraft noise on sleep in the community.

Thirdly, laboratory studies often fail to consider the noise to which people have been exposed during sleep at home, which may be relevant given the evidence of habituation in some noise-induced sleep effects (body movements: Ohrström and Rylander, 1990; awakening: Griefahn and Jansen, 1978; Vallet, Gagneux, and Simonnet, 1980). Such adaptation may have resulted in underestimation of the impacts of noise in studies of individuals with sufficient previous exposure.

Finally, the relationship of noise with sleep disturbance varies depending on how sleep disturbance is defined and measured. For example, amongst dose-response curves derived from 21 studies of the effects of noise (from various sources) on sleep (Pearsons et al., 1995), curves of percent change in sleep stage distribution [see Section 5.1.4.2b] versus noise level were much steeper than curves of arousal/awakening [see Section 5.1.4.2c] versus noise level. This suggests that sleep stages changes are more readily evoked by noise than are arousals. Even different measures of awakening have been found to correlate poorly with one another (Fidell et al., 1995b). Carter (1996) and Smith et al. (1996) provide an overview of various indices of sleep disturbance.

### *Relevant Sound Indices*

There is considerable uncertainty as to which measure of noise exposure is most appropriate for assessing noise-induced sleep disturbance.

Several studies demonstrate weak associations of sleep disturbance with A-weighted equivalent continuous sound pressure level (Eberhardt and Akse, 1987; Ohrström, 1982; Vallet, Gagneux, Clairet, Laurens, and Letisserand, 1983b; Vernet, 1983). For example, Fidell et al. (1994 xxx a or b?; 1995) found no relation between long term (24-hour) LAeq or variants such as Day-Night Level (DNL) and frequency of awakening or between overnight LAeq and reported annoyance due to aircraft noise, in their field

studies of aircraft noise and sleep. Thus, several alternative noise indices have been considered.

The finding that intermittent noise disturbed sleep much more than continuous noise (Ohrström and Rylander, 1982; Thiessen, 1983; Eberhardt et al., 1987) carried with it the implication (confirmed by Eberhardt, 1988) that measures of the level of single noise events would be better predictors of sleep disturbance than LAeq. It is now customary to report the level of single noise events in term of one or both of two measures. The first is L<sub>Amax</sub> and the second is A-weighted Sound Exposure Level (ASEL), where:

$$AS\ EL = L_{Amax} + 10 \log D/D_{ref} \quad (1)$$

and D equals the duration of the noise event and D<sub>ref</sub> equals 1 second. Generally, ASEL values are 5-10 dB greater than L<sub>Amax</sub> for the same noise events, depending on the relation between maximum level and duration of the event. For example, for aircraft noise, the decrease in L<sub>Amax</sub> as aircraft altitude increases is accompanied by greater differences between L<sub>Amax</sub> and ASEL. Pearsons et al (1995) compared L<sub>Amax</sub> and ASEL as measures of the noise levels of single noise events, and concluded that in general ASEL gave higher correlation with sleep disturbance. The ratio of the level of single noise events to background noise level has been found to be at least as important for sleep disturbance as absolute noise level of the event in laboratory and field studies (Eberhardt, 1982, 1988; Eberhardt and Axelsson 1987; Eberhardt, Stråle, and Berlin, 1987; Ohrström, 1982).

Other indices which have been employed in the investigation of noise-induced sleep disturbance include the number of events exceeding a certain sound pressure level, the sound level exceeded during 1% of the measuring time and NPL (Noise Pollution Level, accounting for temporal fluctuations) (Griefahn, 1990; Vallet et al., 1983a, 1983b). Griefahn (1990) offered a method of combining maximum level and number of noise events overnight to determine a critical load for nocturnal noise. Passchier-Vermeer (1994) recently developed a calculation method, on the basis of dose/ response relationships derived from field study data, for combining the number of noise events overnight and the SEL of these events in order to predict the probability of awakenings and sleep stage changes. The percentage of awakenings and sleep stage changes are a linear function of this noise index. Further consideration is given to Passchier-Vermeer's estimation method in Section 12.

Bullen, Hede and Williams (1996) have presented a methodology for a Sleep Disturbance Index (SDI) which is numerically equal to the estimated average number of awakenings per night which would be caused by the noise in question. Typical values of SDI would range from less than 0.2, representing a relatively insignificant level of disturbance, to greater than 5, representing a high level of disturbance. The value of the SDI depends on the number of individual noise events heard per night; the maximum noise levels of events; and the "emergence" of events above the ambient noise. No other methodology allows all these factors to be considered in a systematic and quantifiable way. Bullen et al (1996) also propose a criterion of an SDI value of 1.5 as an appropriate threshold for planning purposes, above which the

sleep disturbance would be considered "unacceptable". This level represents a "doubling" of the ambient level of sleep disturbance.

### *Primary Effects of Noise on Sleep*

#### *Effects of Noise on Sleep Latency*

Increases in the time taken to fall asleep (sleep latency) are considered to be an important component of noise-induced sleep disturbance (Öhrström, 1993b).

For example, reductions in sleep latency have been observed in children (Eberhardt, 1987) when they are moved to a quieter room and in adults when their windows are closed, thus reducing sound exposure (Griefahn and Gros, 1983). Residents of areas exposure above 70dBA outdoors reported greater difficulty in falling asleep, than residents of areas with lower noise levels (Öhrström, 1991). Similarly, Öhrström and Rylander (1990) observed increased sleep latency following exposure to traffic noise at 50 and 60 dB LAmax in both noise sensitive and nonsensitive subjects. Sleep latency was found to be similar for sounds at 45, 50 and 60 dB and it is contended that the number of events above a criterion level per unit time, rather than noise levels per se, is important for this component of sleep disturbance (Öhrström, 1991; Öhrström and Rylander, 1990). Consistent with this hypothesis, Carter and Ingham (1995), in a laboratory study, found an increase in sleep latency with the number of truck noises presented, but no relation to background noise level, nor any interaction between number of trucks and background noise level.

#### *Sleep Soundness and Pattern*

The effects of noise on sleep soundness can be divided into four types: a) body movements, b) changes in EEG-pattern such as transitions towards lighter sleep or EEG changes too short to be classified as sleep-stage changes, and c) awakenings. Interestingly, the use of behavioural versus electrophysiological indicators of sleep soundness produces discrepant findings regarding the impact of noise on sleep soundness.

#### *Body Movements*

The number of body movements which occur during sleep has been regarded as an objective measure of disturbance during sleep (Muzet, Naitoh, Johnson, and Townsend, 1974) and large body movements are associated with number of awakenings (Öhrström and Rylander, 1982) and sleep stage shifts (Dement and Kleitman, 1957). The occurrence of body movements has been found to increase with LAmax (maximum sound pressure level) (Eberhardt, 1987; Öhrström, 1982). For example, Naganuma et al. (1991) exposed subjects to 26 recorded traffic noise events at 55, 60 and 65 dBA for five nights in the laboratory. The authors suggest that above a threshold around 60dBA a rectilinear relationship exists between exposure level and number of body movements. However, the range of sound pressure levels tested were insufficient to justify this conclusion. In contrast, Johnson, Townsend, and Naitoh (1973) and Carter and Ingham (1995) have suggested that the total number of body movements appears to be no greater in noisy nights than in quiet nights, even though they may occur in response

to particular noise events. It has been proposed that body movements may be necessary to relieve pressure points, so that the occurrence of a noise event merely triggers a body movement which may have occurred anyway. It is also possible that the finding reflects reduced duration of sleep in noisy relative to quiet nights, so that even if there is a greater frequency of body movements there may be a lower absolute number of them. However, there was no main effect of noise schedule on total sleep time in this study.

Increased body movements associated with noise exposure have not been found to habituate over 14 nights' exposure (Öhrström, 1989; see also Öhrström, 1993c). However, there is some indication of habituation within each night. Öhrström and Rylander (1990) report the increase in the number of body movements to be slightly lower if there are 64 rather than 16 noise events per night. For 16 noise events, there were three times that number of body movements observed under quiet conditions, regardless of which of three noise levels was used (45, 50 or 60 dBA).

#### *Changes in Sleep Stage Distribution*

Noise stimulation produces changes in the EEG pattern, which may be clear sleep stage shifts or K-complexes (increases of wave frequency) that are only detectable by close inspection of the EEG recording.

It has been argued that decrease in REM sleep duration provides the most sensitive indicator of noise exposure and is likely to occur for sound pressure levels above 45 dB LAmax (Suzuki et al., 1993).

Aircraft noise exposure has been found to reduce REM sleep. Muzet and coworkers (for example, Muzet and Olivier-Martin, 1973; Olivier-Martin and Schneider, 1973), found reduced REM sleep in laboratory subjects exposed to 77-97 dB LAmax jet take-off noises, with compensatory increases in REM sleep observed during the following quiet night. Exposure to aircraft noise in excess of 77-80 dBA may also be associated with the disturbance of REM sleep in newborn babies (Ando and Hattori, 1973).

Field study findings regarding the effect of traffic noise on REM sleep have been somewhat inconsistent. Jurriens, Griefahn, Kumar, Vallet and Wilkinson (1983) observed no effect on REM with traffic noise reduced in the bedroom by 10 dB. Thiessen and Lapointe (1983) found exposure to traffic noise increased REM sleep by 2.4% at 47dB and by 4.8% at 60dB. In contrast, REM sleep decreased following exposure to recorded traffic noise events at 55, 60 and 65 dBA over five nights in the laboratory (Naganuma et al., 1991).

Reduced overnight time in slow wave sleep has also been reported by a number of investigators in laboratory and field studies (Eberhardt 1987; 1988; Eberhardt and Axelsson 1987; Eberhardt et al., 1987; Griefahn and Gros, 1986; Hofman and Liefing, 1992; Otto 1970; Pearsons, Fidell, Bennett, Friedmann, and Globus, 1974; Stevenson and McKellar, 1989; Vallet et al., 1983a; Wilkinson and Campbell, 1984). However in a laboratory study using truck noises at 63-66 LAmax no clear association was found between time in the various sleep stages and the number of truck noises overnight, though there were clear responses to individual noise events, and some effect on sleep latency (Carter and Ingham, 1995).

Shifts towards earlier sleep stages can be detected in the laboratory for sound pressure levels exceeding 40 dB L<sub>Amax</sub> for road, train and aircraft noise (Eberhardt, 1987; Griefahn, 1986; Osada et al., 1968, 1969).

Finally, the frequency of reactions which do not quite constitute a change of sleep stage have been found to increase linearly with the number of noise events per night (Griefahn and Jansen, 1978).

Changes in sleep patterns do not appear to be permanent. Following reduction of inside noise levels after long term exposure the quantity of REM-sleep and/or slow-wave sleep has been observed to increase (Eberhardt and Akse, 1987; Friedmann and Gobus, 1974; Griefahn and Gros, 1986; Vallet, 1979; Vallet et al., 1983a, 1983b). For example, Friedmann and Gobus (1974) found that prior to the cessation of night flights at Dusseldorf airport (outdoor noise levels of 71 dB L<sub>Aeq</sub> for seven hours between 2300 and 0600 hours), the total duration of slow wave (stage 3 and 4) sleep averaged 47 minutes. Following the reduction of nighttime noise to 51 dB L<sub>Aeq</sub> for seven hours between 2300 and 0600 hours outdoors, slow wave sleep increased to a total duration of 68 minutes one week after cessation, and 61 minutes one month after cessation.

It has been suggested that the effects of noise stimulation on sleep depend on the concurrent stage of sleep. However closer examination suggests that the amount of interference induced by a given noise event is roughly equal for all sleep stages. For example, changes in EEG pattern appear to be least likely in REM and Stage 4 sleep (Thiessen, 1972; Lukas, 1975), however Williams (1973) has cited research indicating that this applies only to behavioural measures of awakening. Carter et al (1994b) also found that noise was least likely to elicit an alpha (arousal) response from Stages 4 and 3 (slow wave sleep), with REM the next least likely to show an alpha response. When alpha responses during intervals containing noise events were matched with quiet intervals of the same duration it was found that the noise simply multiplied the number of quiet interval alpha responses by the same factor, regardless of sleep stage.

Reduction in overnight slow wave sleep appears to be more likely in young adults than in older persons, possibly because they have a greater physiological requirement for slow wave sleep.

### *Awakening*

Data regarding the effect of aircraft noise on awakening is scant, however evidence from the laboratory suggests that exposure to traffic noise above approximately 50dB L<sub>Amax</sub> indoors, causes subjects who are not used to the noise to awaken. Awakenings may be detected using behavioural or self-report methods (for example, subjects are required to press a button on awakening, or indicate awakenings in questionnaires administered after the sleep period, respectively) or using EEG measures of awakening (for example, Lukas, 1977; Lukas, Dobbs, and Kryter, 1971). Behavioural and self-report measures may underestimate awakenings, because subject may not awake sufficiently to record or recall each awakening.

Pearsons et al. (1995) reviewed 21 studies of the effects of noise (from various sources) on sleep with a view to developing dose/response



relationships between noise level of individual noise events and sleep disturbance. This is shown in Figures 5.3 and 5.4. Several main sources of variation in the data were identified, the most important for present purposes being whether the studies were carried out in the field or in the laboratory, and whether sleep disturbance was defined and measured in terms of changes in sleep stage distribution or in terms of arousal/awakening. Linear dose/response curves for each combination of these parameters were derived using L<sub>A</sub>max and ASEL as the noise metric, and then compared with dose/response curves developed by previous reviewers. Neither the dose-response relationship for laboratory studies nor that for field studies was well represented by the dose-response relationship developed by FICON (1992) as a compromise between the two (Fidell, 1996). The conclusion reached by Pearsons et al. (1995) that no quantitative model of sleep disturbance could be derived from these data appears to be based largely on the discrepancies between laboratory and field data. In fact the correlations reported by Pearsons et al. (1995) between noise level and the mean values of percent sleep stage change or awakening from each study (which can be regarded as grouped data) were roughly comparable in size with commonly reported group correlations relating annoyance to aircraft noise level.

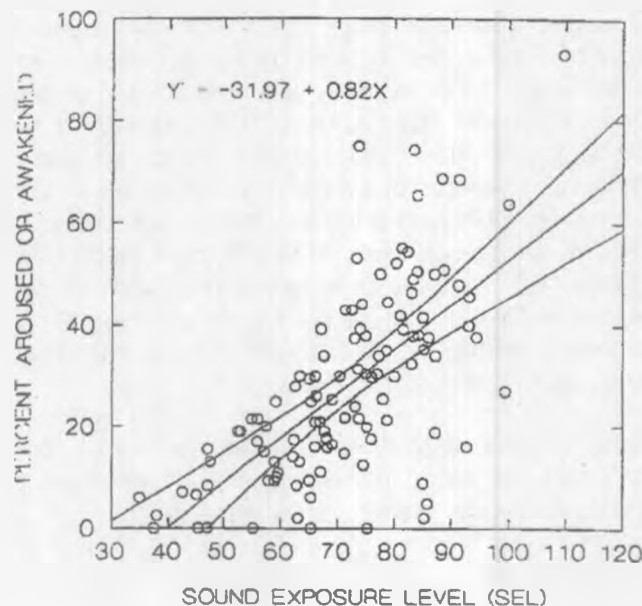


FIGURE 5.3 PERCENTAGE OF RESPONDENTS AROUSED OR AWAKENED AS A FUNCTION OF NOISE EXPOSURE (SEL) FOR LABORATORY STUDIES.

Source: Pearsons et al, 1995.



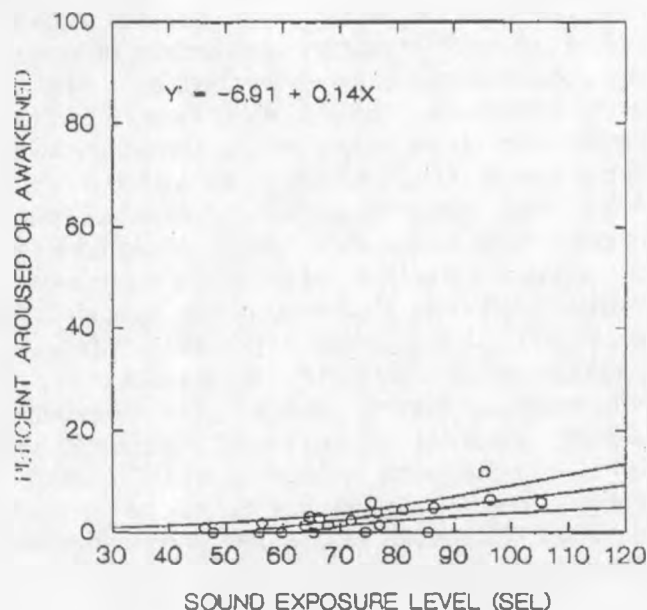


FIGURE 5.4 PERCENTAGE OF RESPONDENTS AROUSED OR AWAKENED AS A FUNCTION OF NOISE EXPOSURE (SEL) FOR FIELD STUDIES.

Source: Pearsons et al, 1995.

Four field studies of aircraft noise and sleep disturbance have been reported since Pearsons et al.'s (1995) review was conducted.

In a field study of sleep disturbance in homes near British airports Ollerhead et al. (1992) observed a dose-response relationship that agreed well with the regression line for field studies identified by Pearsons et al. (1995). Above 75-80 dB LA<sub>max</sub> arousals were found to increase with increasing maximum noise levels. Berglund (1996) suggests that this study may have been flawed by weakness in the outcome measure, use of outdoor rather than indoor noise levels, or use of too narrow a range of signal: background noise ratios.

Horne et al. (1994) monitored the sleep of 400 people living near four busy airports in the UK over a total of 5,472 nights. Arousals were detected by means of actimetry (using accelerometers attached to the wrist), a procedure validated previously against polygraphic measures. The actigraphic measures of arousal ('actiblips') were correlated with individual aircraft overflights. However, only one in 88 aircraft noise events induced an actiblip response. The threshold for a response was stated to be approximately 82 dB LA<sub>max</sub> outdoors (Horne et al. 1994). There were clear individual differences between subjects and domestic and idiosyncratic factors influenced responses to a greater extent than noise exposure. Unfortunately noise measurements were taken outdoors only, and the homes were well noise insulated. Thus, the LA<sub>max</sub> levels are overestimated for the sleep disturbance observed.

Fidell et al. (1995a) examined the relationship of noise measured both indoors and outdoors with awakenings in three groups of subjects: residents

in the vicinity of a civilian airport, in the vicinity of a military airport and in an area not subject to aircraft noise. Subjects recorded awakenings during the night and recall of number and duration of awakenings in the morning using a palmtop computer at the bedside. The observed threshold of awakening was about 55 dB ASEL indoors and the slope of a linear regression line relating indoor ASEL to percentage awakening agreed closely with the dose-response relationship derived from the Pearson et al. (1995) review of field studies of awakening. However, this group of researchers have consistently argued consideration should be given to the likelihood of an arousal/awakening in the absence of a noise event, as well as during or immediately following a noise event (see Horonjeff, Fidell, Teffeteller, and Green, 1982). Thus, Fidell et al. (1994a; 1994b) found that approximately two awakenings per night occur in the absence of any noise event, regardless of noise exposure. Further, while the relationship between indoor ASEL and awakenings was statistically significant, it accounted for only one-third of the variance in behavioural awakening (Fidell et al., 1995b). A logistic probability model indicated that SEL alone accounted for only 5% of awakening with variables such as time since retiring adding, considerably to predictability of awakening.

Fidell et al. (1995b) investigated the relationship between aircraft noise and awakening, measured behaviourally and actimetrically (using two types of actimeter), immediately before and after an airport changeover. Subjects were residents in the vicinity of the old or of the new airport. Indoor and outdoor noise levels were measured concurrently with sleep monitoring. Indoor SEL values for aircraft noise events ranged from about 60 to 95 B. The observed correlations of indoor SEL of individual noise events with actimetric measures of arousal, and with behavioural awakenings were relatively high. However, the intercorrelations between the three measures of arousal/awakening were low, raising concerns about the reliability of measures of sleep disturbance. Nonetheless, the linear dose/response relation of indoor SEL versus awakening again agreed well with that derived in a review of earlier field studies (Pearsons et al., 1995), that obtained by Horne et al., (1994), and by Fidell et al. (1994a).

Awakening has been shown to occur at levels as low as 45dB LAmax (Ohrström, 1983). Some subjects wake as a result of 50% of noises at 55 dB LAmax (Eberhardt et al., 1987). Ohrström and Rylander (1990) found subjects reported more awakenings following exposure to intermittent traffic noise at 50 and 60 dBA than unexposed subjects (see also Ohrström and Björkman, 1983).

There is some evidence of habituation during and across nights. Thus, the probability of awakening in response to a given noise decreases with an increasing number of prior sound exposures per night and the frequency of awakenings per night decreases at least over the first eight consecutive nights (Griefahn and Jansen, 1978). Further, awakenings in response to noise maxima from 90dB are substantially more frequent in acute laboratory studies than in field studies, in which noise exposure has persisted for several years. This finding suggests that habituation has occurred in the field studies. However the field study samples may consist largely of "survivors", and issue which was discussed in the introduction. Nonetheless, awakening frequencies in laboratory studies decrease rapidly with the length of

exposure (Vallet et al., 1980), although complete habituation is far from being achieved. Thiessen (1978) reported that the awakening response could take up to 24 days to habituate.

A number of studies suggest the signal to noise ratio, rather than absolute noise level, determines the probability of awakening. Further, the probability of being awakened increases with number of noise stimuli per night, following to a decelerating function (Griefahn and Jansen, 1978). This relationship is influenced by the interval between sound events and the probability of awakening is greatest for intervals of 40 minutes (Griefahn, 1977). Some studies indicate that the probability of awakening due to a given noise event is lower in the REM sleep stage, compared to non-REM sleep stages, for nonimpulsive as well as impulsive noises (Berry and Thiessen, 1970).

The research reviewed above suggests that average relations between the SEL of individual aircraft noise events and actimetric or behavioural measures of awakening are reproducible. Whether or not a given event will elicit a behavioural waking or actimetric response is not predictable at present although such individual correlations are improved by inclusion of a variety of non-acoustical factors such as age and gender, and (especially) time since sleep onset.

Few studies have considered the time spent awake following arousal, which can be measured with a sleep polygraph, but not actimetry or button-pressing.

#### *Vegetative Responses During Sleep*

Subjects exposed to noise during sleep demonstrate psychophysiological reactions, such as increased heart rate, finger pulse and respiration rate. Both laboratory and field studies of road traffic noise, suggest that noise levels as low as 40 dB LAmax can induce these effects, with minimal habituation occurring during and across nights.

Transportation noise during sleep has been found to elicit vasoconstriction at the finger tips (Muzet and Ehrhardt, 1978).

Guilleminault and Stoohs (1995) showed that sleeping subjects presented with a 5s, 1000 Hz tone at levels above 55 dB always demonstrated an increase in beat-by-beat blood pressure. However, the noise stimuli differed from everyday noise stimuli in virtue of being unfamiliarity and of instantaneous onset. An experiment to determine whether these results can be replicated using recorded truck and aircraft noise is being carried out at present in Sydney by Carter and his colleagues.

Heart rate has been found to accelerate in response to exposure to very low peak noise levels during sleep (Jurriens et al., 1983; Vallet et al., 1983b). Whilst Wilkinson (1984) has argued that the heart rate response to daytime noise exposures is quite small, and within the range of normal variation, the heart rate response during sleep to a single noise event (that is, the difference between the maximum and minimum heart rates reached in the acceleratory and the following deceleratory phases) can be 20 to 30 beats (Di Nisi, Muzet, Ehrhart, and Libert, 1990). Whilst the magnitude of the heart rate

response does not reduce with reductions in sound pressure level (Kumar, Tulen, Hofman, van Diest, and Jurriens, 1983), the number of responses reduces with a reduction in the number of noise events (Vallet et al., 1988). These studies of heart rate response did not control for a time series effect and in a field study which did so, no effect of noise on heart rate was found (Carter et al, 1994).

Hofman, Kumar, and Tulen (1995) found evoked cardiac responses due to peaks in indoor recorded sound levels in 12 subjects sleeping in their bedrooms along a noisy highway. Lowering the indoor sound level by double glazing windows did not reduce the magnitude of these cardiac responses, possibly because the number of peaks remained the same and their intensity may not have been reduced sufficiently by the glazing (Hofman et al., 1995). The magnitude of the evoked cardiac responses was related to the slope and duration of the soundmaxima. Hofman et al. (1995) comment that their findings indicate that cardiac responses may occur in the absence of concomitant signs of arousal or awakening (see also Di Nisi et al., 1990).

Some evidence suggests that cardiac responses to noise during sleep do not habituate (Hofman et al., 1995; Muzet and Ehrhart, 1978), however this may be because studies have been conducted after habituation has already occurred. For example, Hofman et al. (1995) examined cardiac acceleration in 12 subjects living along a highway with high traffic density. They found that cardiac acceleration in response to maxima in sound level did not decrease with time over ten nights. However, since subjects had presumably lived and slept in this setting prior to the study, they may have already habituated to the sound levels experienced there. Whilst some studies indicate a reduction or removal of cardiovascular effects with a reduction in noise levels (for example, Kumar et al., 1983) other studies indicate no effect of noise reductions (for example, Hofman et al., 1995).

The magnitude of the heart rate response depends on the time of night and sleep stage (Di Nisi et al., 1990). The heart rate response, like other arousal effects (Vernet, 1983), is more closely associated with the difference between background level and the maximum sound pressure level than the absolute sound pressure level.

A further potential psychophysiological response to noise exposure during sleep is increased release and excretion of catecholamines, such as noradrenaline and adrenaline. Hygge et al. (1993) found that amongst 9-12 year old children living in the vicinity of Munich airport, those living in noisy areas had significantly higher levels of adrenaline and noradrenaline in overnight urine samples than those living in less exposed areas. Babisch et al (1996) examined the relationship between road traffic noise and overnight urinary catecholamine (noradrenaline and adrenaline) levels in pre-menopausal women whose bedroom window faced a busy street. Noise exposure was estimated from traffic volume to correspond to night time average sound pressure levels ranging from 45-75 dBA outside. Noisy and quiet streets were estimated to differ by 23 dB LAeq,24h. "Multiple regression models revealed a significant ( $p < 0.05$ ) increase in renal noradrenaline excretion of  $0.61 \mu\text{g/g}$  creatine per tenfold increase in traffic volume (logarithmic association). Subjects who lived in streets with more

than 17,000 vehicles/day showed a mean noradrenaline concentration in urine 2.47 creatinine higher than that of subjects who lived in streets with less than 17,000 vehicles/day (categorical association). However, this statistical effect was only found with regard to exposure of the bedroom, not the living room. No relationship was found between traffic volume and renal adrenaline secretion" (Babisch et al., 1996, p2156). These multiple regressions controlled statistically for a wide range of potential confounding variables, including body mass index, weight, age, drug consumption, and employment. The authors point out that it is not clear whether these changes in catecholamine levels reflect primarily acute responses to noise events during the night or ongoing arousal of the sympathetic-adrenal medullary system due to chronic stress of noise exposure. Changes in catecholamine excretion have been associated with subjective sleep disturbance (for disturbance with windows closed but not open: Babisch et al., 1996) and changes in sleep stage distribution (Maschke, Breinl, Grimm, and Ising, 1993). In contrast, in a laboratory study Carter et al. (1993; 1994b) found no difference in levels of overnight urinary catecholamines after experimental 'Quiet' versus 'Noise' nights. The noise stimuli were recorded truck passbys and aircraft flyovers. Similarly, Pimentel-Souza, Carvalho, Siqueira, Alvares and Rodrigues (1996) found no difference in the urinary cortisol of patients in a hospital with an internal nocturnal noise of 53.7 dB LAeq and patients in a hospital with an internal nocturnal level of 45.5 dB LAeq. Carter et al. (1994b) pointed out that overnight urinary catecholamines would be relatively insensitive measures of sympathetic nervous response to noise because they could not reflect momentary surges in response to noise events. Concern for such chronic, but probably relatively small, surges in serum catecholamines due to noise during sleep is justified by data showing cardiovascular sequelae (damage to heart tissue and increased blood pressure) from very high levels of circulating catecholamines. Okada et al. (1993) were able to show immediate sympathetic nervous responses to noise during sleep by means of microneurographic measures of sympathetic outflows to muscles in the leg. However, the noise stimuli (125 millisecond 880 Hz bursts of unspecified intensity) differed from everyday noise stimuli in several important respects, notably its unfamiliarity and sudden onset.

Babisch et al. (1996) report a trend toward lower carboxy-haemoglobin levels in females exposed to higher traffic noise, after effects due to smoking had been statistically removed. However, since this effect did not reach significance it should be regarded cautiously.

#### *Use of Sedatives, Sleeping Pills and Earplugs*

Epidemiological research suggests that exposure to aircraft noise can increase use of sedative drugs, sleeping pills and earplugs. This could indicate increased difficulty in falling asleep and/or disturbance of sleep soundness as a result of nighttime noise exposure.

Grandjean (1974a, 1974b) found increased consumption of tranquillisers and sleeping pills amongst people exposed to aircraft noise. Ohrström (1990, 1991) observed greater self-report of sedative drug and earplug use amongst residents of areas with equivalent exposure levels greater than 70dB than amongst residents of 40dB, 50dB, or 60dB Leq areas. However, the

opposite result was found in a study of the neighbourhood of Munich airport (Deutsche Forschungsgemeinschaft, 1974). In a study designed to overcome the difficulty of using a "survivor" sample, the purchase of sedative drugs was found to increase in a community newly exposed to aircraft noise but not in one where there was no change (Knipschild and Oudshoorn, 1977). In a recent cross-sectional community survey examining the impacts of traffic noise (Lercher, 1996) use of sleeping pills was related to noise level and sensitivity, but not annoyance, whereas tranquilliser use was related to sensitivity only (see also Relster, 1975).

### *Secondary Effects of Noise on Sleep*

After-effects of noise-disturbed sleep such as perceived sleep quality, fatigue, changes in mood and impairment of performance have been studied both in laboratory and field studies.

#### *Sleep Quality*

Generally, data support the contention that exposure to intense nighttime noise lowers self-reported sleep quality. Griefahn (1990) reported that exposure to more than 40 events with 45dB LA<sub>max</sub> resulted in decreases objective and perceived sleep quality. Pimentel-Souza et al. (1996) report that patients of a University hospital with an indoor nocturnal noise of 53.7 dB LA<sub>eq</sub> had a worse perception of sleep (as assessed by 24 items including perceived need for longer sleep, feeling tired on awakening) than did patients at Baleia hospital, which has an indoor nocturnal level of 45.5 dB LA<sub>eq</sub>. Sleep disturbance due to medical care, organic disease or psychological disturbance did not differ between the two hospitals.

Lukas (1975, 1977) found a negative correlation between aircraft noise exposure levels and a sleep quality index constructed from items regarding feelings of well-being, general sleep quality, and estimates of sleep latency (correlation coefficient of -0.89). An association of sleep quality with behavioural and EEG measures of awakening (correlation coefficient of -0.5) was also observed.

Parallel findings have been reported for traffic noise exposure. Ohrström (1982) found a correlation between sleep quality and maximum heavy vehicle noise (60, 70 and 80 dB LA<sub>max</sub>). Similarly, Ohrström, Björkman, and Rylander (1990) observed decreased perceived sleep quality after exposure to traffic noise with 45dB LA<sub>max</sub> in noise-sensitive subjects. Consistent with these findings increased sleep quality has been observed after a 10 dB decrease in the general level of traffic noise (Jurriens et al., 1983).

Perceived sleep quality does not improve with extended exposure to noise (Ohrström, 1993c). Further, reduction in sleep quality is reversible with noise abatement measures (Eberhardt, 1982; Eberhardt and Akselsson, 1987; Griefahn and Gros, 1986; Öhrström, 1983; Wilkinson, 1984).

Reduction in perceived sleep quality are more closely related to maximum than equivalent noise levels (Öhrström, 1982) and is associated with the number of noise events when the sound pressure levels exceed 50 dB LA<sub>max</sub>, and the number of noise events is between 40 and 300 (Björkman,

Levein, Rylander, Åhrlin, and Ohrström, 1986). Although exposure to more than 40 sounds with 45 dB L<sub>Amax</sub> reduced perceived sleep quality (Griefahn, 1990), no self reported effects on sleep were demonstrated at 60 dB L<sub>Amax</sub> when the number of noise events was below eight (Ohrström and Rylander, 1990). This suggests the importance of the number of noise events. Amount of fast REM sleep may be closely related to perceived sleep quality (Berglund and Lindvall, 1995).

#### *Fatigue and Mood*

Because reduction in sleep quality is associated with fatigue and decreased mood (Lukas, 1977; Ohrström, 1982, 1989), these outcomes are also predicted to result from exposure to noise during sleep.

Occupational studies have demonstrated an association between increased fatigue and irritability and exposure to high intensity noise (Jansen, 1962), though there appears to be no simple dose-response relationship between noise levels and fatigue (Matsui and Sakamoto, 1971).

Subjects exposed to high levels of infrasound also demonstrate fatigue symptoms (Mohr et al., 1965). Fatigue might also be the result of strain due to noise exposure rather than noise-induced sleep disturbance.

#### *Moderating Variables of the Effect of Noise on Sleep*

##### *Characteristics of the Noise*

The number of individual traffic noise events, the relation of their maximum level to the background noise level, and their spectral pattern are all important factors in the likelihood and degree of sleep disturbance and physiological response (Eberhardt, et al., 1987; Vallet et al., 1983a; Griefahn, 1991).

Sleep disturbances may occur as a result of noises below the recommended sound pressure level of 45 dB L<sub>Amax</sub> if there are many noise events, background level is low, there is concomitant vibration or a low frequency component is present (Eberhardt, et al., 1987; Vallet, Gagneux, and Simonnet, 1980). For example, number of noise events has been found to be critical in increased sleep latency (Ohrström, 1991; Ohrstrom and Rylander, 1990), the probability of awakening (Griefahn and Jansen, 1978) and subjective sleep quality (Björkman et al., 1990). The signal to noise ratio influences the probability of awakening (Griefahn and Jansen, 1978) and the heart rate response (Vernet, 1983). Thus, the concerns of Fairfield Residents Against Airport Noise (1996) that the impact of aircraft noise may be higher in areas with low levels of background seems warranted with regard to noise-induced sleep disturbance. Nagai et al. (1989) report that individuals exposed to intense low frequency noise, as a result of living next to a superhighway, who initially complained of vibration of windows then suffered from insomnia and tiredness.

It has been argued that noise-abatement measures should aim at reducing the number of intense noise events (Griefahn, 1990). Objective sleep quality is reduced by exposure to more than 40 sounds with 45 dB L<sub>Amax</sub> (Griefahn, 1990; see also Eberhardt, 1982; Eberhardt and Akse, 1987) and Vallet

and Vernet (1991) recommend that a good sleep requires that not more than 10-15 noise events with sound pressure levels around 45 dB L<sub>Amax</sub> occur in one night.

The duration of the noise is also critical to sleep disturbance (Thiessen, 1983). Whilst the influence of continuous noise at sound pressure levels around 50dBA is largely restricted to REM-sleep, intermittent noise can affect sleep stages 3 and 4 in addition (Eberhardt, 1987).

It is unclear during which period of the night people are most susceptible to noise-induced sleep disturbance. According to Eberhardt (1987) people are most sensitive during the first one-third to two-thirds of the night. However cardiac responses to artillery noise during sleep were more pronounced in the early morning than during the first hours after sleep onset (Griefahn, 1989). The impact of noise seems to depend on the concurrent stage of sleep (Berry and Thiessen, 1970; Thiessen, 1972).

#### *Exposure to Daytime Noise*

Exposure to daytime noise is thought to provoke stress reactions which may increase sleep latency (Blois, Debilly, and Mouret, 1980) and the amount of slow-wave sleep (Fruhstorfer, Fruhstorfer, and Grass, 1984). Fruhstorfer, Pritch and Fruhstorfer (1988) found that exposure to daytime noise resulted in reduced duration of REM, shortened sleep cycles and more stage 4 sleep in the second cycle. The authors concluded that these data suggest increased need for recovery after daytime noise stimulation.

#### *Individual Differences and Demographic Variables*

The generally held assumption that specific groups are particularly sensitive to noise-induced sleep disturbances has received inadequate research attention. Shift workers, the sick, the elderly and people with a high stress, anxiety or neuroticism levels, are thought to be particularly susceptible. In laboratory studies "noise-sensitive" persons have reported deteriorated perceived sleep quality (Ohrström and Björkman, 1988).

It has been predicted that shift workers would be particularly sensitive to sleep disturbances, because they sleep during the day. Thus, their normal circadian rhythms may already be disrupted and they are often exposed to more frequent noise events because their sleeping hours are not subject to curfews on aircraft operations. However, data addressing this issue are extremely limited. Ehrenstein and Muller-Limmroth (1975) reported 30 percent loss of overnight SWS to noise in shiftworkers exposed to noise during sleep, a finding not replicated in a study by Carter, Good, Brown, Pang and Clancy, (1995). These conflicting findings, despite the fact that both studies were laboratory studies, suggest that the issue should be further investigated in studies of shift workers exposed to noise while sleeping at home.

Noise-induced sleep disturbance has been thought to present a particular problem to the sick (Lukas, 1975), due to their reduced ability to cope with stress. The effects of noise on cardiac rhythm during sleep in individuals susceptible to cardiac arrhythmia were examined in field study of traffic noise with people sleeping in their own homes, and a laboratory study using



recorded aircraft and traffic noise (Carter and Hunyor, 1988, Hunyor, Ingham, and Tran, 1992a; Carter, et al., 1992b). The field study revealed a weak relationship between noise and ventricular ectopic beats in some sleep stages. However, a large number of statistical comparisons were made in these studies, raising the possibility that some were significant (albeit in the predicted direction) due to chance alone. Moreover, the subject with the greatest frequency of baseline arrhythmias showed no noise effect. In the laboratory study, in which the onset of the noise was scheduled and the subjects all had a similar frequency of arrhythmias, ventricular ectopic beats were related to sleep stage (being more frequent in stage 4) but not to noise per se. There was a tendency for arrhythmias to be less frequent after noise onset if the subject was aroused from sleep stage 4. The authors suggested that ventricular ectopic beats were more frequent during stage 4, when heart rate is at its slowest, because ectopic foci overrode normal pacemaker cells. The possibility that typically increased autonomic tone during REM sleep may be potentiated by noise and exacerbate tachyarrhythmias in subjects with this type of arrhythmia (cf Hobson, 1969) was also identified. More research is required in this area (see Section 6.3).

Findings regarding the influence of age on noise-induced sleep disturbance are mixed. Children and young people have been found to be less susceptible to disturbance by noise, than are middle-aged or older persons (Dobbs, 1972; von Gierke and Nixon, 1972). Elderly people demonstrate more frequent noise-induced awakening than the population average (Eberhardt, 1982) and the probability of awakening due to a given noise event increases with age (Vallet et al., 1980; Vipac Engineers and Scientists Ltd., 1990). However, four to six year-olds are particularly likely to be aroused suddenly from sleep stage 4 and babies, who have suffered gastric difficulties or brain injury, may be particularly susceptible to noise-induced sleep-disturbance (Murphy, 1969). Noise-induced heart rate acceleration during sleep seems to be more pronounced in children (Berglund and Lindvall, 1995), whereas higher levels of overnight urinary noradrenaline were associated with higher age in a group of pre-menopausal women (Babisch et al., 1996).

Babisch et al. (1996) also found that higher noradrenaline concentrations were associated with higher disturbance by noise, but also with lower body mass index or weight, higher alcohol consumption, and smaller number of rooms. Higher adrenaline concentrations were associated with higher disturbance by noise, but also lower body mass index, lower drug consumption, lower prevalence of respiratory disease, and living alone.

Data suggest a greater sensitivity to noise-induced sleep disturbance amongst women than men (Looks, 1972; Steinicke, 1957; Wilson and Zung, 1966). For example, in a laboratory study using simulated sonic booms and recorded aircraft noise (Looks, 1972b). Women were more affected by the noise. Further, susceptibility to noise disturbance increased with age. Similarly, Looks and Dobbs (1972) reported findings which suggested that middle-aged women are particularly sensitive to subsonic jet aircraft flyovers and simulated sonic booms. It is however possible that such differences are due, at least in part, to differences between these groups in habituating to sleeping in the laboratory, rather than differences in susceptibility to noise-induced sleep disturbance per se.

A slightly higher sensitivity to noise during sleep has been observed for individuals with neurotic tendencies (Caille and Bassano, 1977).

The finding that elevations in overnight urinary catecholamine levels are positively associated with noise-induced disturbance to sleep and conversation for disturbances with windows closed but not open (Babisch et al., 1996) was interpreted as an indication of the importance of perceived control (efficacy of coping mechanisms). "Disturbances by noise with the windows open seemed to be less harmful to the subjects because closing the window could effectively reduce the noise (even though they may not do so)." (Babisch et al., 1996, p2158).

Sensitivity to noise is related to reported sleep problems (Lercher, 1996; Niveson, 1992; Nivison and Endresen, 1993; Ohrström, 1989; Ohrström and Björkman, 1988; Ohrström and Rylander, 1982).

The Proposed Third Runway EIS and the Senate Select Committee on Aircraft Noise in Sydney recognised the potential of noise to disturb sleep resulting in disturbance the following day and eventually the possibility of physical, emotional and mental problems. The recommendation of the Australian Standard 2107-1987 that to avoid sleep disturbances background levels not exceed 25-30 dBA rural and outer suburban areas or 30-35dBA in inner suburban areas was presented. Similarly the Australian Standard 2021-1985 recommendation that transient events not exceed 50dB L<sub>Amax</sub> was noted. Particular consideration was given to noise-induced sleep-disturbance in shift workers.

The *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) cites the finding of Vipac Engineers and Scientists Ltd (1990) that elderly people are more likely to awaken as a result of noise exposure.

It was stated that shift workers often suffer from sleep disturbances and expect to sleep during the day. It was concluded that "[a]n increase in noise exposure could aggravate or multiply existing health problems, lead to further loss of sleep and affect the acceptance and tolerance of shift-work by shift workers" (p24.27). The *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) did not identify the absence of data which addresses the issue of whether shift-workers are particularly susceptible to noise-induced sleep disturbance or whether they are just exposed to more noise when they are trying to sleep during the day.

It was also suggested in Kinhill (1990) that patients in hospitals may be particularly adversely affected by noise-induced sleep disturbance. Presumably, this may imply that they are more prone to disturbance, or that such disturbance could potentially be more detrimental to their health given the importance of sleep for recuperation.

Many submissions were made to the *Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) regarding the negative effects of exposure to aircraft noise on health. Many residents complained of sleep loss both in reports to the committee, on the DEAF hotline and in the DEAF general practice survey. Dr Aline Smith

reported cases of insomnia requiring treatment with sleeping tablets which she believed to be due to aircraft noise. As previously identified these data must be regarded speculatively, but do support research findings (as presented here and in the Kinhill (1990).

The view that shift-workers are a group of particular concern in relation to noise-induced sleep disturbance was reiterated in Dr Chambers' submission. However, again data supporting this suggestion are absent.

Submissions from the Royal Prince Alfred Hospital Medical Board reiterates the suggestion made in Kinhill (1990) that noise-induced sleep loss may be particularly problematic for patients, given the importance of sleep to the healing process.

The submission of Profs Bradstock and Sorrell identified the potential health consequences of sleep loss which they claimed were not emphasised in *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990). In particular they identified that "there is evidence that seven hours sleep per night, which is the length of the current curfew, is not sufficient for children, nor the great majority of adults. Published tables indicate that infants one to two years of age require 11 hours sleep per night and two to three hours during the day. Teenagers of up to 18 years still require an average of 8.5 hours of sleep per night..." (Senate Select Committee on Aircraft Noise in Sydney, 1995, p148). They reported that sleep deprivation can have a negative impact on performance and learning, and might result in accidents in the home and on the road.

### 5.3.2 INTERFERENCE WITH SPEECH AND COMMUNICATION

#### *Voice Communication*

Speech is arguably the primary method of communication between humans. Speech signals are generated by a learned motor behaviour which is controlled by feedback from the hearing mechanism and the speech musculature coordinated by the central nervous system. These signals consist of rapid fluctuations in air pressure which radiate spatially, diminishing rapidly in intensity (Flanagan, 1972). Most of the acoustical energy of speech falls between 100 and 6,000 Hz, but cues of up to 8kHz are detected. The most important cue-bearing energy falls between 300 and 3,000 Hz. However, air can support only limited variations in pressure without distorting the signal. For a constant signal to noise ratio, speech spoken loudly is more difficult to understand than when spoken softly (Lazarus, 1990; Rostolland, 1982, 1985).

An informative spoken language must consist of a finite number of distinguishable, mutually exclusive sounds, called phonemes (Flanagan, 1972). In addition to phonemes, the temporal features of speech such as variations in stress (loudness), melody (pitch), and rhythm, which constitute the prosody of speech, are important for understanding. Because speech contains much extra information, many cues are redundant and speech can be understood when some components are missing.

Speech is a multidimensional signal. Its comprehension requires discrimination of differences in the received signal and processing and assimilation of information from acoustic cues to identify meaning. Two successively presented pure tone frequencies may differ by only one part in one thousand yet be perceived as different (Rosenblith and Stevens, 1953). Thus normal listeners can distinguish 350,000 different tones, when these are presented successively in pairs (Stevens and Davis, 1938), though only five different tones when equally loud pure tones are presented individually for absolute judgement of pitch (Pollack, 1952). The threshold for perceiving a difference in intensity may be less than 1dB (Green, 1995; Houtsman, Durlach and Braida, 1980; Riesz, 1928). The acoustic and the physiological noises of the body set limits to the sensitivity of the receiving ear.

These considerations are relevant to the impact of noise on the understanding of speech.

### *Masking and Intelligibility*

Noise may interfere with speech communication by masking simultaneous speech signals, rendering them unextractable. The degree to which noise masks a given desired signal (speech, music) depends on the signal to noise level ratio at critical frequencies; the more intense the level of the masking noise at speech frequencies, the fewer speech sounds are discernible to the listener.

It is difficult to predict the degree to which noise will mask speech with any precision. Whilst existing empirical relationships allow accurate prediction of the audibility of an isolated speech sound in the presence of a specified noise, for the average listener (Kryter, 1985, 1994; Webster, 1969, 1974), communication rarely involves single acoustic signals. Speech generally consists of a rapid sequence of different signals, the intensity and spectral distribution of which is constantly changing. Further, similar fluctuations of the masking noise occur, even when it is judged to be steady. Intermittent and impulsive noises as well as noises fluctuating in level will provide various degrees of masking, depending on the duration and frequency of occurrence of the noise bursts. It is important to realise that the sound pressure level varies with time during an aircraft overflight, so that speech intelligibility based on equivalent levels may be inaccurate (Berglund, 1996).

The relationship of speech discernability with speech "intelligibility" (the percentage of correctly understood key words in a series of sentences) is also uncertain. Sentences in which some sounds are masked may nonetheless be perceived as continuous. This phenomenon is referred to as phonemic restoration by noise for missing speech sounds. Speech interrupted with interpolated noise may be perceived as more complete and continuous than the same speech segments combined with silent gaps (Bergman, 1980; Miller and Licklider, 1950; Warren, 1970). Further, because of the redundancy of speech, many sentences in normal conversation can be understood quite well, even when the proportion of masked individual speech sounds is large. Although a particular sound is masked or even omitted, the remaining sounds may be sufficient to convey the meaning of the word or sentence

from which it is missing. However, the interpretation required to compensate for masking may place additional strain on the listener.

Other features of voice communication which influence the impact of masking on speech comprehension include the presence of reverberation, the distance from speaker to listener, speech rate and clarity, any hearing loss (see Plomp, 1986), the listener's familiarity with the speaker's language, vocabulary dialect or accent, the degree of redundancy in the message, the familiarity and/or importance of the message, and the motivation and attention of the listener. Adequate communication is more likely if the messages are restricted, for example to numbers only, or if the position of noise source is clearly different from that of the speaker. Communication may also be facilitated by additional cues gleaned from lip-reading or observing facial or manual gestures.

Thus, the relationship between the spectrum, level, and temporal characteristics of a masking noise and the "intelligibility" of ordinary speech is very complex. There is some evidence to suggest that speech intelligibility may be reduced more by low frequency noise than other noises (except those in the frequency range of speech itself) (Loeb, 1986; Pickett, 1959). Researchers have examined the intelligibility of nonsense syllables and isolated words in phonetically-balanced lists and of words in real sentences. The intelligibility of ordinary sentences can now be estimated using scores for isolated words. For example, when 75 % of the items on a list of isolated words are correctly perceived, about 95% of key words in an ordinary sentence will be correctly understood (Kryter, 1970, 1994).

### *Speech Interference Indices*

A number of indices have been developed to predict the degree to which a particular noise will interfere with speech comprehension. These indices differ in the manner in which they incorporate various characteristics of the masking noise. The three most common indices are: the articulation index (AI), speech interference level (SIL), and the A-weighted sound pressure level.

### *Articulation Index*

The articulation index (French and Steinberg, 1947; Kryter, 1962) is the most complicated of the three interference indices. "Frequencies below 250 Hz and above 7,000 Hz are not included, as they are not considered to contribute to the intelligibility of speech. The frequency range from 250 to 7,000 Hz is divided into 20 bands, each of which contributes 5 % to the total intelligibility. In order to determine the articulation index for a particular noise, the difference in dB between the average speech level and the average noise level in each of these 20 bands is calculated, and the resultant numbers are combined to give a single index. Essentially, this process predicts how much masking of individual speech sounds will occur and then integrates this information." (Berglund and Lindvall, 1995, p53).

Although the articulation index is the most accurate of the three indices for the prediction of the effects of a large variety of noises on speech intelligibility, it is complicated to use and difficult for the layman to interpret. Thus, simplified procedures for estimating the AI from weighted measurements of octave-band levels have been developed (Kryter, 1962).

### *Speech Interference Level*

The speech interference level (Beranek, 1947) was introduced as simple alternative to the articulation index. The speech interference level omits the input of the lowest and highest frequencies to comprehension more than does the articulation index. There are many variants of the speech interference level index, all consisting of the arithmetic average of the sound pressure level in particular octave bands. For example, one recent speech interference level index averages sound pressure levels in the three octave bands centred around 500, 1,000, and 2,000 Hz (abbreviated speech interference level 0.5, 1, and 2). US National Standards Institute and ISO (ISO TR3352, 1974, ISO 9921, 1988) currently recommend speech interference level (0.5, 1, 2, 4) as the best for predicting the masking potential of a noise.

### *A-Weighted Sound Pressure Level*

The A-weighted sound pressure level is an uncomplicated and effective index of speech interference. The A-weighting process, like the articulation index and speech interference level, emphasises the middle frequencies, without completely omitting low and high frequencies.

This is an adequate index for assessing the interference-capacity of many noises. However, particularly for noises that are dominated by either low or high frequencies, such as the rumble of distant traffic or the hiss of compressed air, the AI provides more accurate prediction of speech intelligibility. The A-weighted sound pressure level is 8 dB higher, on average, than the speech interference level for a noise which produces a given level of interference (Klump and Webster, 1963; Kryter, 1970; Lazarus, 1986, 1987), although this difference might vary substantially for unusual noises.

### *Speech Communication Outdoors*

Figure 5.5 depicts the distances outdoors over which conversation is considered to be satisfactorily intelligible in steady noise (US EPA, 1974). It is based on the following assumptions and empirical observations:

- at a distance of one metre from the speaker relaxed conversation occurs at a voice level of 54-56 dBA (Kryter, 1970; Pearsons et al., 1976). "Normal effort" voice levels, which are used when people wish to project their voices (Korn, 1954), are around 60 dBA and raised voice levels around 66 dBA. However, it should be noted that women's voices are often somewhat softer than men's;
- for 100 % sentence intelligibility the speech level should exceed the noise level by 15-18 dBA (see ISO 9921, 1988; Lazarus, 1990). When the speech level is equal to the noise level, intelligibility falls to 95 %, which is generally sufficient for reliable, although not necessarily comfortable, conversation;
- thus, relaxed speech is 100% intelligible against a noise level of 45 dBA and fairly intelligible against 55 dBA. "Normal effort" speech is fairly intelligible against noise levels of 60dBA; and

- the relationship between intelligible speech level and the distance from the speaker is given by the inverse square law. That is a doubling of the distance from the speaker requires an increase of 3dB (A) in speech level to maintain intelligibility.

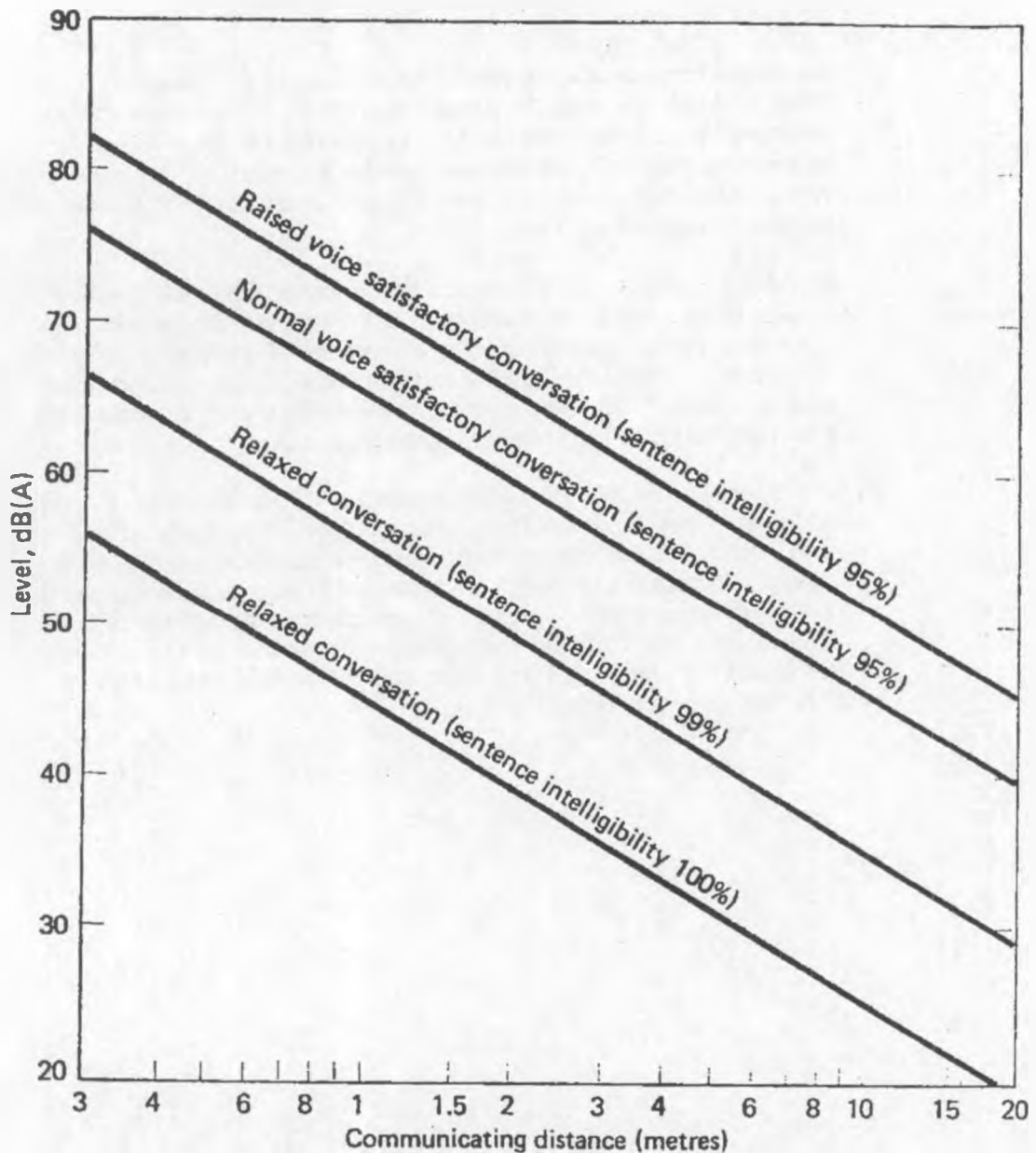


FIGURE 5.5 BACKGROUND NOISE LEVEL (DBA) AT WHICH SPEECH INTELLIGIBILITY IS SATISFACTORY AS A FUNCTION OF SPEAKER-LISTENER DISTANCE FOR RELAXED, NORMAL VOICE AND RAISED VOICE CONVERSATION OUTDOORS.  
Source: US EPA (1974b).

### *Speech Communication Indoors*

Noise-induced speech interference differs from interference outdoors, because of the influence of reverberations from reflections off the walls, floor, ceiling, and furniture. Noise or speech levels, rather than decreasing six decibels for each doubling of distance, may drop by only one or two decibels.

No simple formula exists to predict speech interference indoors. Often data from outdoors are used to predict acceptable noise levels for particular distances up to two metres, and up to eight metres for reverberation times below two seconds. Alternatively standards are set on the basis of noise levels that have previously been found acceptable in similar settings (Berglund and Lindvall, 1995).

*Figure 5.6* (US EPA, 1974b) depicts the estimated sentence intelligibility, at speaker-listener distances greater than one metre, as a function of noise level in a typical living room. In order to achieve the 100% intelligibility which is considered desirable for indoor listening conditions background noise levels must be below 45 dBA. 95 percent intelligibility would be achieved against a background noise level of approximately 63 dBA.

The Speech Transmission Index (Houtgast, 1980) provides a model for evaluating speech intelligibility indoors given background noise and reverberation. A modulation transfer function quantifies the degree to which intensity fluctuations of speech are preserved from the speaker to the listener under such conditions. Scores on the speech transmission index range from zero to one and correlate with speech discrimination in various indoor conditions and languages (Houtgast and Steeneken, 1983; Humes, Dirks, Bell, Ahlstrom, and Kincaid, 1986).



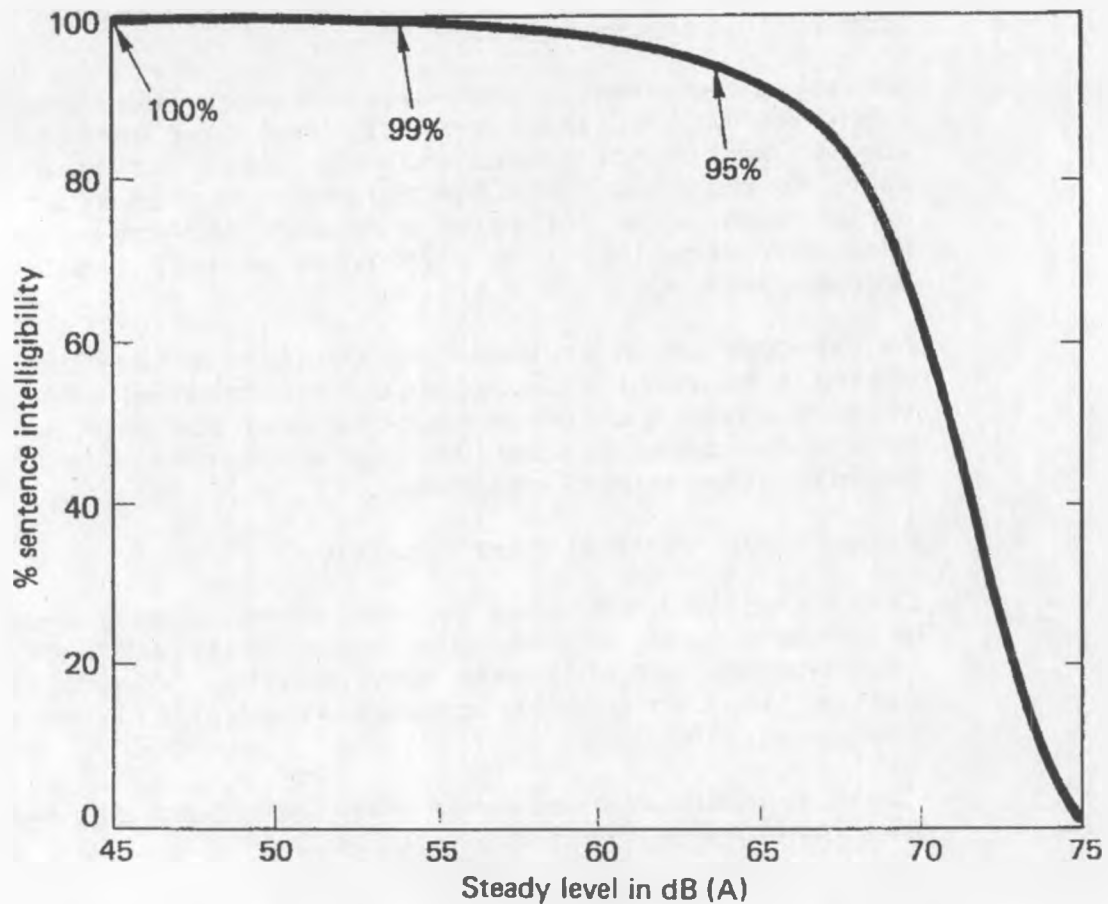


FIGURE 5.6 NORMAL VOICE SENTENCE INTELLIGIBILITY AS A FUNCTION OF BACKGROUND NOISE LEVEL (DBA) IN A TYPICAL LIVING ROOM.  
Source: US EPA, 1974b.

*Variables Moderating the Effects of Noise on Speech Communication*

Noise-induced impairment of speech intelligibility may be particularly prevalent amongst certain groups; including the hearing impaired, the elderly, young children and people for whom the language being spoken is not their first (Dubno, Dirks, and Morgan, 1984; Elliot, 1979; Jokinen, 1973; Smoorenburg, 1992).

There is a more pronounced masking effect of noise on speech discrimination for hearing impaired individuals than for people with normal hearing, especially if the background noise consists largely of speech (Hygge, Rönnerberg, Larsby, and Arlinger, 1992). Masking may be up to ten decibels greater for the hearing impaired, rendering a greater signal-to-noise ratio necessary for equivalent speech intelligibility. This may be due at least in part to the widening of the critical band that frequently accompanies a loss in sensorineural hearing. Hearing impaired individuals often experience a loss of frequency resolution (Bailey, 1983), which reduces their ability to identify distinct acoustical speech patterns in order to extract information from

speech. Further, the combined effect of noise and reverberation is accentuated in the hearing impaired.

The masking effect of noise on speech may also be more pronounced for the elderly (Bergman, 1980; Duquesnoy, 1983). Even minor losses of high frequency hearing common in presbycusis impair speech discrimination in noise. However, young children have also been found to require a more intense speech signal than adults to maintain equivalent sentence intelligibility (Elliot, 1982). These prerequisites are most important in language acquisition.

For individuals who are not familiar with the spoken language, such as children in the process of language acquisition (Nabelek and Robinson, 1982) and second-language persons reduction of speech intelligibility due to noise may be exaggerated. A 5 to 10 dB larger signal-to-noise ratio may be needed for acceptable speech intelligibility.

#### *Indirect Effects of Noise on Speech Disturbance*

Given that individuals with hearing impairment are more adversely affected by masking of speech, noise-induced hearing impairment could result in reduced speech intelligibility under noisy conditions. Distortions in loudness have been shown to contribute to reductions in speech intelligibility (Villchur, 1974).

#### *Comments from the Proposed Third Runway Draft EIS and the Senate Select Committee on Aircraft Noise in Sydney*

According to Kinhill (1990) for speech of "normal vocal effort" with a speaker to listener distance of 2 meters intelligibility is 95% when aircraft noise is 65dB LAeq (cf. US Environmental Protection Agency, 1974). However, it was recognised that children require a stronger speech signal to understand speech as compared to young adults (Vipac Engineers and Scientists Ltd 1990) and that speech signals must be 25dB higher for children than for adults to maintain 100% intelligibility (Elliot, 1982).

Submissions to the Senate Select Committee on Aircraft Noise in Sydney (Senate Select Committee on Aircraft Noise in Sydney, 1995) were in keeping with the data reviewed above and in Kinhill (1990). Goldberg reported a correlation of the frequency of classroom speech disturbances with the ANEF rating of the zone in which the schools were located. Primary school children and children from non-English speaking backgrounds were most likely to be affected. Complaints discussed in the Senate Select Committee Report (Senate Select Committee on Aircraft Noise in Sydney, 1995) relate to disturbance with conversation and listening to the television or radio. Conversation disturbance is reported to have a particularly negative impact in medical and educational institutions.

### **5.3.3 INTERFERENCE WITH GENERAL TASKS**

Noise can affect performance if presented concurrently with the task or if prior exposure has led to lasting deficits. The influence of noise on task performance depends somewhat on the type of task. Tasks that demand

continuous and sustained attention to detail or to multiple cues, or that require large working memory capacity tend to be adversely influenced by noise. Data pertaining to the impact of noise on industrial productivity are inconclusive.

For example, results from a joint four-country study show consistent worsening of performance after a change in sound pressure level of road traffic noise of about 10 dBA (Jurriens et al., 1983). Exposure to noise has consistently been found to produce deficits on immediately following tasks, such as proof-reading and persistence on challenging puzzles (for a review see Cohen, 1980).

### *Mechanism of Noise-Induced Performance Deficits: Distraction and Arousal*

Noise could be expected to interfere with task performance, because of its ability to act as a distracting stimulus, depending on the meaningfulness of the stimulus, various physical features of the noise, and the psychophysiological state of the individual.

The occurrence of a novel event tends to cause distraction and consequent interference with concurrently performed task. These effects diminish once the event becomes familiar. It has been shown experimentally that the onset of an unfamiliar noise functions as a novel event, as indeed does the sudden stopping of a familiar noise (Kryter, 1970, 1994; Glass and Singer, 1972).

Noise stimulation can influence an individual's psychological and physiological arousal, and consequently performance. According to Hebb (1955), changes in stimulation activate areas of the cerebral cortex besides those directly involved in the appropriate cortical responses. This diffuse activity increases the individual's arousal. Optimal performance occurs at moderate arousal levels, but varies with the difficulty of the task, whereas extremely low or high arousal levels are associated with performance deficits. Thus, exposure to loud noise potentially increases or decreases task performance depending on previous arousal levels. Intense noise has been found improve performance in sleep deprived, tired individuals, even on tasks which are subject to significant interference by noise when performed by non-sleep-deprived individuals (Corcoran, 1967; Wilkinson, 1963).

### *Tasks Involving Motor Activities*

Steady noise has minimal impact on many motor tasks once it has become familiar. For example tasks such as tracking or controlling tasks where average, rather than instantaneous, levels of performance are important do not suffer from concurrent exposure to continuous sound levels (Broadbent, 1957; Kryter, 1970, 1994). Under such conditions it seems that noise is likely to reduce the accuracy rather than the total quantity of work (Broadbent, 1971). Many mechanical or repetitive tasks found in factory work would fall into this category. Exposure to moderate levels of noise may improve performance of monotonous tasks by elevating arousal. For example, McGrath (1963) observed an improvement in visual vigilance performance following exposure to auditory stimuli at 72 dBA.

### *Tasks with High Attentional Demands*

In tasks requiring sustained visual attention, noise exposure may not reduce overall levels of performance but brief periods of inefficiency are common. The errors which occur appear to result from a shift in response criteria rather than reduction of signal detectability; responses tend to be faster and are more often false alarms (Broadbent, 1981; Cohen et al., 1986).

Tasks which require continuous and careful monitoring of signals or cues (for example, warning systems) may be negatively affected. However, noise-induced elevation of arousal may increase alertness and thus produce better performance. Becker, Ami, Warm, Dember and Hancock (1995) examined the effects of intermittent jet craft noise on the performance of a 40 minute vigilance task involving feedback stimuli. Compared to subjects performing under quiet conditions, noise-exposed subjects profited less from feedback. The authors argue that this reflects interference with information processing.

Noise has a reliable and sustained effect on tasks that require attention to multiple cues, such as monitoring two different signals (Cohen et al., 1986; Smith, 1989). The task(s) which are of lesser importance on the basis of instructions or of expected payoffs, are marred by errors (Hockey, 1979), such as slow or absent responses to cues. This phenomenon is not a consequence of narrowed attention (Berglund and Lindvall, 1995), as formerly proposed.

### *Tasks with High Demands on Memory*

Noise exposure introduces deficits in incidental memory (Cohen et al., 1986; Hockey, 1979; Jones, 1984). For example, amongst subjects presented with semantic information, noise exposure did not effect recall of the contents but reduced recall of the position of the word on the slide (Hockey, 1979). Noise-induced interference with helping behaviour may be related to inattention to incidental cues (Cohen and Lezak, 1977) or to other effect such as effects on mood.

"Subjects appear to process information faster in working memory during noisy performance conditions but at a cost of available memory capacity. For example, in a running memory task in which subjects are required to recall in sequence letters that they have just heard, subjects recall recent items better under noisy conditions but make more errors farther back into the list (Hockey, 1979)" (Berglund and Lindvall, 1995, p83). This finding is consistent with an arousal effect combined with variation in task difficulty. Lower arousal is optimal for more difficult tasks while higher arousal produces better performance on easier tasks (see Cofer and Appley, 1964, p520-529). Thus, Hockey's (1979) results appear to reflect a noise-induced increase in arousal with recall of recent items representing an easier task and recall of distant items difficult tasks.

### *Cognition and Reading in Children*

Aircraft noise might be predicted to interfere with cognition and reading in children both by impairing acquisition, as a result of disturbing speech communication and concentration, and by impairing performance.

### *Methodological Considerations*

A methodological conundrum arises in research on the effects of noise on education in children: should the learning (acquisition) and or the testing (performance) be conducted in quiet or noisy conditions? Ignoring this issue is potentially of great detriment to research, especially if it is conducted in schools, which may vary substantially in noise exposure. The issue has generally been discussed in the context of distinguishing between learning (acquisition) and performance, with the claim being that testing under quiet conditions ensures that any observed deficits reflect poorer learning rather than poorer performance in noise affected children. An issue which has received relatively little attention is the distinction between present and past learning. For example, a deficit in learning a list to be recalled (rather than a deficit in performing the recall task) may due to noise interfering directly with the learning of that list or to, say, poorer reading skills as a result of noise interfering with prior learning. Conducting acquisition under quiet conditions may be regarded as a solution to this issue. It may seem obvious then that acquisition and testing should be conducted under quiet conditions. However, this approach has problems, and other approaches have been considered.

Consider first the case in which acquisition and testing are conducted in quiet conditions. This approach is often taken by the Hygge groups and the added control over experimental conditions is clearly of value. On the face of it, if children from noisy schools show deficits relative to children from quiet schools, it can be concluded that noise interfered with learning of the skills/knowledge necessary to acquire the skills/knowledge relevant to the experimental task. Since testing is performed under quiet conditions, deficits induced directly by noise should not be seen in performance. Since acquisition is performed under quiet conditions, deficits induced directly by noise should not be seen in acquisition. However, since the children from noisy schools have been exposed to noise when they were learning the skills/knowledge necessary to perform the experimental task, such as reading skills for example, they show deficits relative to children from quiet schools in the experimental task. There are, however, several difficulties with this interpretation. For example, the acquisition and performance of children from noisy schools may be impaired as a result of fatigue due to noise exposure. Further, the phenomenon of state dependent learning may disadvantage the children from noisy schools relative to those from quiet schools in the acquisition phase. Although conditions are physically equated for the children from quiet and noisy schools, they may have differential familiarity and arousal with the conditions. Children from noisy schools may be familiar with learning under noisy, but not quiet, conditions, and may have adapted their learning to a different arousal level, or may have adapted their arousal to particular noise levels. In contrast, scholastic pursuits are associated with quiet conditions and consequent arousal levels in the children from quiet schools.

Consider second the case in which acquisition and testing are conducted in noisy conditions. In this case it is difficult to establish whether any deficits observed in the children from noisy schools relative to the children from quiet schools are due to deficits in performance, current or past acquisition. This design also does not account for the influence of fatigue due to chronic

noise exposure in the children from noisy schools. The confounding effects of familiarity and arousal will also present a problem with this design, only here it is the children from quiet schools for whom the experimental conditions are not familiar.

Consider third the case in which acquisition and testing are conducted in the conditions with which the children are familiar: quiet conditions for the children from quiet schools and noisy for the children from noisy schools. Again, it is difficult to establish whether any deficits observed in the children from noisy schools relative to the children from quiet schools are due to deficits in performance or deficits in acquisition during the experiment, or deficits arising prior to the experiment, which then effect the experiment. Again, there is no control for the influence of fatigue due to chronic noise exposure in the children from noisy schools. Whilst the confound of differential familiarity and arousal is removed, this approach introduces other problems. The influence of the experimental sound conditions and the influence of familiarity may be in opposite directions, may be additive or may interact, differentially for the two groups. That is, the familiar setting (noisy for noisy schools, and quiet for quiet schools) may help with the task, yet the absolute effects of noise may be to distract and so harm performance, or to activate and so aid performance.

Consider fourth the case in which the noise levels are changed from training to testing. Such a procedure adds the complexity of generalisation effects from training to testing without resolving the more basic issues above.

Consider finally the case in which both acquisition and testing are conducted under both quiet and noisy conditions. This is arguably the most informative approach in that it allows for examination of main effects and any interactions of conditions, while disambiguating the relative effects of noise on acquisition and performance and allowing investigation of the effects of familiarity and arousal. This approach has not generally been taken, with the result that our understanding of the effects of noise on the learning and performance of children is substantially incomplete. Further research is thus indicated.

#### *Noise and Cognition and Reading in Children*

Several cross-sectional studies and two longitudinal community studies demonstrate negative associations between chronic exposure to noise (mostly aircraft or road traffic) and deficits in cognition and reading among children (Cohen et al., 1986; Evans, 1990; Evans and LePore, 1993; Evans et al., 1995; Evans, Bullinger, Hygge, Gutman, and Aziz, 1994; Hygge, 1993; Hygge, Bullinger, and Evans, 1993, 1994, 1996; Romero and Lliso, 1995). A reasonably consistent dose-response relationship between aircraft noise exposure and delay in reading acquisition has also been demonstrated (Green, Pasternack, and Shore, 1982a).

The impact of noise on cognition and reading in children has been examined in a combined cross-sectional and longitudinal community study before and after changes in the location of Munich airport (Evans et al, 1995; Evans et al., 1994; Hygge, 1993; Hygge et al., 1993, 1994, 1996). Before the closing of the old airport and the opening of the new airport children were assigned to groups on the basis of their current and forecasted noise exposure. Two

experimental groups were comprised of children living near the old airport who were currently exposed to high levels of aircraft noise and children living near the new airport who were going to be, respectively. Sociodemographically matched control groups were comprised of children living near the old airport who were currently not exposed to high levels of aircraft noise, and children living near the new airport who were not going to become exposed to high levels of noise as a result of the opening of the new airport, respectively. The reading and cognition of these children was trained and tested under quiet conditions before the airport changeover (Stage 1), and again one and three years after the changeover (Stages 2 and 3, respectively). The forecast effects of the changeover on noise exposure levels was accurate for all groups except the new airport control group, for whom levels did increase slightly as a result of the airport opening (although they had not been expected to). In the vicinity of the old airport, children who had been chronically exposed to noise demonstrated significantly impaired in word-list reading and long-term (one day) text recall at Stage 1, but not Stages 2 and 3, testing relative to the control group. In the vicinity of the new airport, as would be predicted there were no significant differences between the experimental and control groups before the opening of the airport (Stage 1 testing). The reading and recall of these groups did not differ at Stage 2, but at Stage 3 testing significant differences were apparent for both tasks. Thus, the researchers concluded "for cognitive tasks requiring central processing...there are deficits for children chronically exposed to aircraft noise. However, when the chronic noise exposure ceases... the impairments heal within a couple of years. When chronic noise is introduced... it seems to take a couple of years for impairments to develop" (Hygge, 1996, p2191).

Chronic noise exposure may produce reading deficits in children by way of impairing their auditory discrimination. Cohen, Glass and Singer (1973) found deficits in auditory discrimination and reading in children exposed to noise at home but tested under quiet conditions. The association between ambient residential noise levels and reading deficits was largely accounted for by auditory discrimination deficits.

In class-room experiments with children, acute exposure to aircraft and road traffic noise, but not railway traffic noise and verbal noise, at 66 dB LAeq, was associated with significant impairment of long-term (one week) recall of text. For exposures at 55 dB LAeq aircraft noise exposure was associated with more impairment than road traffic noise (Hygge, 1993, 1994).

Several factors may increase the likelihood of noise-induced reading deficits. Children in the later elementary grades show stronger impairments, possibly due to having experienced longer exposure durations. Children exposed to noise both at school and at home are more likely to suffer reading deficits than those only exposed at school. Pre-existing speech or language difficulties may exaggerate the impact of noise on reading and cognition, possibly by increasing masking due to noise. Furthermore, a negative relation is suggested between noise levels in the home and cognitive development among infants and pre-school children (Evans, 1990; Wachs and Gruen, 1982). However, the extent to which such differences are caused by noise versus other factors, such as possible differences in socio-economic status, is unknown.

### *Noise and Productivity*

Studies which have assessed the relationship between noise levels and productivity have frequently been poorly designed and have seldom found any adverse effects. However productivity in noisy industrial settings has been found to increase when ear protection is worn (Broadbent, 1971; Cohen, 1974; Smith, 1989).

### *Leisure Activities*

Exposure to aircraft noise has been found to interfere with leisure activities (for example, Berglund et al., 1990; McKennell, 1973), including television viewing (Galloway and Bishop 1970) and listening to music (Hede and Bullen, 1982a). Such interference may contribute to negative reactions towards the noise.

In a community survey around several Australian airports (Hede and Bullen, 1982a) activity disturbance was found to be the most common effect of aircraft noise. *Figure 5.7* depicts the percentage of respondents reporting disturbance to various activities against noise level. (Noise level is expressed as NEF3, which refers to Noise Exposure Forecast, where Version 3 refers to a particular choice of time of day weightings (see Hede and Bullen, 1982a for details) The majority of respondents reported at least one of the various disturbances considered at levels even lower than 25 NEF. Disturbances to conversation and activities involving listening (television, radio, music) were most common.

Disturbance of leisure activities has also been observed with exposure to noise from other sources (for example, for railway noise: Ohrström, 1996; for impulsive noise; Rylander and Lundquist, 1996)

### *Moderators of the Effect of Noise on Task Performance*

Activity disturbance is greater in areas in which noise is accompanied by vibration than in areas where there is noise alone (Öhrström, 1996), thus raising the possibility that aircraft noise, with its strong low frequency component has the potential be more disturbing than sources which do not produce vibration or rattle.

The impact of the noise on task performance seems to be influenced substantially by uncontrollability of noise as well as by its intensity (see Cohen et al., 1986; Vipac Engineers and Scientists Ltd., 1990). Intermittent noises with a strong low frequency component, like aircraft noise, are also more likely to interfere with task performance (Vipac Engineers and Scientists, 1990).

Self-reported noise sensitivity has received attention as one potential moderator of the effects of noise on task performance. Highly noise sensitive subjects have been found to perform significantly more poorly in deep mental processing tasks under noisy conditions (for example, difficult mental arithmetic) than less noise sensitive subjects (Arvidsson and Lindvall, 1978; Belojevic, Öhrstrom, and Rylander, 1992).



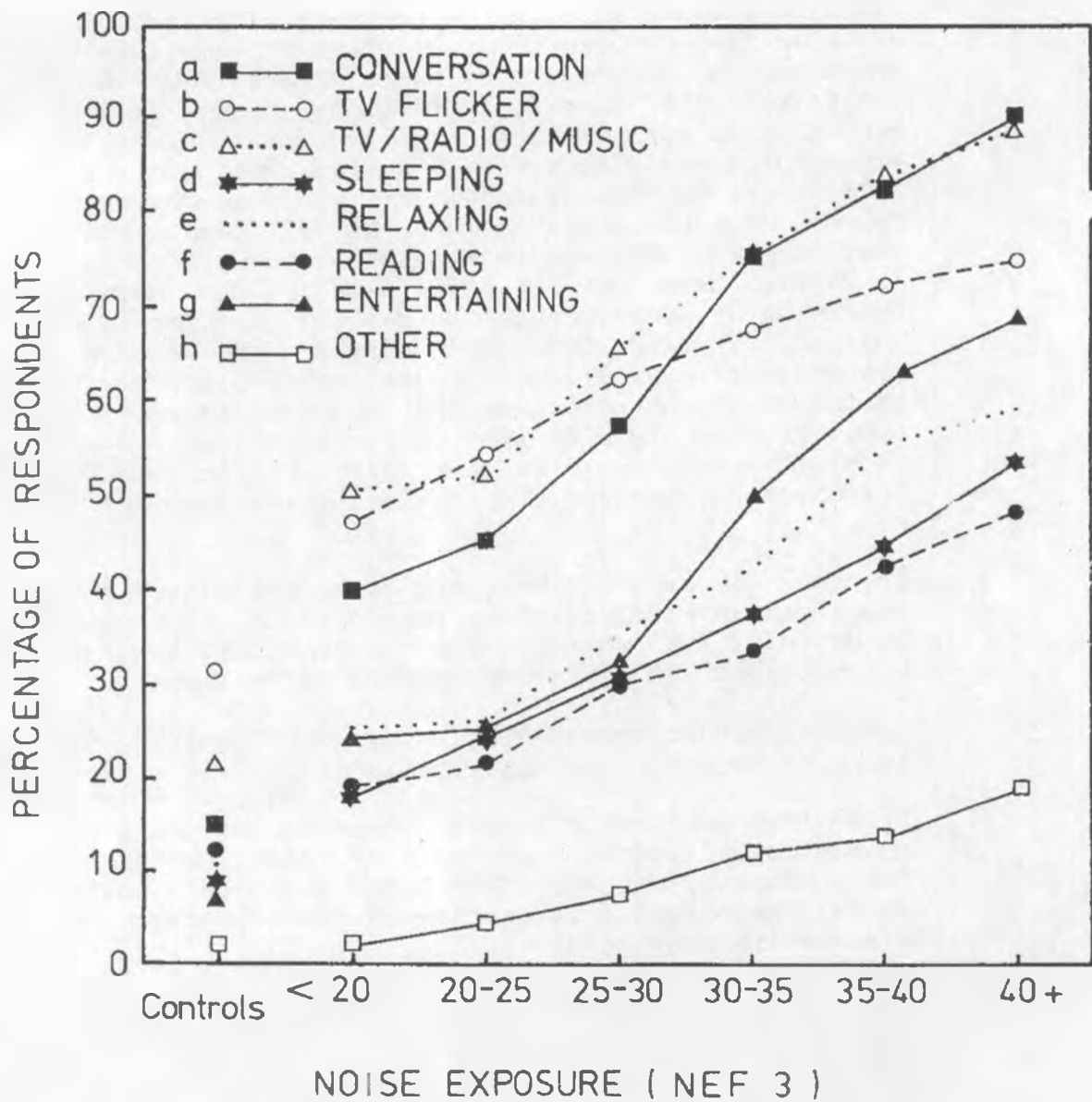


FIGURE 5.7 PERCENTAGE OF RESPONDENTS REPORTING ACTIVITY DISTURBANCE AS A FUNCTION OF EXPOSURE TO AIRCRAFT NOISE (NEF3).  
Source: Hede and Bullen, 1982a.

*Indirect Effects of Noise on Performance; the Effects of Sleep and Speech Disturbance*

Noise exposure may reduce task performance by causing fatigue, either through sleep loss (Berglund and Lindvall, 1995) or strain. Thus, Le Vere, Morlock, and Hart (1975) found decreased performance in a choice reaction/memory time test after nightly exposure to 24 80 dB LAeq aircraft noises (see also Le Vere, Bartus and Hart, 1972; Wilkinson and Campbell, 1984). Similarly, Ohrström and Bjorkman (1988) found increased reaction

time 3-choice task after subjects had been exposed to 57 truck noises at 60 L<sub>Amax</sub> overnight. Ohrstrom and Rylander (1982) found increased 3-choice reaction time after intermittent, but not continuous traffic noise. Wilkinson and Campbell (1984) found that double glazing improved the simple reaction time of subjects sleeping in their own homes. Further, after nighttime exposure to traffic noise at 60 dB L<sub>Amax</sub> slower reaction times were observed than following exposure at 50 dB L<sub>Amax</sub> (Öhrström and Rylander, 1990). In contrast, Carter and Ingham (1995) found no effect of overnight truck and traffic noise on performance on the Stroop test nor on the Wilkinson Many Sums test. Chiles and West (1972) found no deterioration in performance of tasks involving monitoring, mental arithmetic, and pattern discrimination following nightly exposure to simulated sonic booms (100 N/m<sup>2</sup> at one hour intervals for 12 nights). No unambiguous influence of exposure to 80, 85, and 90 dBA tonal pulses (with a 22 second interval throughout 24 hours for 10 days) on various performance tests was observed by Cantrell (1974). Evoked response activity in EEG recordings were observed during sleep indicating detection of the noises.

It is also possible that noise exposure could interfere with task performance or acquisition by masking critical cues [see Section 5.2]. Thus, possible impairment of cognition and reading in children may be due at least in part to a learning deficit due to reduced intelligibility of teachers' speech.

*Comments from the Proposed Third Runway Draft EIS and the Senate Select Committee on Aircraft Noise in Sydney*

Noise-induced disturbance of education, recreational and occupational activities received considerable attention in the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) and Report of the Senate Select Committee (Select Committee on Aircraft Noise in Sydney, 1995).

According to Kinhill (1990) continuous noise levels above 90dB interfere with "noise sensitive" tasks such as those requiring information gathering, vigilance and analytical processing. Interference was hypothesised to be more likely if noise is intermittent, unexpected, uncontrollable or has a high frequency component.

With regard to the impact of aircraft noise on educational activity, the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) referred to the conclusion of a review of relevant US data (Buntin, 1989), that the maximum noise level inside classrooms should not exceed 45 dB L<sub>Aeq</sub> during a "worst case" hour, or 49 dB L<sub>Amax</sub>. The Australian Standard 2021-1985 recommendation that indoor levels remain below 55 dB L<sub>Amax</sub> in teaching and assembly areas and 50 dB L<sub>Amax</sub> in libraries and study areas was also presented. These recommendations do not account for the possibility that some learning deficits may at least in part reflect noise exposure outside school hours, reflecting, for example, noise-induced sleep disturbances.

Kinhill (1990) cited studies which have shown that children attending schools in high noise areas are more likely to have lower scores on aptitude

tests (Kryter, 1985), to have below-grade reading ability (Green et al., 1982a), and to give up following failure and to be easily distracted (Cohen et al, 1980). However, it is not clear whether these data reflect performance versus acquisition deficits and to what extent any such deficits result from exposure to noise outside school hours. The study of Cohen et al. (1980) was designed to test for an acquisition deficit in that children were tested under quiet conditions, so their performance should not have been impaired by noise. However, this raises the possibility that children from noisy schools performed more poorly due to state dependant learning; that is, skills/knowledge acquired under noisy conditions may not generalise to testing under quiet conditions, whereas for children from quiet schools there was no such mismatch of learning versus testing conditions. The *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) interpreted the finding of Cohen et al. (1980) as evidence for an impact of noise on learning independent of speech disturbance. However, even if the observed deficits were due to impairment of acquisition rather than performance, impairment of acquisition may have been due, at least in part, to speech disturbance. Kinhill(1990) cites findings showing that also in pre-school children noise exposure is associated with impaired rate and quality of learning (Bronzhaft and McCarthy, 1975; Cohen et al, 1973; Cohen et al., 1980). In the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) it was recognised that interference in learning may reflect difficulty concentrating, communicating, resting and sleeping due to noise.

According to the *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) presented evidence to suggest that:

- students at schools exposed to aircraft noise had lower aptitude levels;
- some retardation of reading achievement among children was found in two areas exposed to aircraft noise in New York;
- difficult tasks require more perseverance where there was unpredictable, persistent or uncontrollable noise, which may result in some students exposed to aircraft noise having difficulty concentrating, potentially undermining the quality of their work; and
- concerns about the impact of aircraft noise on pre-school children related mainly to communication and learning abilities.

According to the *Senate Select Committee Report on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995), the EIS Supplement acknowledged a direct relationship between aircraft noise exposure and interruption of learning activities but asserted that there was no evidence for a long-term impact on learning because "[e]xperiments with school children often fail to find detrimental effects of noise on speed or accuracy of performance... or impairment of reading or math skill".

The *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) focussed strongly on the potential impacts of aircraft noise on educational activities.

The Committee heard submissions from principles, teachers and students that exposure to aircraft noise resulted in disturbance of communication during lessons, assemblies (and other ceremonies) and outdoor recreational activities, often making lessons were impracticable. Further, teachers reported increased distraction in students. Parents also expressed concerns about the education of their children. These submissions do identify that aircraft noise may disturb communication, thus making teaching difficult. They do not, however, constitute scientific data which examine the extent to which aircraft noise interferes with acquisition or performance in educational settings. Further studies are required to resolve this issue. Teachers also claimed that students who lived in noise affected areas were even more distracted than other students, lending credence to the hypothesis that exposure to noise outside school hours also interferes with education. The potential for noise-induced sleep disturbance to interfere with learning was also recognised in a submission from the Federation of Parents and Citizen's Associations of New South Wales. This should also be examined empirically. A few submissions recognised that children from non-English speaking backgrounds were likely to be particularly vulnerable.

The *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) referred to a survey of teachers and students by Goldberg, in which a "very significant statistical correlation between the frequency of disturbance to communication, and the ... ANEF rating of the zone where the school was located" (Senate Select Committee on Aircraft Noise in Sydney, 1995, p120). Primary school children and children from non-English speaking backgrounds were more likely to be adversely affected by aircraft noise. The Report presents these findings as evidence for disturbance of educational activities by aircraft noise. However, the study basically provides evidence for noise-induced speech disturbance and does not assess the impact of such disturbance on learning.

Kinhill (1990) also considered the potential of aircraft noise to disrupt leisure activities and the Sydney "outdoor culture". It referred to the Australian Standard 2107-1987 which recommends that noise levels in outdoor recreational areas not exceed 35-40 dB. The study focussed mainly on the impact on a few specific areas such as the recreational foreshore at Botany Bay. Consideration of more general impacts on the recreation of residents in noise affected areas was restricted to quoting the experience of several residents with interference of television viewing and conversations both on and off the telephone.

The *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) received numerous complaints about disturbance of leisure activities due to aircraft noise. For example, people complained of interference with reading and listening activities such as conversation, listening to the radio and watching television. Disturbance of television watching is supposedly exacerbate as a result of picture distortion due to flyovers. Aircraft noise was also reported to have disrupted the outdoor culture that characterises the Sydney lifestyle. Thus, people complained of no longer being able to garden or entertain outdoors, particularly since such activities are not protected by noise mitigation measures such as home insulation. Again, these reports provide

anecdotal evidence of noise-induced disruption of leisure activity, but do not provide an indication of the prevalence of such effects in the community nor of the extent to which these disturbances are due to aircraft noise rather than some other factor, such as road traffic noise.

Kinhill (1990) did not focus specifically on losses in productivity due to noise except to recognise the potential of noises above 90dBA to interfere with performance. It was claimed that disturbance depended on the morale and motivation of the person affected as well as the nature of the task, with routine tasks less likely to be affected. Consistent with these claims, the evidence suggests that certain (more difficult) tasks are more likely to be disturbed by aircraft noise.

The *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) emphasised the potential of noise exposure to reduce productivity, mostly by way of disrupting sleep. That is, it was asserted that evidence suggests that noise can result in sleep loss, which in turn might result in degraded concentration and reduced performance at work. Further, sleep loss, noise induced stress and stress-related complaints were offered as potential causes for increased absenteeism. Noise-induced disturbance of concentration was held to be particularly detrimental to the work of surgeons, nurses and airline pilots. No evidence was offered for any of these assertions.

## 5.4 REACTION TO SOUND EXPOSURE

### 5.4.1 SOUND, LOUDNESS, NOISINESS AND REACTION

The concepts of loudness, noisiness and "annoyingness" (a reaction) are distinct and differentiable (Berglund, Berglund, and Lindvall, 1975a, 1976; Hellman, 1982). However, it seems likely that they are related (Berglund et al., 1986; Peploe, Cook and Job, 1993). Nonetheless, the relationships between physical characteristics and judgements of perceptual characteristics such as loudness and evaluative judgements such as annoyingness is by no means simple, especially for complex sounds such as aircraft noise (Berglund and Job, 1996; Muller, Schmidt, and Paulsen, 1996; Preis, 1996)

Because noise is, by definition unwanted sound, an individual must react negatively to a sound in order for it to be perceived as noise. Thus the mere perception of noise is likely to be associated with a population reaction. A number of authors have suggested that perceived loudness may also be a critical determinant of reaction and indeed this is a hidden assumption in the formation of close-response of sound pressure level and reaction (Berglund, Berglund, and Lindvall, 1975a; Fastl, 1985; Fastl, Markus, and Nitsche, 1985; Fastl and Yamada, 1986; Hellman, 1982; Hellman, 1985; Namba and Kuwano, 1984; Schick, 1981; Stassen, 1980; von Brennecke and Remmers, 1983; Weber and Mellert, 1978). In a recent examination of perception of traffic noise (Parizet, Deumier, and Milland, 1996), loudness correlated at a level of 0.96 with annoyance (similar size correlations have been observed for aircraft noise; Berglund et al., 1975b). On closer examination of the data, two groups of subjects could be distinguished: those for whom there was a

strong correlation between loudness and annoyance, and those for whom this correlation was weak. The authors concluded that some subjects based their judgement of annoyance on perceived loudness while others did not. However, a causal inference such as this is not warranted by correlational data, and only 15 subjects were tested. Muller et al. (1996) found that loudness and annoyance were correlated for a series of highway noises but not for a series of "environmental" noises including ticks of a clock, rustling paper, steps on a stone floor, a crying baby, and church bells. In addition to loudness, factors such as perceived intrusiveness and information content have also been found to influence annoyance. In response to complex sounds (Preis, 1996; Preis and Berglund, 1994).

Neither loudness, noisiness nor annoyingness is solely determined by sound pressure level (Preis, 1996; Zwicker, 1987), however both noisiness and annoyance are likely to be more influenced by non-acoustic factors than is loudness (Berglund and Lindvall, 1995). "Perceived noisiness" as defined by kryter to be similar to annoyingness has been found to be a better predictor of the adverse reactions to sound than loudness (Kryter, 1970). Both perceived noise and perceived quietness may influence reactions such as annoyance (Guski, 1983).

#### 5.4.2 RELEVANT SOUND INDICES

Reaction to sound is partially determined by the auditory experience it produces. Thus, in order to predict the reaction to a particular sound, it would be useful to have a model relating the physical characteristics of the sound to the auditory experience, and another relating the auditory experience to reaction. Development of such models has proved difficult because of the influence of a wide range of modifying variables operating at both stages. For example, not only characteristics of the sound determine the auditory experience.

A wide range of sound metrics have been constructed in an attempt to provide the most practical and accurate prediction of auditory experience and reaction.

It has been argued that measures like  $L_{eq}$  and  $L_{max}$  currently allow the best prediction of annoyance (Buchta, 1993; Vos and Geurtsen, 1987). For example, in an Australian study of the effects of aircraft noise on Royal Australian Air Force personnel in their working environment (Bullen et al., 1985), reaction was found to be predicted as well by  $L_{eq}$  and NEF as any other indice used. However, this result arises at least in part from the high correlations between the various noise metrics and indices.  $L_{Aeq}$  is now widely used in standards and legislation throughout the world as the basis on which to develop a dose-response relationship for community noise annoyance, as well as regulation in relation to hearing impairment (ISO 1989, 1990).

However, whilst  $L_{Aeq}$  is particularly useful for steady and broadband noise, it is unsuitable for comparing reactions to two different noise sources (Fields and Walker, 1982; Gjestland and Oftedal, 1980). In order to improve prediction of reaction for various noise characteristics and sources,  $L_{Aeq}$  is often modified by way of "penalty" factors to account for the effects of

tonality, impulsiveness, low-frequency components, modulation, time of day (day, evening, night), noise source (for example, aircraft, road traffic, industrial source) and type of neighbourhood (for example, rural, suburban, commercial). Background noise may also be considered in its own right (Fields, 1993a), but may also be a factor in the measurement of noise exposure (for example, Bullen et al., 1991).

Noise indices based on other than equivalent sound pressure level and its derivatives may also be important in prediction of reaction. For example, maximum sound level and number of events or total duration above a particular sound level have also been shown to be relevant (for example, Lambert, Champelovier, and Vernet, 1996).

#### 5.4.3 DOSE-RESPONSE RELATIONSHIP

Negative reaction to noise may occur in the majority of urban inhabitants, and is likely to affect a greater proportion of the population than other overt impacts of sound exposure (Berglund and Lindvall, 1995).

Reaction to sound exposure has been examined in over 300 community surveys (Fields, 1991, 1993b), most of which have focussed on the relationship between annoyance and sound pressure level. These surveys generally identify a relatively high positive correlation (greater than 0.8) between sound exposure and reaction, independently of which dose scale was employed and which noise source was considered (for example, Finke, Guski, and Rohrmann, 1980; McKennell, 1963, 1980; MIL Research Ltd, 1971; TRACOR, 1971; for review see Job, 1988a), indicating that the noise indices provide a useful guide to the prediction of reaction. This is shown in *Tables 5.2 and 5.3*.

Australian community surveys of reaction to aircraft (Hede and Bullen, 1982a; Job et al., 1991), a rifle range (Hede and Bullen, 1982b), road traffic (Brown, 1987), quarry blasting (Murray and Avery, 1984), power stations (Job and Hede, 1989), and artillery (Bullen et al., 1991) noise, have produced results which are not inconsistent with those from overseas in terms of noise reaction correlations (see Job, 1988a; but see Bradley, 1996 for some differences in levels of reaction from country to country) (see *Table 5.4*). Thus, data from other countries appear to apply to Australia although cultural and climatic differences which may, for example, influence opening or closing of windows and noise insulation of the home may in turn influence reaction.

**TABLE 5.2** CORRELATIONS BETWEEN REACTION AND NOISE EXPOSURE FROM COMMUNITY SURVEYS IN SEVERAL COUNTRIES FOR NOISE FROM A VARIETY OF SOURCES FOR INDIVIDUAL AND GROUPED DATA.

Study	Country	Type of Noise	Sample size	Correlation: Individual data	Correlation: Group data
Borsky, 1983	USA	Aircraft	942	0.58	
Bradley, 1978	Canada	Road	1150	0.50	0.85
Bradley and Jonah, 1979	Canada	Road	300	0.49	
Bullen and Hede, 1984	Australia	Artillery	1626	0.22	0.57
Bullen <i>et al.</i> , 1985	Australia	Aircraft	624	0.58	
Fidell <i>et al.</i> , 1983	USA	Quarry blasting	1042		0.75
Fields and Walker, 1982	U.K.	Railway	1453	0.46	
Gambart <i>et al.</i> , 1976	Belgium	Road	247	0.61	0.94
Garcia, 1983	Spain	Road	430		0.56
Grandjean <i>et al.</i> , 1973	Switzerland	Aircraft	3939	0.59	0.95
Grandjean <i>et al.</i> , 1973	Switzerland	Road	944	0.43	
Griffiths and Langdon, 1968	U.K.	Road	1000	0.29	0.88
Griffiths <i>et al.</i> , 1980	U.K.	Road	222	0.44	0.86
Hall <i>et al.</i> , 1979	Canada	Aircraft	292		0.84
		(general aviation)			
Hall <i>et al.</i> , 1979	Canada	Aircraft	673		0.68
		(commercial aviation)			
Hall <i>et al.</i> , 1979	Canada	Road	292		0.56
Hede and Bullen, 1982a	Australia	Aircraft	3575	0.36	0.84
Hede and Bullen, 1982b	Australia	Rifle range	201	0.29	0.95
Kamperman, 1980	USA	Sonic boom	2000		0.96
Langdon, 1976	U.K.	Road	1359	0.21	0.85
Large and Ludlow, 1975	U.K.	Construction	535	0.52	
Large and Ludlow, 1975	U.K.	Road	535	0.38	
McKennell, 1963 and 1973	U.K.	Aircraft	1731	0.46	0.99
McKennell, 1978	U.K.	Aircraft	2500 +	0.26	
		(supersonic)			
Moehler and Knall, 1983	Germany	Road	525		0.66
Moehler and Knall, 1983	Germany	Railway	525		0.94
MIL Research, 1971	U.K.	Aircraft	4699	0.40	
Murray and Avery, 1984	Australia	Quarry blasting	170	0.29	0.89
Rohrmann <i>et al.</i> , 1973	Germany	Aircraft	660	0.56	
Rylander <i>et al.</i> , 1972	Sweden	Aircraft	2900		0.78
Rylander <i>et al.</i> , 1976	Sweden	Road	811		0.78
Schomer, 1983	USA	Aircraft	231		0.89*
Schuemer and Schuemer-Kohrs, 1983	Germany	Road	1516	0.52	
Schuemer and Schuemer-Kohrs, 1983	Germany	Railway	1516	0.46	
Seshagiri, 1979	Canada	Drop forging	609	0.30	
Shibuya <i>et al.</i> , 1975	Japan	Road	939	0.36	
Sorensen and Magnusson, 1979	Sweden	Rifle	323		0.99
		Range			
Taylor <i>et al.</i> , 1980	Canada	Aircraft	21	0.40	
TRACOR, 1971	USA	Aircraft	3590	0.37	
Mean			1196	0.42	0.82
Standard deviation			1154	0.12	0.14

\* Calculated from data given.

Source: Job, 1988a.



TABLE 5.3 AVERAGE (AND STANDARD DEVIATION) OF CORRELATIONS BETWEEN REACTION AND EXPOSURE TO ROAD, AIRCRAFT, IMPULSIVE AND RAIL NOISE FOR INDIVIDUAL AND GROUPED DATA

Noise source	Correlation: Individual data		Correlation: Group data	
	Mean	s.d.	Mean	s.d.
Road	0.42	0.12	0.77	0.14
Aircraft	0.46	0.12	0.85	0.10
Impulsive	0.28	0.04	0.83	0.17
Rail	0.46	0.00	0.94	0.00

Source: Job, 1988a.

TABLE 5.4 AVERAGE (AND STANDARD DEVIATION) OF CORRELATIONS BETWEEN REACTION AND NOISE EXPOSURE FROM COMMUNITY SURVEYS IN AUSTRALIA, CANADA, GERMANY, SWEDEN, SWITZERLAND, UNITED KINGDOM, AND USA FOR INDIVIDUAL AND GROUPED DATA

Country	Correlation: Individual data		Correlation: Group data	
	Mean	s.d.	Mean	s.d.
Australia	0.35	0.14	0.81	0.17
Canada	0.42	0.09	0.73	0.14
Germany	0.51	0.05	0.80	0.20
Sweden	...	...	0.85	0.12
Switzerland	0.51	0.11	...	...
United Kingdom	0.38	0.10	0.90	0.06
USA	0.48	0.15	0.87	0.11

Source: Job, 1988a.

An extensive community study around Sydney, Richmond, Adelaide, Perth and Melbourne airports examined the relationship between exposure and reaction (Hede and Bullen, 1982a). The "general reaction" index was comprised of items relating to "affectedness", "dissatisfaction", annoyance, activity disturbance, complaint disposition, fear of crashes, and perceived impact of aircraft noise on health. Individuals were considered to be "seriously affected" if they scored above 8 on the general reaction index. NEF3 correlated significantly with the percentage of the population "seriously affected" ( $r=0.733$ ). The relationship of Ldn with the percentage of the population "seriously affected" is presented in Figure 5.8.

Similarly, annoyance with traffic noise has been found to correlate with residential traffic noise exposure (for examples see, Bradley and Jonah, 1979; Garcia, 1983; Grandjean, Graf, Lauber, Meier, and Muller, 1973; Langdon, 1976; Rylander, Sørensen, and Kajland, 1976) detected a high correlation between Leq and annoyance for urban traffic noise. Laboratory studies have also demonstrated that road traffic Leq influences annoyance (Rasmussen, 1979; Labiale, 1983). However, Leq has been found to correlate relatively poorly with annoyance for heavy vehicle noise (Rylander, Sørensen, and Kajland, 1976). Re-evaluation of relevant data by a working group of the

ISO suggests that annoyance correlates with  $L_{eq}$  for traffic-noise exposure (Sandberg, 1993).

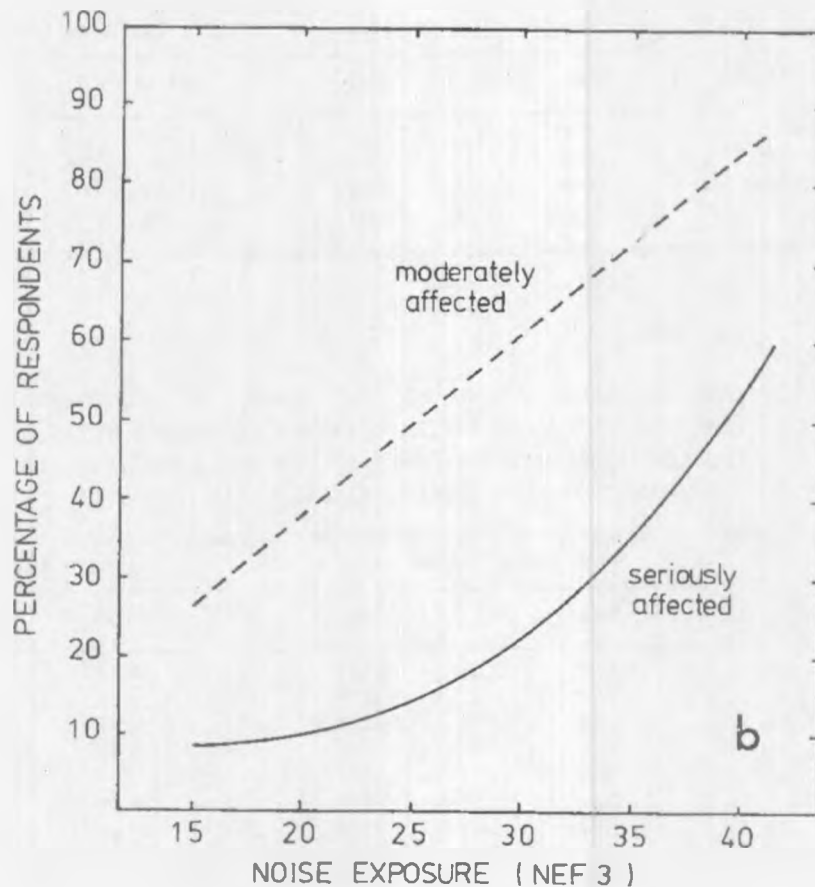


FIGURE 5.8 PERCENTAGE OF RESPONDENTS "MODERATELY AFFECTED" OR "SERIOUSLY AFFECTED" AS A FUNCTION OF EXPOSURE TO AIRCRAFT NOISE (NEF3) FOR CLUSTERED DATA.

Source: Hede and Bullen, 1982a.

A number of attempts have been made to synthesise community survey data in order to establish the association between prevalence of reported annoyance and noise exposure from various transportation sources. Schultz (1978) offered the first classic synthesis, employing data from a dozen community questionnaire surveys. The dose-response relationship, in terms of day-night average sound level ( $L_{dn}$  expressed in dBA) and percentage of respondents "highly annoyed", respectively, was found to be best described by the third-order polynomial function depicted in Figure 5.9.

The Australian aircraft noise data presented in Figure 5.8 are only poorly matched by synthesis curve produced by Schultz (1978). Hede and Bullen (1982a) argued that the discrepancy results at least in part from the difference between their definition of "seriously affected" and Schultz' definition of

"highly annoyed". When reaction was defined more stringently in keeping with Schultz' definition of "highly annoyed", the relationship with Ldn depicted in Figure 5.10 was observed. Thus represented the Australian data are reasonably well fitted by Schultz' (1978) curve.

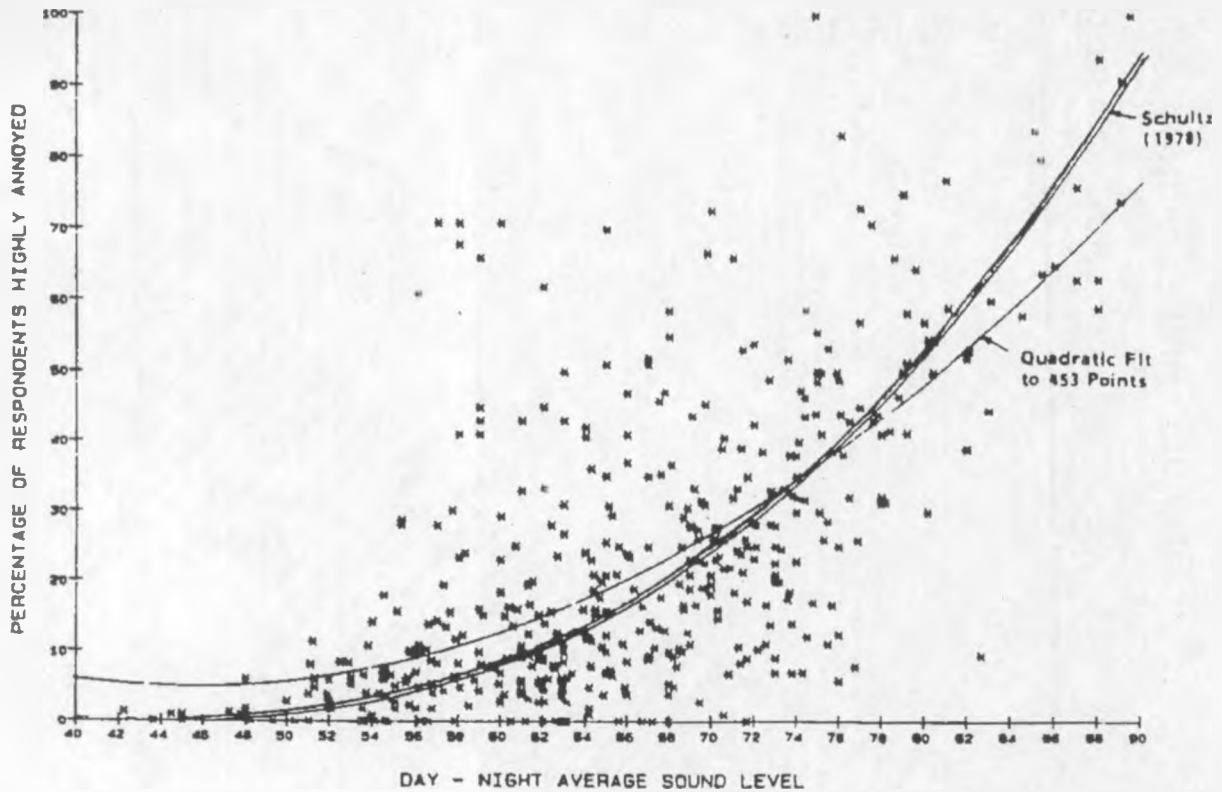


FIGURE 5.9 PERCENTAGE OF RESPONDENTS "HIGHLY ANNOYED" AS A FUNCTION OF EXPOSURE TO GENERAL TRANSPORTATION NOISE (DBA Ldn) ACCORDING TO THE LAST SQUARES QUADRATIC FIT AND THE THIRD-ORDER POLYNOMIAL FIT (SCHULTZ, 1978).

Source: Fidell et al, 1991.

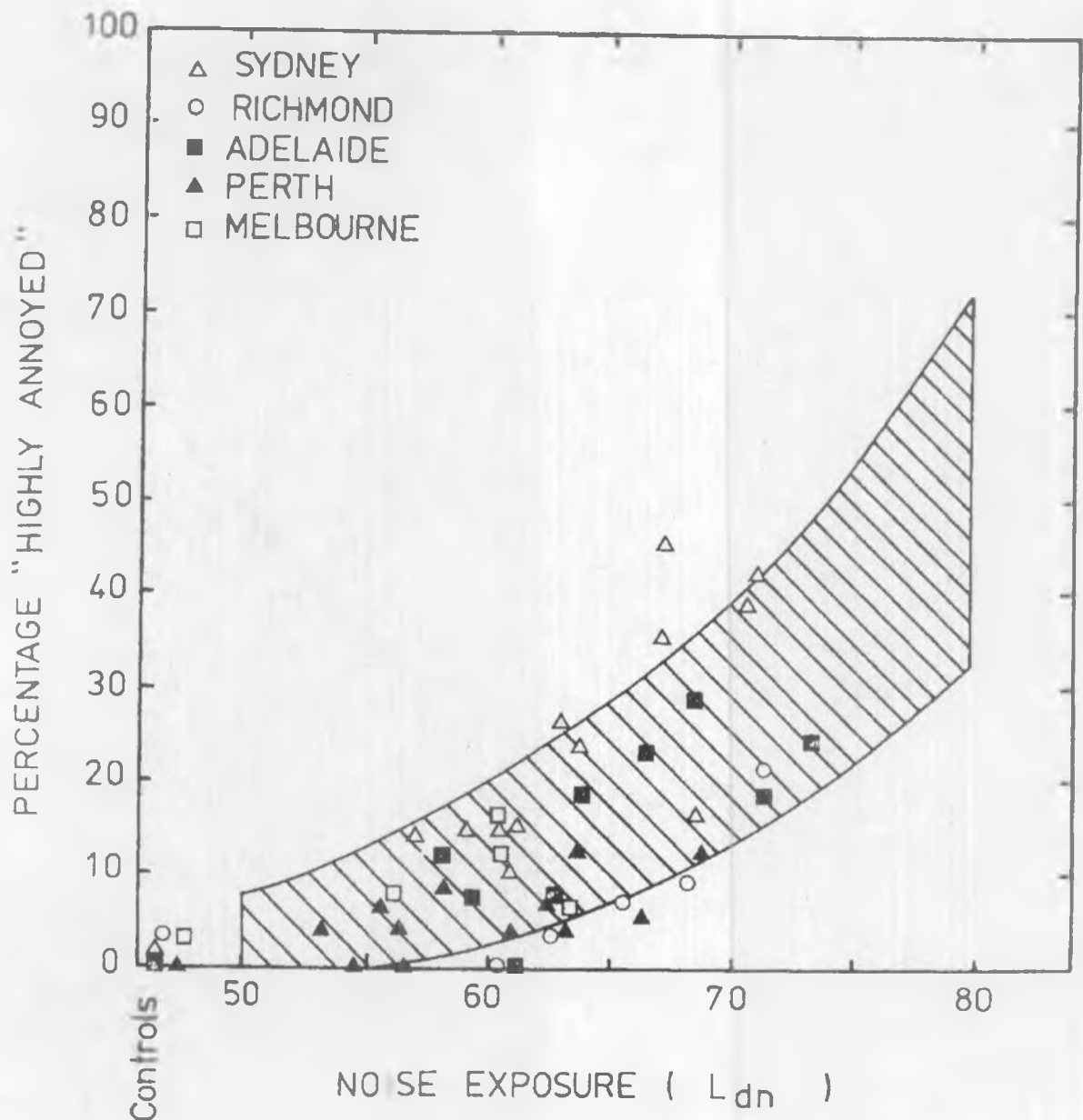


FIGURE 5.10 PERCENTAGE OF RESPONDENTS "HIGHLY ANNOYED" AS A FUNCTION OF EXPOSURE TO AIRCRAFT NOISE (NEF3) FOR CLUSTERED DATA.

Note: Shaded Area Covers 90% of the Data Points Given by Schultz (1978).  
Source: Hede and Bullen, 1982a.

Fidell, Barber and Schultz, (1991) have since updated the original synthesis by incorporating data from 15 subsequent studies including the study by Hede and Bullen (1982a), thus tripling the number of data points originally employed (see Figure 5.9 and also Fields, 1994). Whilst Schultz' (1978) dose-response function was found still to provide a reasonable fit to the data, a second-order function was also appropriate.

In general, these syntheses support the hypothesis that there is a steady increase in annoyance with sound pressure level, with no clear

discontinuities which could serve as a basis for setting limits to noise exposure. The syntheses suggest that sound exposures with Ldn less than 55 dB are likely to cause minimal annoyance in many cases. However, it is important that these relationships not be applied outside their intended ranges (Fidell et al., 1991). It is also important to appreciate the spread of data points contributing to these syntheses which suggest that it may be useful to include a measure of variance around any selected level.

Since Schultz (1978) published the single dose-response curve to describe the relationship between annoyance and exposure to transportation noise from a range of sources, its adequacy has been debated. A refined curve was offered by Kryter (1982, 1983) and commented on by Schultz (1982b). Miedema (1993; see also Bradley, 1994; Fields, 1994) also performed meta-analysis of data from several studies involving mobile (aircraft, highway and other road traffic and railway noise) as well as stationary sources (impulse noise as well as non-impulse).

The difficulty with comparing the outcome of these various syntheses is the use of different selection criteria as well as the fact that different approaches to reanalysis of the same data can produce quite different findings. *Figure 5.11* depicts the dose-response curves produced by different analyses of the same data.

A general caution with synthesis of various studies of noise reaction is that the differences between the results from these studies not be ignored. Whilst some of these differences may be the result of measurement "errors" due to the use of different techniques of assessing either (or both) noise exposure and reaction, they may also reflect real differences in the noise-reaction relationship from one situation and for one individual to another (Hall, 1984).

Perhaps the primary limitation of the Schultz (1978) dose-response function and its update (Fidell et al., 1991), is the assumption that the same function is valid for different sources of transportation noise (road, rail, aircraft), and perhaps non-transport noise as well. However, examination of this assumption within one study (Hall et al., 1981; van Kamp, 1990) revealed a greater reaction to aircraft than to traffic noise at the same noise level (but see De Jong et al., 1995). In an Australian study, a greater percentage of respondents were at least moderately annoyed by aircraft noise than by noise from other sources (including traffic, trains, garbage collection, lawn mowers, domestic pets, road works, neighbours television) at noise levels above NEF3 20 (Hede and Bullen, 1982a) (see *Figure 5.12*). Miedema's (1993) meta-analysis further undermines the assumption; for equal Ldn, aircraft noise and highway noise are more annoying than other road traffic noise, which in turn is more annoying than railway noise (trains, trams) (see also, Miedema, 1987; Mohler, 1988; but see Yano et al., 1996a). Further, impulse noise is more annoying than any transportation noise, especially at low levels (Miedema, 1993). However, on the basis of a review of the relevant literature, Job (1988a) concluded that the correlations between noise exposure and reaction are comparable for the various noise sources with the exception of impulsive noise. Nonetheless, these findings are not inconsistent, and indicate that a similar proportion of reaction is predictable from noise exposure for various non-impulsive noises even though the functions relating

noise and reactions may differ across sources. A dose-response curve specifically for aircraft noise (Bradley, 1994) suggested that 15% of a population will be highly annoyed when exposed to 56 dB LAdn, whereas the Schultz (1978) curve suggested that a noise level of 65 dB LAdn is required for 15% of the population to be highly annoyed. This comparison further supports the possibility that aircraft noise causes more reaction than does road or rail noise.

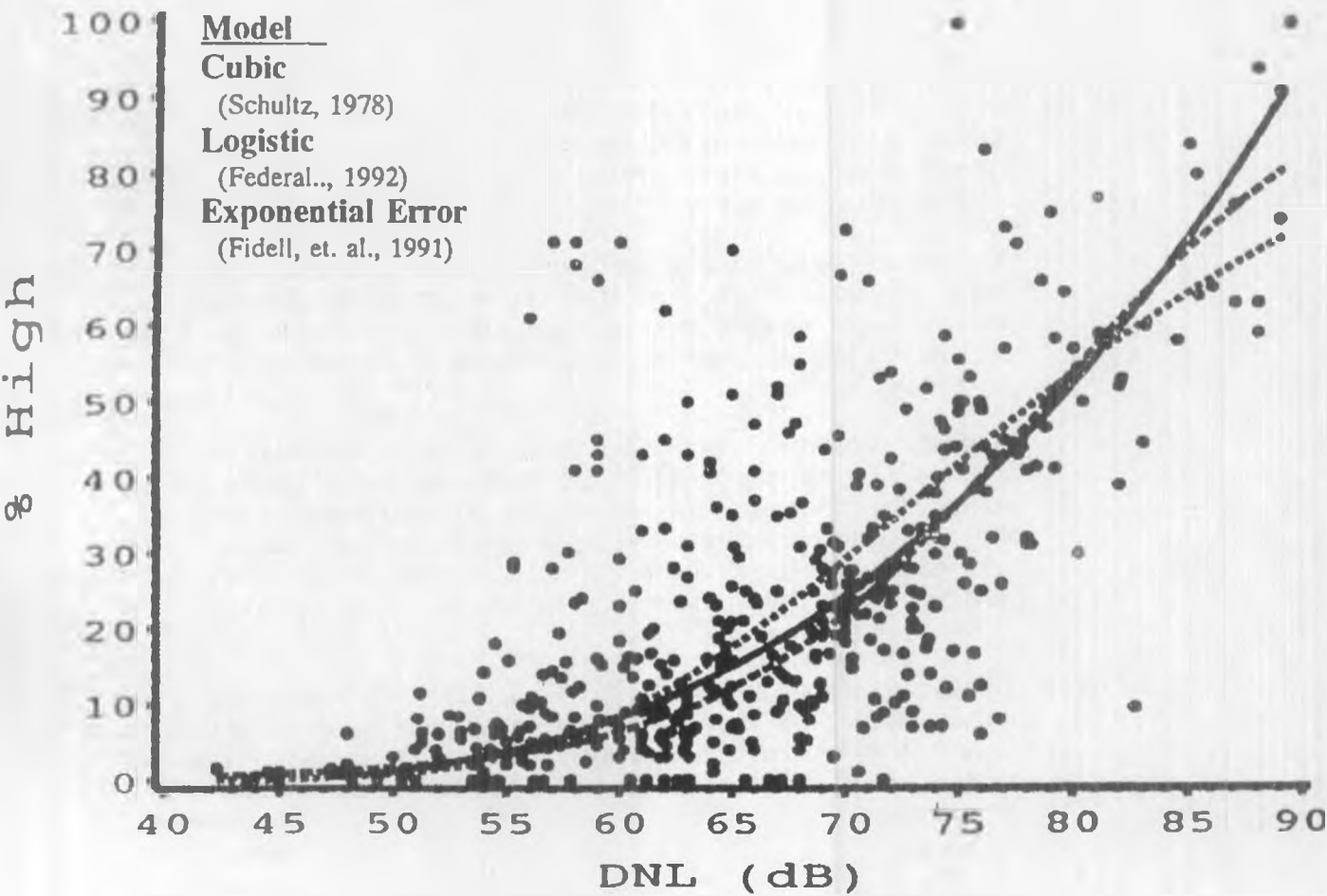


FIGURE 5.11 PERCENTAGE OF RESPONDENTS "HIGHLY ANNOYED" AS A FUNCTION OF EXPOSURE TO GENERAL TRANSPORTATION NOISE (DBA LDN) ACCORDING TO A CUBIC FUNCTION (SCHULTZ, 1978), AN EXPONENTIAL ERROR FUNCTION (FIDELL ET AL., 1991), A LOGISTIC FUNCTION (FEDERAL, 1992) FIT TO THE SAME DATA (FIDELL ET AL., 1989).

Source: Fields, 1994.

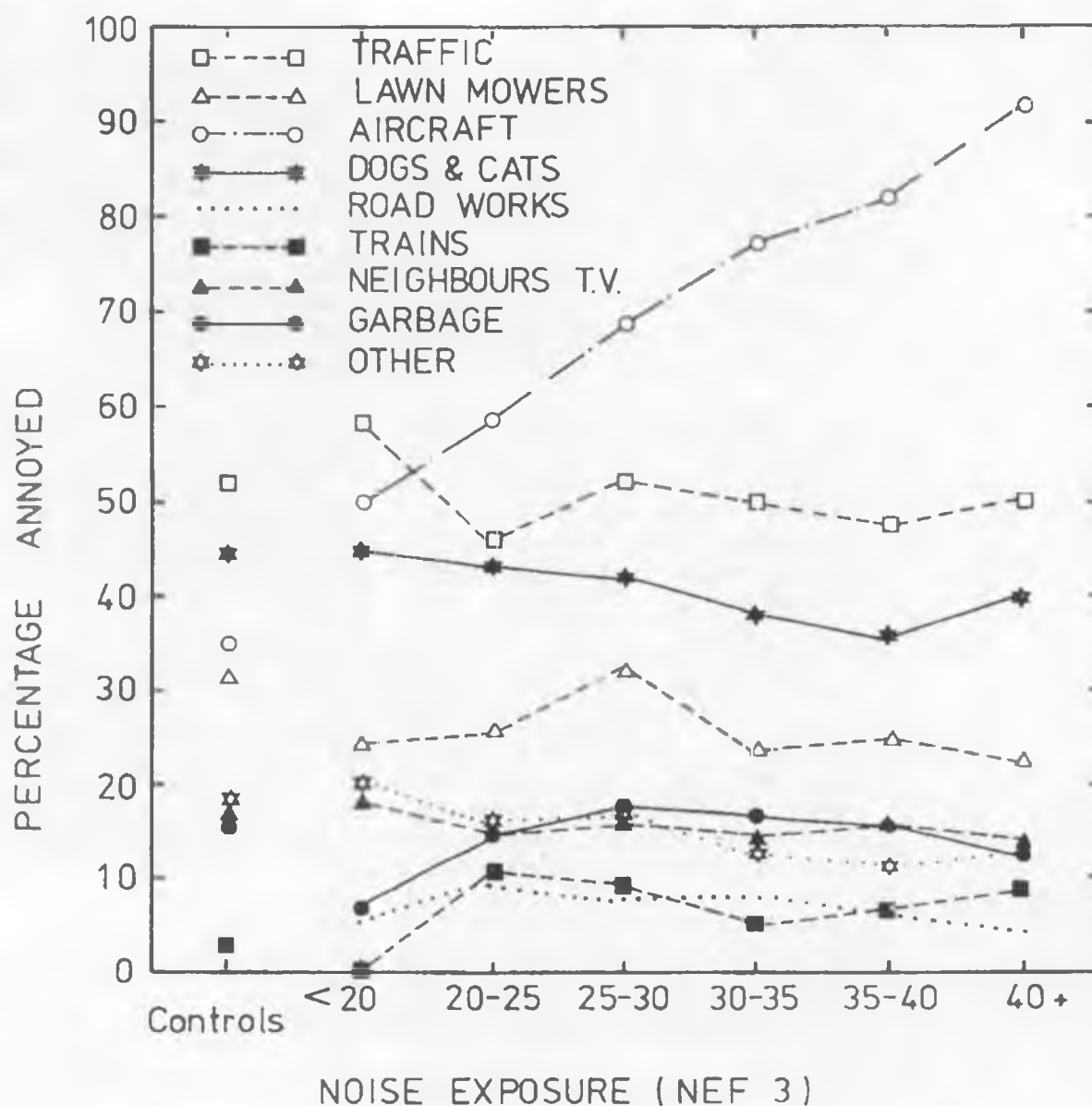


FIGURE 5.12 PERCENTAGE OF RESPONDENTS RATING THEIR ANNOYANCE AS AT LEAST 4 ON THE OPINION THERMOMETER (0 = NO ANNOYANCE, 10 = VERY MUCH ANNOYANCE) AS A FUNCTION OF EXPOSURE TO AIRCRAFT NOISE (NEF3).

Source: Hede and Bullen, 1982a.

It is conceivable that situational factors other than noise source cause the noise-reaction relationship to vary from one study to another. Thus, the data points from which dose-response functions are derived (for example, Fidell et al., 1991, Kryter, 1982, 1983; Miedema, 1993; Schultz, 1978) are so scattered as to cast doubt on the reliability of predictions of reaction to a certain noise exposure on the basis of the mean curve.

It is also critical that within-study differences in the reactions of individuals and communities not be overlooked (see Figures 5.9, 5.10 and 5.11).

Intersubject variability in reaction is relatively low at low sound pressure levels but very high at moderate and intense sound pressure levels (Fields, 1983, 1993b), and the correlation coefficient between noise exposure and individual annoyance has varied from 0.21 (Langdon, 1976) to 0.64 (Lambert, Simonnet, and Vallet, 1984) with an average of 0.42 (Job, 1988a). Sound pressure levels typically predict only 10 to 30% (on average 18%) of the variability in the annoyance responses of individuals (Job, 1988a). Communities have also been found to vary considerably in their reaction to the same sound level. Differences may be as great as the equivalent of a 15 dB difference in sound pressure level, with an average standard deviation of the equivalent of a 6 dB difference (Fields, 1983).

This low correlation between exposure and individual and community reaction result partially from invalid or inaccurate measurement of noise and/or reaction, or from a failure to consider confounding or moderating variables. It is important to recognise many factors besides noise exposure (for example, noise sensitivity, attitude to the noise source, etc) may influence reaction, such that prediction of reaction cannot be based on noise measures alone.

Finally, it is important that the existence of such dose-response functions does not promote the view that total exposure is the most critical aspect of noise in the determination of reaction, or that annoyance is remotely all of noise reaction. The number of noise events has been found to influence reaction (Björkman, 1988, 1991; Labiale, 1983; Rasmussen, 1979; Rylander, Sjöstedt, and Björkman, 1977; Rylander, Björkman, Åhrlin, and Berglund, 1980) as has maximum level. Evidence suggests that complex indices (comprised of annoyance as well as a range of other outcomes including complaint disposition, and activity disturbance) and indices phrased in more general terms (for example "dissatisfaction" and "affectedness") provide a more valid and reliable measure of annoyance (Job, 1993; Job et al., 1996)

#### 5.4.4 BEHAVIOURAL REACTIONS TO NOISE

##### *Means of Avoiding or Coping with Noise Exposure*

Residents in a noise area have several ways of coping with its impact. They can:

- improve the noise insulation of buildings (for example, by adding double glazing, insulating the roof, installing seals around doors and windows);
- use the noise insulating properties of buildings to a greater extent (for example, by closing windows);
- try to change their judgements about the environment or redefine their personal needs and attitudes;
- try to change their activities in a way that reduces the impact of the noise (for example, sleeping in airport curfew hours, turn up the television volume, engage in less noise sensitive activities);



- try to change the rooms in which activities occur (for example, by moving bedrooms to the less noise-affected side of the residence);
- try to influence the source by protest activities (such as complaints by letters, phone calls or personal visits to authorities, formation of citizen movements, participation in rallies/demonstrations, and running judicial processes); and
- move to a less noise affected area.

These processes may ultimately lead to consequences for the individuals and for the society.

#### *Changes to the Physical Environment and Use of Insulation*

Adoption of noise mitigation measures, such as installing home insulation, closing windows or changing the position of rooms in the house (according to the sensitivity of their function to noise), constitute an element of reaction to noise exposure. However, adoption of such measures may be impeded by perceived or actual limitations in their efficacy or convenience.

Data from a community survey conducted by Babischet al. (1996) suggest the potential efficacy of closing windows for reducing disturbance by noise. Amongst women living in the inner city streets, with windows open 74% report disturbance of relaxation, 68% with communication, and 58% with sleep. With windows closed the corresponding percentages are much reduced (20%, 16%, and 17%, respectively). A recent survey of a small group of residents in Sydney before and after the installation of home insulation (Narang, Butler, Schull, and Job, 1995) suggested that the insulation was effective in reducing activity disturbance and negative reaction. For example, before the insulation was installed 100% of the sample reported disturbance to indoor relaxation, outdoor relaxation, conversation and watching television or listening to music. After the installation the corresponding figures were reduced to 20%, 10%, 40% and 20%. Prior to home insulation, 92.3% of respondents were highly annoyed and 7.7% were considerably annoyed. Following the installation of insulation, 50% were highly annoyed, 30% considerably annoyed and 10% moderately annoyed. 100% of the sample rated their dissatisfaction in the highest 4 categories, whereas afterward only 58.3% of respondents rated their dissatisfaction in this range. However, this study was based on a small sample and was conducted over a short period of time. Longer term followup is required before such benefits of insulation can be predicted with confidence. For example, seasonal variations in the desire to have windows and doors open and consideration of the costs of artificial ventilation could not be considered in the time frame of the study. Home insulation has been found to achieve a reduction in annoyance consonant with the amount of sound it eliminates only when the amount of sound elimination is above a certain threshold (Bitter and Willigers, 1980). Peeters, de Jong and Tukker (1981) found annoyance with railway noise to be virtually independent of the home insulation qualities. Insulation may be of limited efficacy in reducing annoyance because outside and inside sound exposure are both important in determining annoyance and people often undermine their insulation, for example by not closing windows.

Studies which have examined inside and outside noise levels are uncommon. In such studies reaction may be more closely related to outside noise level than to inside level. For example, TRACOR (1971) observed reaction correlated at 0.37 versus 0.21 with outside and inside levels, respectively in Phase 1. In Phase 2 the respective correlations were 0.49 versus 0.25. While not tested by TRACOR, the difference in the correlation of reaction with indoor versus outdoor levels, was statistically significant (see Job, 1988a, p994). An Australian study of reaction to aircraft noise on RAAF bases revealed that whether reaction was best related to inside or to outside noise levels was itself determined by whether the building occupants could open/close windows and doors to influence the noise level (Job et al., 1985, 1991).

People often prefer to leave their windows open, especially at night, in order to have fresh air, pleasant temperatures and a sense of freedom. For example, 66 % of residents in the vicinity of Heathrow and Gatwick airports were found to sleep with open windows, regardless of whether their homes were insulated (DORA, 1980). Individuals tend not to close their windows before they go to bed unless they suffer sleep disturbance (Taylor, 1984). This might explain the paradoxical finding that annoyance is sometimes greater amongst people who sleep with their windows closed than those who do not. They may be annoyed about having to close their windows or by their sleep disturbance. Narang et al. (1995) found that approximately 80% of their sample (residents in a high noise area) reported closing doors or windows that they would otherwise keep open both before and after the installation of home insulation. Whilst 80% were satisfied with the effects of home insulation in the bedroom, less than 50% were satisfied with the effects in the kitchen or living and dining areas.

#### *Modification of Activities or Their Location*

In a community survey of the impacts of environmental noise (including transport noise) Schulte-Fortkamp (1996) found that individuals sought to manage interference due to noise by "predominantly using those rooms in the house in which outside environmental noise...is least perceptible, turning up radios and television sets..., turning on music to mask the outside environmental noise' (p2353). Respondents also reported determining the function of certain rooms on the basis of the noise in those rooms (Schulte-Fortkamp, 1996). In a community survey of residents in a noise affected area Narang et al. (1995) found that 76.9% of the sample reported turning up the television or radio etc in order to cope with the noise. Moving to quieter rooms or staying in doors more were reported by 23.1% and 69% of respondents respectively. Following the installation of home insulation the proportion of the sample who reported turning up the T.V. etc. was reduced to 40%. The number of people who reported moving to quieter areas increased to 80%, suggesting that the insulation increased appeal of this solution. The frequency of staying indoors as a solution did not change or created greater differentials in noise across the various rooms.

#### *Complaint and Protest*

Individuals may endeavour to cope with exposure to noise by engaging in protest activities or complaining to governmental agencies.

Noise is one of the environmental issues which most frequently causes public protest and complaint (Rohrmann, 1990b). It has certainly caused considerable protest with the introduction of the third runway at Sydney airport (Carter, Job, Peplow, Taylor and Morrell, 1996). However, typically only five to 10% of exposed residents ever protest or complain. Further, the number of complaints made is poorly correlated to noise exposure (Avery 1982; McKennell, 1963, 1980; McKennell and Hunt, 1961; Schümer and Zeichart, 1989; TRACOR 1971) possibly due to the influence of factors such as education, self-confidence, political orientation, or belief that complaints will have any influence.

Hede and Bullen (1982a) found that the correlation of noise exposure with "active complaint" (such as direct approach to the authorities) (correlation coefficient of 0.09) was lower than with general reaction (correlation coefficient of 0.28). "Passive complaint" (such as signing a petition) had a higher correlation with noise exposure (correlation coefficient of 0.19), possibly because petitioners concentrate their activities in high noise areas. Complaints may also be seen as a form of coping (Lercher, 1996a).

### *Residency Decisions*

Exposure to noise may influence peoples' decisions about where they live, both in terms of moving in and moving out (Michelson, 1980; Rohrmann, 1991).

Field studies have identified that noise exposure is often considered in moving or housing decisions (Bullen et al., 1985; Rohrmann, 1991; Schümer-Kohrs and Schümer, 1974). However it has only moderate influence on eventual behaviour, probably because of the overriding influence of economic and social factors (for example, see Landale and Guest, 1985), such as financial, occupational or family constraints.

Further, in selecting a new residence people appear either to underestimate the impacts of noise exposure, or overestimate their ability to cope with it. However, even with these unrealistic expectations, people appear to self select for noise sensitivity, so that community dissatisfaction may be decreased by increasing noise awareness of individuals considering moving to the affected area (Berglund and Lindvall, 1995). Consistent with this possibility is the not uncommon finding of a negative correlation between residents' noise exposure levels and their noise sensitivity (for example, -0.28: Langdon, 1976; -0.13: Hede and Bullen, 1982b).

Interestingly, amongst people who recently moved into a noise affected area (length of residence less than one year) previous knowledge and expectations about the noise levels in the area explained 19% of variance in general reaction, compared to the 6% explained by noise exposure (Hede and Bullen, 1982a). Apart from the possibility that prior expectations modify reaction, this finding may reflect the fact that people who were previously aware of the problem are likely only to have moved to the area if they are not noise sensitive. Alternatively, subjects who have reported having a strong negative reaction may feel obliged to account for this by claiming the noise was unexpected (Hede and Bullen, 1982a). Such issues are not really resolved in community surveys.

### *Social Behaviour*

Some evidence suggests that noise exposure may potentate aggression and reduce helpfulness. Noise exposure has been found to result in extreme judgements of others (Siegel and Steele, 1980) and to exaggerate aggression due to provocation or pre-existing anger/hostility (Jones and Chapman, 1984; Konecni, 1975).

It has been suggested that both during and immediately following noise exposure willingness to help is lowered (Korte and Grant, 1980; Korte, Ympa, and Toppen, 1975; Mathews and Canon, 1975; Page, 1977). Noise-induced interference with helping behavior may be related to inattention to incidental cues (Cohen and Lezak, 1977).

#### **5.4.5 MODERATING VARIABLES OF THE IMPACT OF NOISE ON ANNOYANCE AND DISSATISFACTION**

A number of acoustical, psychological and situational factors have been proposed to account for the substantial variation observed in individual reaction (Fields, 1993b; Gunn, 1987; Job, 1988a; Langdon, 1987).

Fields (1993b) evaluated the evidence on 22 personal and situational explanations for reaction to environmental noise in residential areas by conducting a metaanalysis of the findings from 136 surveys conducted up until 1988 which were deemed to meet the following criteria for quality. Questions on annoyance were required to appear in the context of questions about noise around the home and inquire about the respondent's overall current feelings about noise from a specified source. Questions did not have to be phrased in terms of annoyance. For example, "bothersomeness" was also considered, although complaint disposition and activity disturbance were not. Methods were required to ensure that the effects of the moderating variables in question could not be confounded with the effects of other variables or of variations in measurement. Analysis was required to remove the influence of noise exposure. Analysis was also required to assess the impact of the variable in terms of whether the annoyance scores of the subgroups formed by the moderating variable differed by the equivalent of 3 dBA, differed by 5% of total annoyance, or of whether the moderating variable explains at least 1% of the variance in annoyance scores. Whilst the studies reviewed considered reaction to noise from a variety of sources, many of them considered aircraft noise in particular. Thus, the findings are likely to be applicable in the present context. Fields' (1993b) meta-analysis is included in the discussion of various moderating variables in the following sections.

### *Characteristics of the Sound*

Sound characteristics which may influence reaction include its intensity and its spectral, temporal, and impulsive characteristics. The characteristic which is critical may vary across reaction and noise source. For example, reaction to aircraft noise may be primarily determined by sound pressure level, whereas reaction to noise from a typewriter may be primarily determined by features of their temporal pattern (Berglund, Berglund, and Lindvall, 1976).

### *Maximum Sound Level*

Whilst equivalent sound pressure level (or derivatives of it) has been the most commonly used noise metric for the purposes of establishing the impact of noise on reaction, another measure of sound intensity may be relevant.

Laboratory and field studies on annoyance after exposure to noise from aircraft, road traffic, train, shooting ranges, construction, blasting and artillery ranges demonstrate that general annoyance and personal perceptions of the exposure situation are highly related to the sound pressure level from the noisiest events (trucks, noisiest aircraft type, etc.). For example, annoyance with sound generated by heavy vehicles has been found to correlate strongly with maximum sound pressure levels (Langdon, 1976; Rylander et al., 1976), but not Leq (Rylander et al., 1976). Annoyance with aircraft noise was more closely associated with L<sub>max</sub> than to energy equivalent levels in some community studies (for example, Bjorkman, Ahrlin, and Rylander, 1992). However, many other studies have revealed a closer relationship to energy equivalent levels than to maximum levels (aircraft; Hede and Bullen, 1982a; Bullen et al., 1985; for a review see Fields, 1984). In studies of impulsive noise equal energy and peak levels may not differ significantly in the prediction of reaction (for example, Bullen et al., 1991) and reanalysis of noise-reaction relationships in terms of an equal energy unit have also proven viable (Bullen and Job, 1985).

### *Low Frequency Noise and Vibration*

There is evidence that loudness judgements and annoyance reactions are greater for sounds with low frequency components than other sounds with equal sound pressure level independently of which weighting scheme is employed (Berglund et al., 1996; Goldstein, 1994). Interestingly, Walker and Chan (1996) examined annoyance with two low frequency stimuli, one with a peak at 50Hz and one with a peak at 80Hz and found the latter to be more annoying. In contrast, Fuchs, Verzini and Skarp (1996) found that tones at 10Hz, 20Hz, 40Hz were judged less favourably than were tones at 80Hz when all tones were roughly 25 dB above hearing threshold. The following reasons have been proposed to account for the greater annoyance produced by low frequency sound (Lindberg and Backteman, 1988):

- strong low-frequency components produced by aircraft may rattle doors, windows, and other contents of houses. These secondary physical sound sources may be at least as annoying as the original noise. Further the vibration itself may be annoying or disturbing, thus increasing observed annoyance (Bullen et al., 1991; Griffin, 1990; Howarth and Griffin, 1990; Kastka and Paulsen, 1991; Kryter, 1985, 1994; Meloni and Kruger, 1990; Ohrström, 1996; Ohrström and Skanberg, 1996; Sato, 1993; Yano et al., 1996b);
- low-frequency components above certain intensity and frequency thresholds can result in a feeling of vibration and/or static pressure in the head, ears, neck, shoulders, back and feet (see Berglund et al., 1996; Fuchs et al, 1996); and

- low-frequencies produce periodic masking effects in medium and higher frequencies, and thus can potentially interfere with speech communication.

The tendency of low frequency sound to be more annoying than high frequency sound may partially explain the finding of greater reaction to aircraft noise than to road noise and this in a study which compared the two sources directly (Hall et al., 1981; see also Miedema, 1993). Aircraft sound has a stronger low frequency component than does road traffic noise.

Respondents of an Australian community survey, when given a choice as to which aspect of aircraft noise they find most "bothersome", elect "loudness", rather than the "low roar" or the "high pitched whine" of the engine (Hede and Bullen, 1982a). Nonetheless, this study did identify reaction to rattle or vibration caused by low frequency noise to be a significant component of reaction.

### *Impulsive Noise*

Community studies of reaction to artillery ranges (Bullen et al., 1991; Vos, 1996), rifle ranges (Buchta, 1996; Hede and Bullen, 1982; Jakobsen and Plovsing, 1996; Rylander and Lundquist, 1996; Sørensen and Magnusson, 1979), drop forging (Seshagiri, 1979), explosives (Buchta, 1996; Fidell, Horonjeff, Schultz, and Teffeteller, 1983; Murray and Avery, 1984; Schomer and Sias, 1996) and sonic booms (Rylander et al., 1974; Schomer and Sias, 1996) suggest that reaction to impulsive noise differs from reaction to non-impulsive noises in a variety of ways (for reviews see Job, 1988a; Rice, 1996). Firstly, greater reactions have been found for impulsive noises. Thus, Bullen et al. (1991) reported that the level of artillery noise required to produce a given level of reaction was about 30 dBA lower than the level of intermittent noise required. The difference was not as great if the sound exposure was expressed in terms of C-weighted Leq (see also Schomer, 1981). Second, there is greater individual variation in reaction to exposure to impulsive noise than for other sources, which does not appear to be due to less accurate measurement of noise exposure (Job, 1988a). These differences between reactions to impulsive and non-impulsive noise are poorly understood.

Nonetheless, there are also similarities: reaction to impulsive noise is reasonably well predicted by equal energy noise indices (see Bullen and Job, 1985; Bullen et al., 1991), and is also influenced by attitude and noise sensitivity.

### *Number of Noise Events*

The many investigations of the impact of the number of noise events on annoyance with sound from aircraft, road traffic, train, shooting ranges, and artillery ranges (Bjorkman, 1991; Bullen and Hede, 1986; Fields, 1984; Fields and Powell, 1985; Lambert et al., 1996; Rylander et al., 1980) indicate that annoyance is influenced by the number of events (in a specified period) up to a threshold above which an increase in the number of events has no further impact.

Findings from a longitudinal study of changes in reaction in response to changes in the operation of Dusseldorf airport reported by Kastka, Mau, Muth and Siegmann (1996) suggest the importance of the number of noise events. Residents from 25 sample points in the vicinity of the single flight path, categorised according to the distance of their residence from the flight path into "close", "middle distance", "far" or "horizon" groups, were interviewed in 1987 (n=499) and again in 1995 (n=750). Sound level measurements were made at each of the 25 sample points on both occasions. During the intervening period a near doubling of the number of aircrafts occurred, whilst the average intensity of each movement decreased as a consequence of fleet modernisation. In both 1987 and 1995, the percentage of respondents highly annoyed by the noise correlated significantly with both noise exposure (1987:  $r = 0.74$ , 1995:  $r = 0.91$ ) and distance from the flight path (1987:  $r = -0.74$ , 1995:  $r = -0.84$ ), which were strongly correlated with one another (1987:  $r = -0.94$ , 1995:  $r = -0.93$ ). However, the dose-response relationship for 1987 was "flatter" than that for 1995. The percentage of respondents highly annoyed by aircraft noise increased from 1987 to 1995 in the "close" and "middle distance" areas, but not in the "far" or "horizon" areas. The increase in public actions against the noise (10% of respondents in 1987 to 21% of respondents in 1995) occurred mainly in "close" (24% to 49% of respondents) and "middle distance" (11% to 34% of respondents) areas. One plausible interpretation of these findings emphasises the importance of number of noise events. The reduction in intensity of each noise event may result in some proportion of noise events remaining below background noise levels in distant but not near areas. Thus, whilst average sound pressure levels will increase to an equivalent extent in near and distant areas, the increase in number of noise events may only be experienced in near areas. Thus reaction increases in near but not distant areas. An alternative interpretation of these data is that people became more environmentally aware, or for other reasons, react more to noise in 1995 than in 1987.

Evidence suggests that the number of noise events influences annoyance over and above the influence of sound pressure levels. For example, in a recent community study, annoyance with aircraft noise was in fact found to be more closely related to the number of noise events above 70 dBA than  $L_{Aeq}$  (Björkman et al., 1992). However, this study is somewhat exceptional. In regression analysis the number of events has been found to add to, but not alone surpass, the prediction of annoyance afforded by equal energy units (Bullen and Hede, 1986; Bullen et al., 1991). Fields (1984) performed a meta-analysis on the data from eight surveys and concluded that whilst  $L_{eq}$  provides the best estimate of noise-induced annoyance, the number of noise events also influences reaction. In keeping with this conclusion the influence of the number of noise events (n) on percentage of annoyed subjects (%s) may be expressed by the formula:

$$\%s = LA + k \log (n) \quad (1)$$

where LA is A-weighted sound level and the value of k can vary within -3.7 to +23.8 depending on the type of noise event index being used (Fields, 1984).

There is virtually no evidence regarding reactions to very infrequent noise events, such as might be expected at a small airport. An experimental study of reaction to as few as one helicopter noise event per day suggested that under such circumstances reactions are largely predicted by Leq (Fields and Powell, 1985).

#### *Time Course of Noise Events*

A number of aspects of the temporal pattern of sound events may also be critical to reaction.

It has been suggested that traffic noise annoyance depends not only upon the average or typical sound pressure level but also upon the magnitude of the fluctuation, and the Traffic Noise Index (TNI) was developed accordingly (Griffiths and Langdon, 1968). However, these findings may not be readily applicable to aircraft overflights, which do not provide a fluctuating background hum, but rather are discreet events. NNI (Noise Number Index) may be more appropriate for such sources.

Some evidence suggests that reaction may be influenced by whether sound is time-limited, depending on sound intensity. Thus, time-limited noises like those from pile drivers, jack hammers, and typewriters, are relatively more annoying than aircraft noise at low sound pressure levels (below 50 dB LAmax). However, at high sound pressure levels the reverse is true (Berglund et al., 1976; see also Holmberg, Landstrom, Kjellberg and Tesarz, 1996).

The duration of certain noise exposures may be critical to their influence on reaction. For example, annoyance with a dog barking at night may depend on the duration of the barking (see Berglund and Lindvall, 1995). This may simply reflect the equal energy principle in that longer duration corresponds to more exposure to energy from the sound source, although the role of informal content cannot be discounted.

The distribution of noise in a given period (for example, a day, a month, a year) may also be critical in determining reaction to it. Thus, in an investigation of annoyance caused by low frequency sounds from artillery fire, Vos (1992) found that respondents experienced less annoyance the more the shooting was restricted to a smaller number of days or evenings per year, within limits.

#### *Day-and-Night Noise Exposures*

The time of day at which a sound occurs is also thought to influence reaction to it. Sounds which occur in the evening or at night are often found to cause more annoyance than acoustically similar sounds which occur during the daytime (for example, Ohrstrom, 1996; Rylander and Lundquist, 1996; Sattler and Rott, 1996). A meta-analysis of ten studies with a total of 22,000 respondents supported this assumption (Fields, 1985, 1986). However, the size of difference in reaction to a particular sound at night versus during the day cannot be specified with accuracy.

Many cumulative noise indices, such as the Ldn and Noise Exposure Forecast (NEF), incorporate a "penalty" weighting of 10 dB for nighttime noise



(usually between 7pm and 7am, unless an evening period is defined). Some indices also include a weighting of 5 dB for sounds which occur during the evening (usually between 7 and 10 p.m.). Bullen and Hede (1983) found that residents in the vicinity of an airport estimate the need for non-interference of noise to be most important between 6 and 9 p.m. Lambert et al. (1996), suggest that the noise index which will best predict annoyance differs for different times of day, with most relevant for daytime noise and the number of noise events or the length of time over 70 dBA most relevant for the evening.

There are a number of reasons why nighttime sound may be particularly annoying. Firstly, nighttime noise might produce sleep disturbance. Second, the impact of nighttime noise on a variety of outcomes may be exacerbated because it is superimposed on lower background noise levels than those typical during the daytime (partially due to decreased indoor activity). Indeed, at low levels of background noise the annoyance from the noise source increases (Berglund and Lindvall, 1995).

### *Situational Variables*

A number of situational variables may influence reaction to noise, including personalised exposure, whether there has been a recent change in noise exposure or whether the noise is from a number of sources.

### *Personalised Exposure*

According to a metaanalysis of five relevant studies (Fields, 1993b), only one supported the hypothesis that annoyance is increased by the number of hours the residents are at home. This finding may reflect the possibility that exposure away to the same source from the home may be equivalent to or greater than exposure at home, if the relevant respondents spend much of their time away from home in a place where they are exposed to the same noises. Further, Fields (1993) suggested that it "may also be that annoyance is governed by feelings during the time at home and is not diminished by the amount of time that a noisy home environment can be avoided" (p2758). This suggestion, along with the importance of outside noise level in determining reaction, is consistent with the possibility that attitude to the noise "bombardment" of the home is a critical factor of reaction (see Job, 1988a, 1993).

It has, however been stressed that the noise dose received at work increases the annoyance expressed with the noise at home (Bertoni, et al., 1993).

Isolation from the noise, in terms of home insulation, the presence of air-conditioners, orientation of important rooms away from the noise source, time spent outdoors, or the extent to which outdoor activity is facilitated by the climate, was shown by 82% of eleven relevant studies to be associated with lower annoyance (Fields, 1993b; see also Ohrstrom, 1993a). Two studies found that annoyance decreased after the installation of home insulation in comparison to the annoyance measured before the change. However, this finding could reflect a "placebo effect" brought about by the residents' knowledge of the installation of insulation (Fields, 1993b). Narang et al., (1995) found that although the installation of insulation appeared to produce substantial improvements in terms of activity disturbance and

reaction, more than half of the respondents reported that having the windows closed or open made not difference to the insulation. This finding is consistent with the view that knowledge of the insulation's presence, rather than its presence per se, produced much of its positive effects.

#### *Annoyance Before and After Intervention or Change in Noise Levels*

Studies have consistently demonstrated that the reaction produced by a change in noise level is often greater than would be expected from the change in noise exposure alone (Kastka, 1980; Langdon and Griffiths, 1982; Brown, 1987; Brown et al., 1985; Raw and Griffiths, 1985; Griffiths and Raw, 1986, 1989; Job, 1988b; for a synthesis see Fields, 1992, 1993b). Thus, the increase in community dissatisfaction that could be expected to result from commencement of aircraft operations at a new airport would be greater than predicted on the basis of dose-response relationships for unchanged noise exposure. Similarly, noise abatement measures might produce a greater decrease in dissatisfaction than would be expected from the magnitude of the noise exposure reduction. The size of this additional decrease in reaction corresponds to about 5 dB for aircraft and 10 dB for road traffic noise (LAeq). For example, in a community survey involving 3,400 residents in German towns Kastka (1980; in vallet, 1996) found that the reduction in annoyance with traffic noise in response to a reduction of only 1 dB LAeq was equivalent to a reduction of 6-14 dB LAeq. This finding may reflect increased regularity of traffic flow and efficient advertising campaigns (Vallet, 1996).

In Fields' (1993b) meta-analysis, 80% of relevant and quality surveys supported the hypothesis that people overreact (report more annoyance than would be predicted for an existing noise of the same level) to an increase in noise exposure. 50% of relevant and quality surveys supported the hypothesis that people overreact to a reduction in noise levels (with 38% showing no important effect, and 12% showing an important effect in the opposite direction).

A number of explanations of this phenomenon have been proposed. The most obvious explanation, that reaction habituates (Brown et al., 1985), is unlikely to provide a complete account of the over-reaction effect (Job et al., 1996). Firstly, evidence suggests that there is minimal habituation in reaction to noise (Griffiths and Raw, 1989; Weinstein, 1982). In Fields' meta-analysis, 50% of findings support the hypothesis that with time annoyance with a new source decreases, however, 33% of studies revealed an important effect in the opposite direction. Nonetheless, some effects of sleep do appear to habituate and the failure to detect habituation may be due to habituation already having taken place before the relevant studies began (see Section 8).

Some data also suggest the possibility that people make changes which help them cope with the noise (such as installing insulation or changing the function of more noise exposed rooms)(for example see Raw and Griffiths, 1990; Schulte-Fortkamp, 1996). In a population which has been chronically exposed to high noise these adjustments have already occurred and so when the noise is reduced it is heard even less than it would be by people who have not needed to make such adjustments due to having resided in the low

noise areas. Conversely, when people have not made such adjustments because they have not been exposed to high levels of noise, but become exposed, they are then functionally exposed to more noise than a population adjusted to high noise levels (see Raw and Griffiths, 1990).

It should be noted that most studies cited in this review are of populations which are likely to have already adjusted to noise physiologically and behaviourally. Thus, reaction to noise outlined in this review is reaction at this adjusted level. It should not be anticipated that reaction will reduce with time to a level below the levels predicted here. Rather, a greater level of reaction should be expected for at least several years after an increase in noise exposure.

Overreaction to changes in noise exposure may also reflect changed expectations due to the change in noise exposure itself, changed attitudes to the noise source (Job, 1988a, 1988b), or influence of the change on response criteria. Job (1988b) suggested that changes resulting in increased noise exposure may be fuel for negative attitudes toward the noise source, being seen as evidence that those in charge of the noise source are not concerned about the noise or are not doing enough about it. Given the apparent role of attitude in determining reaction, (see Section 5.4.4) this may result in a potentiation of negative reaction to the new exposure level. In contrast, changes which result in reduced noise exposure, may improve attitudes toward the noise source, with a consequent exaggeration of the reduction in reaction.

The finding that overall or nighttime noise annoyance changed in only 2% of a population experiencing large changes in noise levels due to the complete abolition of nighttime flights around Los Angeles airport (Fidell and Jones, 1973), has been attributed to testing before changes in reaction had occurred (Vallet, 1996).

Very small changes in noise levels may not be detected. For example, Fidell, Silvati and Pearsons (1996) reported that a large majority of respondents around Seattle-Tacoma airport noticed either no change or increases in aircraft noise, despite reductions of approximately 1.5 dB Ldn in the previous two years. They conclude that there is "little reason to believe that decreases of 1.5 to 3 dB in aircraft noise occurring over an extended period are likely to be noticed in airport neighbourhoods". It is not known whether the same is true of increases. It is possible that this change was not noticed when others have been, because it was not publicised. Any publicised change to airport operations may make aircraft noise more topical and more noticed. For example, Yamada and Kaku (1996) investigated changes in a reaction as a result of a reduction of noise levels in the environs of Osaka International Airport following the 1994 opening of Kansai International Airport elsewhere in the city. Respondents in areas where noise levels had dropped by 3-5 dB were interviewed in 1995 and asked whether aircraft noise "became quieter", stayed "the same as before", or "became noisier" since the opening of Kansai. A greater percentage respondents thought aircraft had become quieter (72%) or had stayed the same (22%) than thought it was noisier (1%) (5% either did not answer or reported difficulty determining if or how levels had changed).

Gjestland, Granoien and Liasjo (1995) also performed a study in which small increases in noise did not produce an increase in negative reaction, and tended to have the opposite effect. However, these findings may be explicable in terms of the attitude toward the military aircraft noise. Gjestland et al (1995a, 1995b) measured reaction to noise in the vicinity of a combined civil and military airports before and after two, two to three week, training exercises, during which noise exposure levels increased by approximately 6 dB. Measurements during the training exercise were conducted for exercise one only. Respondents were grouped into 5 db exposure zones according to their baseline (non-training exercise period) exposure levels. The increase in noise levels appeared not to influence spontaneous mention of aircraft noise as a disliked feature of their neighbourhoods, nor the percentage of respondents who when asked how annoyed they were by aircraft noise replied that they were "very annoyed". Thus, the annoyance ratings during the first exercise were equal to ratings before the exercise for the majority of respondents, which may reflect a response bias toward not reporting a difference. More respondents were less concerned during than before the exercise, than were more concerned during than before the exercise. For the second exercise, most respondents were equally annoyed by aircraft noise before and after the exercise. More respondents were less annoyed than were more annoyed by noise after compared to before the exercise. These findings would seem to confirm the importance of attitude in determining reaction (see Section 6.5.3.1). The tendency for greater annoyance before than during or after the exercises may reflect apprehension prior to their commencement or may reflect the possibility that people enjoyed the exercises, treating them like an airshow (Gjestland, 1995, personal communication). The positive attitudes may also have reflected positive opinions about the (erroneously) anticipated use of the aircraft in a very popular war effort (the Gulf War). Knowledge that the increases in noise were temporary is also likely to have tempered reaction.

Another seemingly anomalous finding is the observation of increased reaction in the face of decreases in equivalent and average maximum sound pressure levels. A recent study of reaction to aircraft noise has been conducted in the vicinity of Dusseldorf airport, where noise levels have decreased by 0.5 dB Leq per year and average maximum levels have decreased, since 1985 (Kastka, 1995). The percentage of residents who are highly annoyed has nonetheless increased from 29% in 1987 to 45% in 1993, perhaps due to an increasing number of events.

#### *Annoyance of Noise from Joint Sources - Role of Background Noise Levels*

In the community, noise generally derives from a number of sources at any given time (Vos, 1992). People are generally able to distinguish noises from different sources within compound signals, but sometimes mistake one source for another (Berglund, Berglund, and Lindvall, 1980). This issue may be relevant to a new airport in that the airport noise will be added to existing noises., and the airport operation may add to other noises (for example, increased ground transport noise).

Researchers have proposed a range of models to predict the perceived loudness of compound noises (Berglund, Berglund, Goldstein, and Lindvall, 1981; Diamond and Rice, 1987; Hellman, 1982; Ollerhead, 1980; Powell,

1978, 1979; Rice and Izumi, 1984; Taylor, 1982; Vos, 1992; for a review see Ronnebaum, Schulte-Fortkamp, and Weber, 1996). For example, according to the vector summation model the perceived loudness of the compound noise is given by the summed loudness of the masked constituent noises. A dominance model states that the loudness of the compound noise equals the loudness of the component noise which is loudest when heard alone. According to Vos' (1992) model, for combinations in which annoyance with noise from one source is substantially higher than annoyance with noise from other sources, it is the annoyance from the most annoying source which determines total annoyance. For combinations in which annoyance with noise from each source is approximately equivalent, the total noise annoyance is about 45 dB LAeq greater than the annoyance from the most annoying source (see also Solberg, 1996).

Laboratory data indicate that annoyance with compound noises may be predicted reasonably accurately using a dominance model, provided none of the constituent noises have strong tonal components. Nonetheless, Miedema (1987) argued that it is not yet possible to dismiss the possibility that annoyance with a compound is greater than the maximum of the ratings from the individual sources.

The accuracy of the dominance model is consistent with the conclusion of a meta-analysis of annoyance surveys that the annoyance with a target noise in background noise is mostly unaffected by the background (ambient) noise (Fields, 1993a, 1993b, 1996a). Fields (1996a) concluded from an analysis of 57,000 responses to 35 target noises by approximately 35,000 respondents in 20 community noise surveys, that a 20 dB increase in ambient noise exposure is predicted to effect reaction no more than a 1 dB increase in target noise. Thus, the concerns of Fairfield Residents Against Airport Noise (1996) that the impact of aircraft noise may be higher in areas with low levels of background noise seems to be unwarranted with regard to noise reaction. Nonetheless, Fields (1996a) acknowledged that this prediction is somewhat imprecise, such that the impact of 20 dB increase in ambient level may in fact be equivalent to a 3 dB increase in target. Further, investigation of a wider range of ambient noise levels than has been studied to date may reveal a larger effect (Fields, 1993b). In laboratory studies, annoyance with a noise of given intensity has been found to be greater with low background noise than with high background noise (for example, Walker and Chan, 1996). The failure to observe this effect in field studies may reflect the fact that the potential impact of low background noise per se may be countered by the ameliorating impact of factors associated with it, such as increased neighbourhood satisfaction. Further, sound level meters may be influenced by background noise, thus overestimating the target noise (and thus annoyance with the target noise) in areas with high background noise.

Which noise of a compound is perceived as loudest or most annoying not only depends on the intensities of the constituents (Berglund, 1981; Berglund et al., 1980), as might be expected from the fact that even for simple noises neither loudness nor reaction depends only on intensity. For example, in areas exposed both to aircraft and traffic noise, "overall annoyance" is most influenced by aircraft noise (Diamond and Rice, 1987; Diamond and Walker, 1986) consistent with the claim that aircraft noise is more annoying than traffic noise (Miedema, 1993).

### *Individual Differences and Demographic Variables*

A substantial body of evidence suggests that more variation in reaction to noise is explained by person factors than by acoustic features of the sound (Berglund and Lindvall, 1995; Job, 1993).

These person factors include, attitude to the noise source (Bullen et al., 1985; Cederlöf, Jonsson, and Sörensen, 1967; Fields, 1993b; Fields and Walker, 1982; Job, 1988a; TRACOR, 1971), information conveyed by the noise, fear of the health/safety impacts of the noise and its source, noise sensitivity (for example, Fields, 1990; Finke, Guski, and Rohrmann, 1980; Gunn, 1987; Job, 1988a; McKennell, 1980; McKennell and Hunt, 1961; Rohrmann, Schumer, Schümer-Kohrs, Finke, and Guski, 1973), living conditions, socio-economic status, individual needs (for example, sleep, rest) and tastes (for example, loud music). Demographic variables such as age and gender do not appear to be influential (Fields, 1993b).

Job (1988a) in a review of community surveys of reaction to noise compared the correlation of reaction with noise to the correlation of reaction with attitude to the noise and its source (with and without noise controlled) and with sensitivity (with and without noise controlled). The correlation of noise with attitude and sensitivity was also considered. The reviewed data are presented in Table 5.5 and will be discussed in the ensuing sections.

TABLE 5.5A CORRELATIONS OF NOISE WITH REACTION, OF ATTITUDE WITH NOISE, AND OF ATTITUDE WITH REACTION (BOTH WITH AND WITHOUT NOISE CONTROLLED), FOR A VARIETY OF NOISE SOURCES

Study	Noise Source	Noise/Reaction	Noise/Attitude	Reaction/Attitude	Reaction/Attitude: Noise controlled
Borsky (1983)	Aircraft	0.58		0.26	-
Bullen et al. (1986)	Aircraft	0.36	0.22	0.68	-
Hede & Bullen (1982a)					
Bullen & Hede (1984)	Artillery	0.22	0.10	0.55	-
Bullen et al. (1985)	Aircraft	0.58	0.21	0.45	-
Dankittikul et al. (1993)	Road (Japan)	0.49	n.s		-
Dankittikul et al. (1993)	Road (Thai)	0.23	n.s		
Fields & Walker (1982)	Railway	0.36	-	-	0.50
Garcia et al. (1993)	Aircraft	0.32	0.27	-	-
Hede & Bullen (1982b)	Rifle range	0.29	0.11	0.78	-
Job & Hede (1989)	Power stations	0.19	0.04	0.43	-
Lagdon (1976)	Road	0.21	-	-	-
Large & Ludlow (1978)	Construction	0.52	0.12	0.34	-
Lopez-Barrio & Carles (1993)	Road	0.30	-	-	-
McKennell 91978)	Super-sonic aircraft	0.26	-	0.42	-
McKennell (1963/73)	Aircraft	0.46	0.11	0.35	0.34
Nivison & Endresen (1993)	Road	n.s			
Nixon & Borsky (1965)	Sonic boom	-	-	sig.	-
O'Laughlin et al. (1986)	Rifle range	0.06	-	0.54	-
Schuemer & Schuemer-Kors (1983)	Railway	0.46	-	0.20	-

Study	Noise Source	Noise/Reaction	Noise/Attitude	Reaction/Attitude	Reaction/Attitude: Noise controlled
Schuemer & Schuemer-Kors (1983)	Road	0.52	-	0.22	-
Stansfeld (1992)	Aircraft	-	-	-	-
Stansfeld (1992)	Road	-	-	-	-
Tarnopolsky et al. (1978)	Aircraft	sig.	-	-	-
van Dongen (1980)	Road	0.30	-	-	-
Wolsink & Sprengers (1993)	Wind turbine	0.09	-	n.s	-
Yano et al. (1991)	Road	0.27	-	-	-
Mean		0.34	0.15	0.44	0.42
s.d.		0.15	0.08	0.18	0.11
number of cases		22	8	12	2

Source: Job, 1994.

TABLE 5.5B CORRELATIONS OF NOISE WITH REACTION, OF SENSITIVITY WITH NOISE, AND OF SENSITIVITY WITH REACTION (BOTH WITH AND WITHOUT NOISE CONTROLLED), FOR A VARIETY OF NOISE SOURCES

Study	Noise Source	Noise/Reaction	Noise/Sensitivity	Reaction/Sensitivity	Reaction/Sensitivity: Noise Controlled	Sensitivity & Noise/Reaction
Borsky (1983)	Aircraft	0.58	-	0.15	-	-
Bullen et al. (1986) Hede & Bullen (1982a)	Aircraft	0.36	-0.03	0.35	-	-
Bullen & Hede (1984)	Artillery	0.22	0.01	0.33	-	-
Bullen et al. (1985)	Aircraft	0.58	0.01	0.26	-	-
Dankittikul et al. (1993)	Road (Japan)	0.49	n.s	-	-	-
Dankittikul et al. (1993)	Road (Thai)	0.23	sig.	-	-	-
Fields & Walker (1982)	Railway	0.46	-	-	0.45	-
Garcia et al. (1993)	Aircraft	0.32	-	-	-	-
Hede & Bullen (1982b)	Rifle range	0.29	-0.13	0.21	-	0.30
Job & Hede (1989)	Power stations	0.19	0.05	0.18	-	-
Langdon (1976)	Road	0.21	-0.28	-	-0.08	0.45
Large & Ludlow (1978)	Construction	0.52	0.01	0.31	-	-
Lopez-Barrio & Carles (1993)	Road	0.30	0.03	-	0.34	-



Study	Noise Source	Noise/Reaction	Noise/Sensitivity	Reaction/Sensitivity	Reaction/Sensitivity: Noise Controlled	Sensitivity & Noise/Reaction
McKennell (1978)	Super-sonic aircraft	0.26	0.30	-	-	-
McKennell (1963/73)	Aircraft	0.46	-0.03	0.25	0.25	-
Nivision & Endresen (1993)	Road	n.s	-	0.36	-	-
Nixon & Borsky (1965)	Sonic boom	-	-	-	-	-
O'Laughlin et al. (1986)	Rifle range	0.06	-0.19	0.35	-	-
Schuemer & Schuemer-Kors (1983)	Railway	0.46	-	0.19	-	0.54
Schuemer & Schuemer-Kors (1983)	Road	0.52	-	0.32	-	0.65
Stansfeld (1992)	Aircraft	-	-	0.68	-	-
Stansfeld (1992)	Road	-	-	0.49	-	-
Tarnopolsky et al. (1978)	Aircraft	sig.	n.s	n.s	-	-
van Dongen (1980)	Road	0.30	n.s	-	-	-
Wolsink & Sprengers (1993)	Wind turbine	0.09	-	-	-	-
Yano et al. (1991)	Road	0.27	-	0.30	-	-
Mean		0.34	-0.01	0.32	0.24	0.49
s.d		0.15	0.15	0.13	0.23	0.15
number of cases		22	10	16	4	4

Source: Job, 1994.

#### *Attitudes Toward the Noise and its Source*

Individuals with more negative attitudes toward the noise source are more likely to be annoyed by the noise (Fields, 1993b; Job, 1988a, 1993). In Fields' (1993b) meta-analysis, the four attitudinal hypotheses considered were supported by the great majority of relevant studies. Thus, annoyance appears to be greater if the respondent fears the noise source (supported by 100% of 14 relevant studies), believes the noise could be prevented by designers, pilots or authorities (100% of six, see also Job, 1988a), is aware of non-noise problems associated with the source, such as air quality (two of two) or does not believe that the noise source is important (three of four). The notion that individuals who benefit from the noise source (users, or



employees, or dependants of employees of the source) may have a better attitude toward it and thus might react more favourably toward it, was undermined by Fields' (1993b) meta-analysis. 89% of nine appropriate studies found no relationship between individuals' reaction to the noise and whether they were users, or employees, or dependants of employees of its source. Only one of the appropriate studies demonstrated a positive relationship. Fields (1993b) proposed that the disadvantages of being a user or employee of the source may counterbalance its advantages in producing and attitude to it and reaction to the noise.

Job (1988a) concluded from a review of correlations between attitude and reaction, and between attitude and noise, and between reaction and noise, which were observed in community studies, that "[t]he pattern of results suggests that attitude is, in part, a genuine factor affecting reaction, and, in part a result of reaction" (Job, 1988a, p997) (see Table 5.5).

Preliminary analysis of the first wave of surveys conducted for the Sydney Airport Health Study, a study of the effects of the airport and the third runway in particular (Job et al., 1996c), provided data supportive of attitude change as a factor in reaction to noise. Job et al. (1996) found that 56% of the variance in reaction was accounted for by three attitudinal factors- one reflecting local concerns with the airport (for example, disagreement that the airport is of value to the neighbourhood, agreement that aircraft cause pollution), one reflecting financial concerns (for example, views that the airport is a waste of money, that only the wealthy benefit from it, that it does not benefit the economy) and one reflecting misfeasance (for example, the belief that the government is not doing enough to stop noise pollution). The anticipated changes to noise exposure with the opening of the third runway were widely publicised, offering the opportunity to test a peculiar prediction of this theory. That is, when people know the changes will occur in the future, this should be enough to change attitudes, which in turn should be enough to change in reaction even before the changes in noise exposure have actually taken place. The relevant data were all collected before the third runway was opened, so no relevant changes in noise exposure had yet occurred and could not have been the cause of any observed changes in attitude or reaction. The data clearly supported predictions based on Job's (1988b) theory. Residents of areas expecting an increase in noise (from low to high noise exposure) had more negative attitudes toward the airport and more reaction to noise than residents of areas expecting to maintain low noise exposure. Residents of areas expecting a decrease (from high to low noise exposure) had less negative attitudes toward the airport and less reaction to noise than residents of areas expecting to remain exposed to high noise levels. The alternative account that residents may deliberately "reward" relevant authorities for reduced noise by reporting greatly reduced reaction, or "punish" decisions resulting in increased noise by showing greatly increased reaction (Job, 1988b), is also consistent with the findings reported by Job et al. (1996c).

Hede and Bullen (1982a) in a thorough examination of the effects of aircraft noise around several Australian airports, found that negative attitude toward aircraft and the airport (ten item index) was the best predictor of general reaction (comprised of "affectedness", "dissatisfaction", annoyance, activity disturbance, complaint disposition, fear of crashes, and perceived impact of

aircraft noise of health) in a regression analysis, accounting for 45.8% of variance in general reaction (see *Figure 5.13*). Note that Hede and Bullen (1982a) treated fear of crashes as a component of reaction not attitude, whereas others have treated fear as an attitudinal variable. On logical grounds fear would appear to be a reaction to noise although it may be determined at least in part by beliefs about aircraft safety. Thus, the status of fear is not easily determined. The possibility that negative attitudes toward the noise source is itself part of a reaction to noise should be recognised. In keeping with the suggestion that at least in some instances attitude is part of reaction, (but see McKennell, 1978), Bullen et al. (1985) studied two airforce bases in Australia and reported that negative attitudes toward the noise source were associated with noise exposure to such an extent that their apparent effect on reaction could be entirely accounted for by noise exposure. However, while attitude does generally show a positive correlation with noise exposure, the relationship is much weaker than that between reaction and noise exposure (mean correlations of 0.15 versus 0.42 in Job's 1988a analysis of relevant studies).

Hede and Bullen (1982a) also report a substantial relationship between fear of aircraft crashes and general reaction (partial correlation coefficient = 0.443) (see *Figure 5.14*). The 107 out of 1480 Sydney subjects who spontaneously mentioned a crash which occurred just prior to the survey had a higher general reaction than the rest of the Sydney sample. This result, however, is merely suggestive. Memory of the crash may have caused more negative reaction, or more negative reaction may have increased motivation to mention the crash. A recent community study has assessed the impact of a crash on annoyance (Reijneveld, 1994). In the vicinity of the crash 36.8% of respondents (n = 305) were annoyed before the incident and 60% after. In a control area (n = 1006) no change in annoyance was observed from before to after the crash. However, these findings may have been influenced by changes in noise levels. In the crash area, post-crash measures were taken immediately after recommencement of aircraft flyovers (three to ten weeks after the crash), whereas in the control area there was no break in flyovers. However, since annoyance reactions are thought to adapt only minimally (Weinstein, 1982), dishabituation is unlikely to have produced the elevated annoyance in the crash area. Nonetheless, the report of Fairfield Residents Against Airport Noise (1996) that some residents in the vicinity of the proposed site of a Second Sydney Airport at Badgerys Creek are fearful of aircraft crashes represents some cause for concern. However, the actual rate of such fears in the community should be further considered with an awareness that residents may be politically motivated to report such fears.

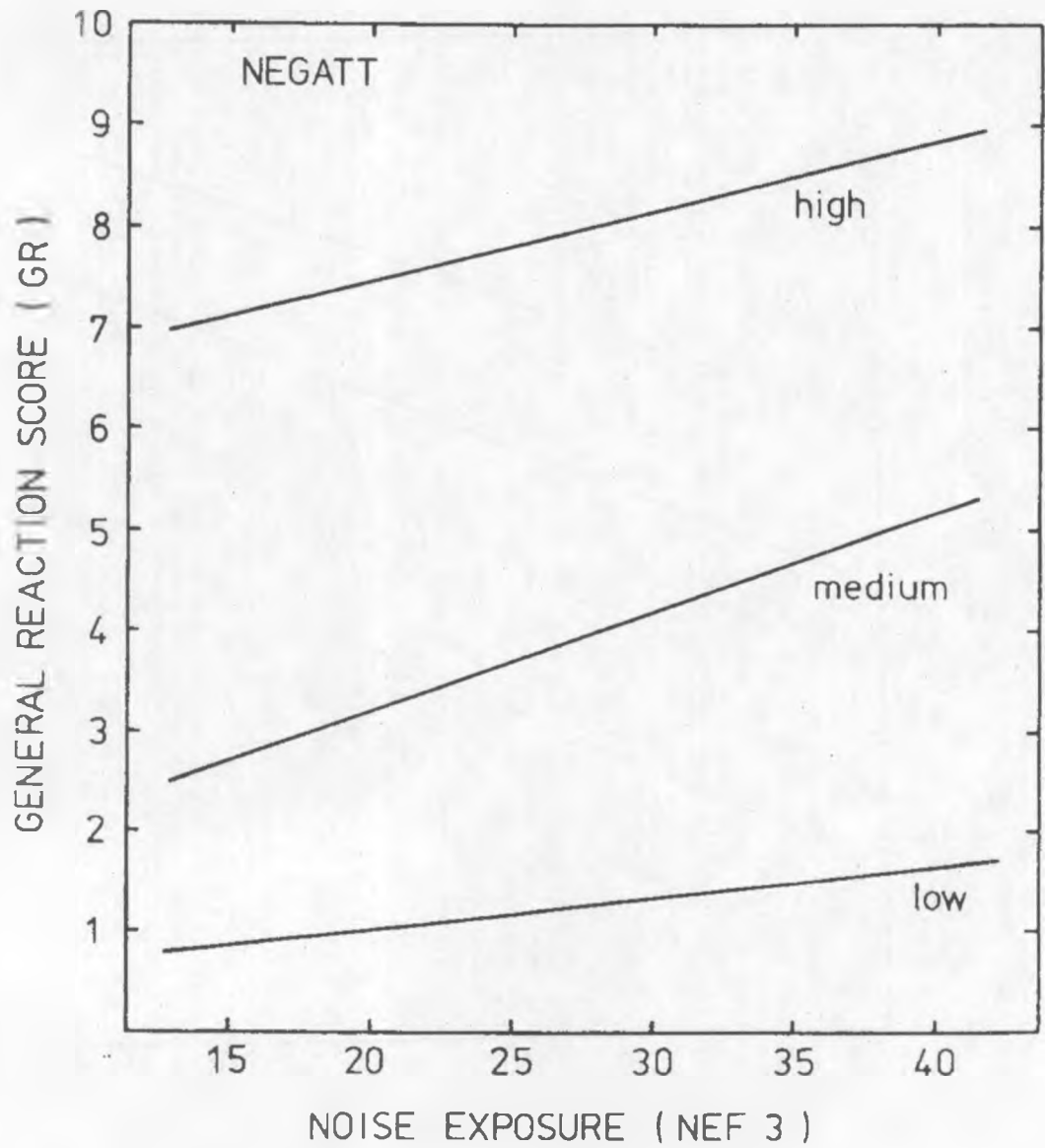


FIGURE 5.13 GENERAL REACTION SCORE AS A FUNCTION OF EXPOSURE TO AIRCRAFT NOISE (NEF3) FOR RESPONDENTS WITH HIGH (AT LEAST 7), MEDIUM (FROM 3 TO 7), OR LOW (LESS THAN 3) SCORES ON A SCALE ASSESSING NEGATIVE ATTITUDES TOWARD THE NOISE OR ITS SOURCE (NEGATT).

Source: Hede and Bullen, 1982a.

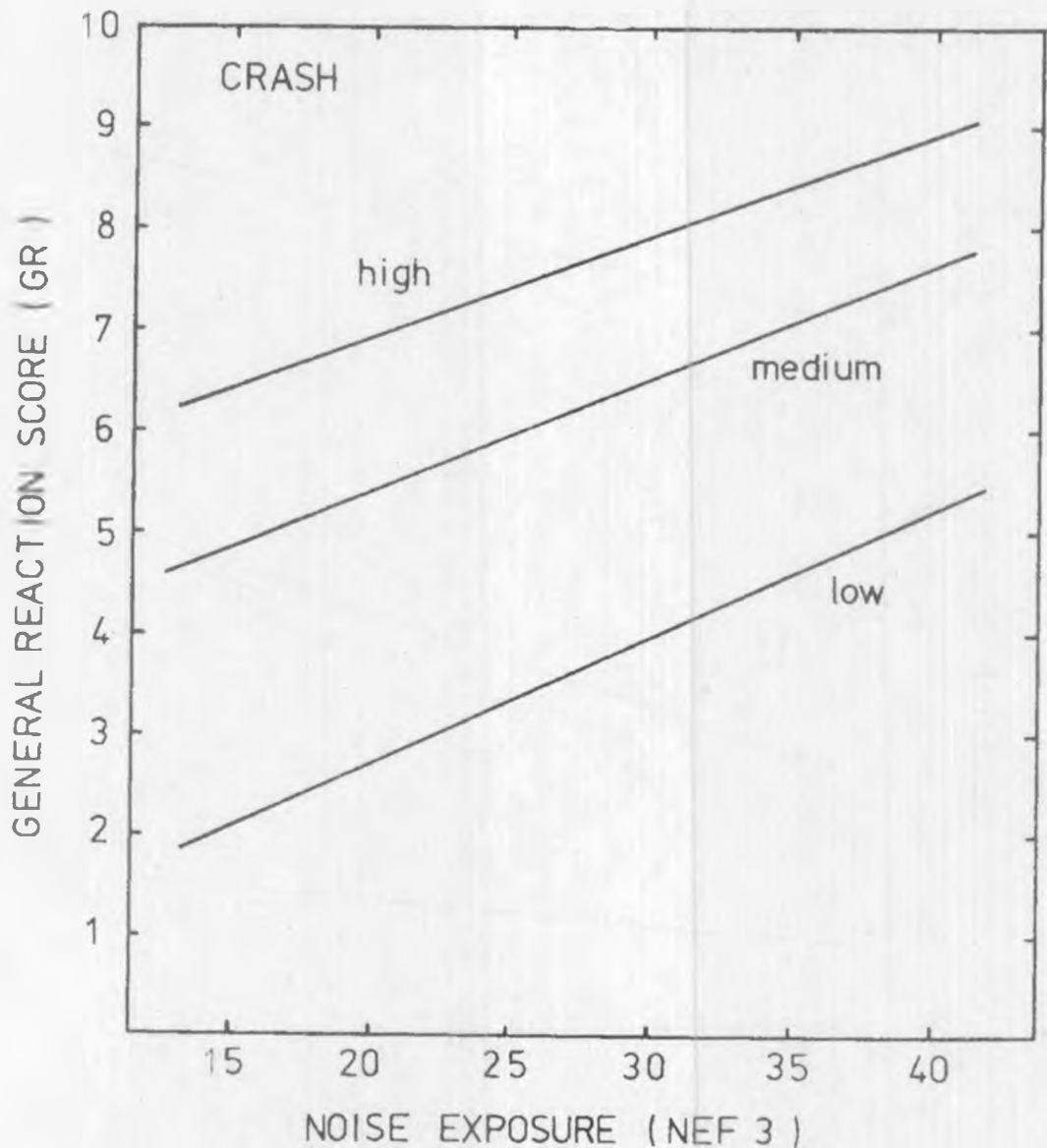


FIGURE 5.14 GENERAL REACTION SCORE AS A FUNCTION OF EXPOSURE TO AIRCRAFT NOISE (NEF3) FOR RESPONDENTS WITH HIGH (AT LEAST 8), MEDIUM (FROM 4 TO 8), OR LOW (LESS THAN 4) SCORES ON A SCALE ASSESSING FEAR OF AN AIRCRAFT CRASHING (CRASH)

Source: Hede and Bullen, 1982a.

Several studies reported since Job's (1988a) and Fields' (1993b) reviews were written, have supported an influence of awareness of non-noise impacts of the noise source on reaction to the noise (Dankittikul, Izumi, Yano, Kurosawa, and Yamashita, 1993; Lercher and Widmann, 1993; Ohrstrom, 1996; Sato, 1993; Kastka et al., 1996). For example, Yano et al. (1996b) report that vehicle exhaust increased annoyance with traffic noise

Evidence also suggests that noise reaction is negatively related to neighbourhood satisfaction (Aubree, 1973; Langdon, 1976; Jonah et al., 1981; Rohrmann, 1984; see also Fields, 1993b) and perhaps to the aesthetic appeal of the site (for evidence bearing on this issue see: Aubree, 1973; Langdon, 1976; Kastka and Hangartner, 1986; Sabadin, Suncic, Hrasovec, and Verhovnik, 1991; Dankittikul, et al., 1993). That is, individuals who are satisfied with their neighbourhood tend to react less to the noise (for example, in terms of annoyance). However, the causal sequence is not clear in this relationship. Furthermore, each of these variables may be related to a third variable but not to each other. For example, awareness of non-noise consequences of the noise source may promote dissatisfaction with the neighbourhood as well as potential reaction to the noise. The relationship between reaction and neighbourhood satisfaction may underlie the finding that for the same noise exposure, residents of large urban communities have more negative reactions to noise than residents of small towns (Bradley and Jonah, 1979), who in turn have higher annoyance than residents of rural areas (Vallet, Carrere, and Lacoste, 1983).

One ingenious way of examining whether attitude is a modifying variable (versus a part or a consequence of reaction) is to examine the nature of relationships between the variables. While the underlying causal sequences cannot be definitively determined from correlational data, informed commentary can be made. McKennell (1978) reported such analysis of the effects of a patriotic attitude on reaction to Concorde overflights in the U.K. Importantly, he found that patriotism was associated with reduced reaction to an equal extent regardless of noise exposure. This finding does not fit readily into claims that attitude is influenced by reaction or by noise exposure. Rather, the finding suggests that the attitude is a genuine modifying factor. The analysis of other data presented by Bullen et al. (1991) suggests that attitude may be, in part, influenced by noise exposure or reaction. This issue is not readily settled by available data. However, the balance of evidence suggests that, at least in some cases, and possibly to an incomplete extent, in all cases, attitude influences reaction.

Laboratory studies which manipulate attitude may also be employed to determine whether attitudes play a causal role in determining reaction. A recent laboratory study (Vera, Vila, and Godoy, 1995) support the causal role of attitude. All subjects were exposed to two 15 minute exposures of recorded traffic noise at 85-95 dBA, separated by a 10 minute recovery period. All subjects received statements designed to change attitudes toward the noise (for example, this noise is unnecessary", "what a horrible noise", "they should not make this noise", "I am not able to control this noise", "I can't stand it") during one exposure period, but not the other, with the order of "statement" versus "no statement" periods counterbalanced across subjects. Subjects were required to rate the aversiveness of the noise and the duration of the noise at the end of each exposure period. In both stimulation periods, the subjects who received negative statements rated the noise as more aversive than did the subjects who did not receive the statements. However, this difference was not significant. Further, the noise was rated as more aversive in the "statements" versus the "no statements" condition only for subjects who experienced the "no statements" condition first, reflecting the fact that the aversiveness of the noise appeared to increase substantially from the first to the second stimulation periods and/or that the effects of the

statements persisted. It may be the case that the statements directly affected mood and thus ratings, rather than actually affecting reactions to the noise. Finally, since subjects were to read statements during noise exposure, any increase in aversion in the "statements" condition may have been due to annoyance resulting from noise-induced disturbance of the reading task. A similar pattern of results was observed for the ratings of noise exposure duration.

The relationship of attitudes with reaction should not be interpreted as an indication that reaction is false or invalid. Rather, it indicates the unsurprising reality that one's attitude to noise exposure moderates the impact such exposure has in terms of reaction. It makes intuitive sense that someone who enjoys rock music is not going to be annoyed by it, whereas someone who dislikes rock and feels that it is not music at all, is likely to find it annoying. The latter group's annoyance should not be dismissed as invalid or irrelevant because others like rock and are not annoyed by it. Similarly, train enthusiasts may like train noise and some people may like aircraft noise or at least have positive attitudes toward the benefits of air transport. These positive attitudes do not render the dissatisfaction, annoyance and disturbance of others any less real. It is, however worth noting in this context that some types of sound are more likely to provoke negative attitudes than others, particularly those which are believed to have negative consequences.

#### *Noise Sensitivity and Other Personality Traits*

Noise sensitivity has also been found to influence reaction (for example, McKennell, 1963, 1973, 1980; TRACOR, 1971). Fields' (1993b) metaanalysis concluded that all 14 relevant studies which met the criteria for quality supported the hypothesis that a general sensitivity to noise increases annoyance. Job's (1988a) review of correlations between sensitivity and reaction, between sensitivity and noise and between reaction and noise suggests that there is a relationship between sensitivity and reaction which cannot be explained entirely by noise exposure, although the direction of causality in this relationship is ambiguous. The moderating influence of sensitivity on reaction is also supported by findings of studies conducted subsequent to these reviews (e.g. Stansfeld, 1992; Stansfeld, Gallacher, Babisch, and Elwood, 1993; Yano et al., 1996b).

As an example in the Australian setting, Hede and Bullen (1982a) reported a partial correlation coefficient of 0.246 between noise sensitivity and general reaction (see *Figure 5.15*). In another Australian study, Bullen et al. (1985) found that some items designed to assess sensitivity were associated with the reactions of Royal Australian Air Force personnel to aircraft noise in their working environment, without being associated with noise exposure. Sensitivity accounted for 7% of the variance in general reaction, as compared to 34% accounted for by noise exposure (Leq). Australian studies of other noise sources have also consistently identified the importance of noise sensitivity in reaction to power station noise (Job and Hede, 1989), artillery noise (Bullen et al., 1991), rifle range noise (Hede and Bullen, 1982b), and individual impulsive noises from distant explosions (Job, Peploe and Cook, 1995).

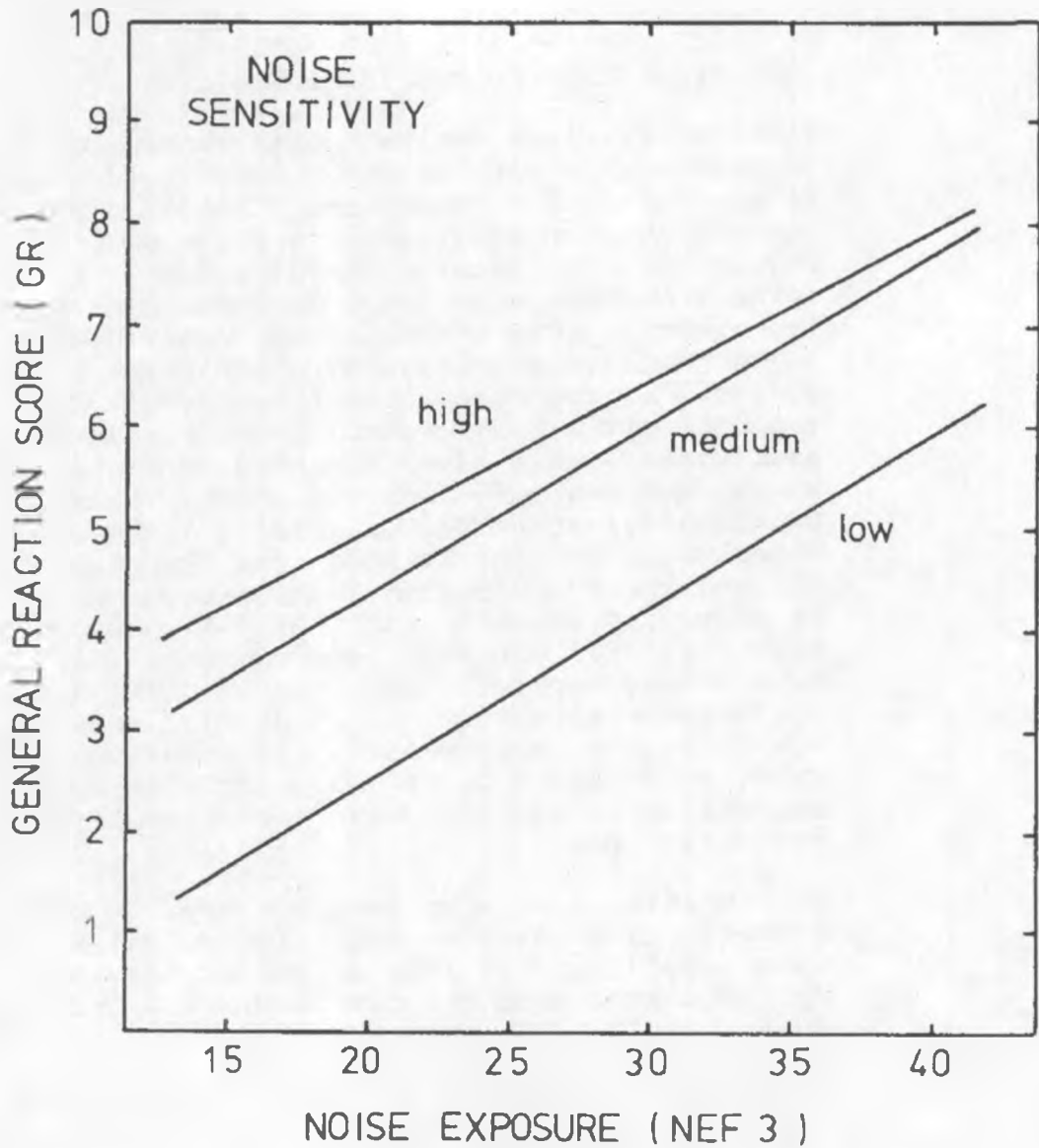


FIGURE 5.15 GENERAL REACTION SCORE AS A FUNCTION OF EXPOSURE TO AIRCRAFT NOISE (NEF3) FOR RESPONDENTS WITH HIGH (AT LEAST 8), MEDIUM (FROM 4 TO 8), OR LOW (LESS THAN 4) SCORES ON A SCALE ASSESSING NOISE SENSITIVITY

Source: Hede and Bullen, 1982a.

Inconsistent evidence has been found regarding the relationship between reaction to noise and other personality traits, including Type A/B profile (Moch, 1984; Nivison and Endresen, 1993), neuroticism/extroversion (Broadbent, 1972; Jonah et al., 1981; Jones and Davies, 1984; McLean and Tarnopolsky, 1977; Rohrmann, 1984; Stansfeld, 1992), negative affect (Job, 1993; Stansfeld, 1992; Stansfeld et al., 1993; Weinstein 1980), locus of control (Jones and Davies, 1984; Pulles et al., 1990; Rotter, 1966; Thomas and Jones, 1982; Van Kamp, 1990) and non-complaining attitude (Pulles et al., 1990). Perceived ability to predict, control or adapt to the noise also reduces reaction to it (Glass and Singer, 1972; Graeven, 1974; Rohrmann, 1984; Cohen and Spacapan, 1984).



*Age, Length of Residence, Gender, Socio-Economic Status*

Fields (1993b) concluded from a meta-analytic examination of the influence of nine potential demographic variables on annoyance with noise, that none of these variables had an important effect. Only 16% of the 19 relevant quality surveys supported the contention that older people are more annoyed by noise than younger people, whereas 53% of these surveys suggest that age has no effect on noise annoyance. Length of residence also appears to have no effect on reaction to noise, with only 4 out of 16 relevant studies suggesting that longer residency is associated with reaction, 8 suggesting no effect, and 4 suggesting the opposite effect. In the Australian context, Bullen et al. (1985) found no significant effect of age on reaction to military aircraft noise, whereas Hede and Bullen (1982a) found that older individuals had less negative reactions to civil aircraft noise, as well as less negative attitudes toward the noise source and lower fears of crashes. Another Australian study of reaction, to artillery noise, also found a small effect of age on reaction—again with older people reacting less although age only accounted for 2% of the variance in reaction (Bullen et al., 1991). The occupational sample of Bullen et al. (1985) is likely to have been more restricted in age range than that of Hede and Bullen (1982a) and Bullen et al. (1991), making detection of a correlation more difficult. Job et al. (1995) report that reaction to individual impulsive events in the home was influenced by age, however the age did not influence reaction to noise events at the time they were experienced and was hypothesised to exert its influence at the point of recall, integration and report.

Every one of 15 relevant, quality studies meta-analysed by Fields (1993b) indicated that gender has no effect on reaction to noise. In keeping with this finding neither Bullen et al. (1985) nor Hede and Bullen (1982a) found significant effects of gender on reaction to aircraft noise in the Australian context.

Fields' (1993b) meta-analysis also considered the moderating effects of a number of indicators of socio-economic status, including status ranking, income and education. For each of these indicators, more relevant quality studies suggested that these variables had no effect on reaction, than suggest they have an effect. High ranked status residents were found to be more annoyed than lower ranked status residents was supported by four out of 12 appropriate studies, whereas 8 studies demonstrated no effect. Income and annoyance were found to be positively related in 38%, but unrelated in 62%, of 8 appropriate studies. Higher education was associated with reaction in 23% of 13 relevant quality studies, but was not related with reaction in 77% of such studies. No studies revealed the opposite influence of any of these variables. In the Australian context, both Bullen et al. (1985) and Hede and Bullen (1982a) found no effect of socio-economic status on reaction to aircraft noise.

Similarly, Fields' (1993b) meta-analysis revealed no effect of home ownership or type of dwelling (see also Lercher and Widmann, 1993). These data undermine the assumptions that residents of multiple unit dwellings react less to exterior noise on account of their higher exposure to interior noise and that financial investment increases reaction to noise (Fields, 1993b). In fact, data regarding the relationship between reaction to noise



and concern for property devaluation due to noise are inconsistent (DeVany, 1976; Kryter, 1994; Taylor, Breston, and Hall, 1982).

#### 5.4.6 INDIRECT EFFECTS OF SOUND EXPOSURE ON ANNOYANCE

As well as immediate reaction to noise, adverse reactions may result from negative impacts of noise on health and performance.

It is possible that perceived deleterious effects of noise on auditory and non-auditory physical health could provoke a negative reaction to the noise.

The impact of noise-induced activity disturbance and performance deficits on reaction to noise has received considerable attention (Babisch et al., 1993; Borsky, 1980; Cohen and Weinstein, 1981; Gunn, 1987; Hall, Taylor, and Birnie, 1985; Lambert et al., 1984; Lindvall and Radford, 1973; McKennall, 1963, 1973). Amongst subjects exposed to simulated traffic noise at 85 dB LAeq in the laboratory, annoyance was associated with the perceived influence of noise on performance and performance efficiency (Arvidsson and Lindvall, 1978).

Similarly, annoyance has been found to be associated with interference with activities such as conversation, mental concentration, rest, or recreation (for example, in Australia: Hede and Bullen, 1982a, 1982b; Bullen et al., 1991; Job et al., 1991) and for some sounds the critical factor in determining reaction is whether they are perceived as intrusive (Berglund et al., 1990). Widmann (1996) examined the relationship of annoyance with the intelligibility of speech signals of several intensities amongst subjects simultaneously exposed to steady traffic noise at 64.5 dBA or 74 dBA. For each halving of the speech to noise ratio annoyance was found to increase linearly by 18.5% for traffic noise at 64.5 dBA, and by 13% for traffic noise at 74 dBA. However, the role of traffic noise level was confounded with noise variability, because the more intense traffic noise was also more variable. Further, the generalisability of data based on the intelligibility of a list of one syllable words to actual conversation, which has a context and potentially greater importance to the subject, is tenuous. Holmberg et al. (1996) found that the annoyance produced by noise in the workplace was greater for individuals performing tasks that involved verbal communication than those involved in other tasks (see also Ohrstrom and Skanberg, 1996). Gunn, Shigehisa, and Shepherd (1977) found that the maximum annoyance reduction to aircraft noise occurred when a given amount of energy was removed from octave bands in the frequency range 800-1,600 Hz. This noise is likely to have produced maximum masking of speech signals (Miller, 1947), and thus maximum disturbance of communication or television viewing. The importance of interference with television viewing in determining reaction to aircraft noise is widely accepted (Galloway and Bishop 1970).

The importance of sleep disturbance is suggested by the finding that annoyance during night time influences the total daily annoyance level (Lambert et al., 1984). However, Fidell et al. (1994) found no relation between overnight LAeq and reported annoyance due to aircraft noise in their field studies of aircraft noise and sleep. Yano et al. (1996b), however, found a relationship between sleep quality and annoyance with road traffic

noise. In a community study around Australian airports (Hede and Bullen, 1982a) respondents were asked which of a range of activity disturbances they would most like to eliminate. Only 19.1% of all respondents but 26.7% of seriously affected (defined in terms of general reaction) respondents nominated sleep disturbance. Amongst seriously affected respondents, sleep disturbances were regarded as worth eliminating more than any other disturbance. However, these data may underestimate the importance of sleep disturbance because many respondents in the Hede and Bullen (1982a) study were protected by the night time curfews which were operational at Sydney airport.

For aircraft noise, interference with rest/recreation/watching television is particularly critical to reaction. In contrast, for annoyance with road traffic noise sleep disturbance is a particularly critical activity disturbance (Berglund and Lindvall, 1995). The critical activity disturbance may differ for aircraft and traffic noise because of differences in the typical distribution of exposure for these noise sources.

Whilst, activity disturbance has been employed as an index of reaction to noise, each noise outcome may be influenced by other factors and high level of activity disturbance have been observed in the absence of high annoyance. Thus, indices of noise-induced activity interference may be best treated as a supplement to scales of general annoyance with the noise.

#### 5.4.7 COMMENTS FROM RECENT SYDNEY AIRPORT STUDIES

The *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) gave substantial consideration to community reaction to aircraft noise, and the *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) gave it somewhat less consideration.

Kinhill (1990) presented the dose-response relationship of Hede and Bullen (1982a), but did not refer to any other analyses or meta analyses which have examined the relationship between aircraft noise and reaction. It was suggested that outside the 20 ANEF contour noise is not a significant problem, in the 20-25 ANEF contour noise is a moderate problem and within the 25 ANEF contour noise begins to present more of a problem, in terms of the number of people who are likely to be "affected" by the noise (according to the criterion of Hede and Bullen, 1982a, which includes "dissatisfaction", "affectedness", "annoyance", complaint disposition, activity disturbance, fear of crashes and presence of symptoms). However, in using the dose-response curve to generate predictions, Kinhill (1990) did not explicitly recognise that reaction to a particular noise level tends to be higher when exposure has just increased to that level, than if exposure has been at that level for some time. However, reference was made to a US finding (citing Muldoon and Miller, 1989) that people object to increases of more than 5 dB Ldn in the noise exposure. (Note that the ANEF is a long term average metric, in which exposure data over many months would typically be used).

It was recognised in the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) that reaction

can be influenced by factors besides noise exposure. According to this study, demographic factors, such as age, sex and marital status, have been found to correlate only weakly with reaction (citing Bullen, 1984), but reaction has been found to be stronger in people who are afraid of an aircraft crash, concerned about potential health effects or who are suffering activity disturbances. Kinhill (1990) does not identify the potential importance of negative attitudes to the noise source, perceived uncontrollability of the noise or noise sensitivity, to mention a few of the reaction modifiers addressed in the present review. The potential of noise mitigation measures to contribute to negative reactions by disrupting people's lifestyles, for example by restricting their freedom to open windows, was suggested in the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990).

Kinhill (1990) reported that complaints received on a complaints hotline had increased since mid-1988, with 56% relating to aircraft loudness, 7% relating to noise outside curfew, 7% relating to noise and inconvenient times other than outside the curfew and 3% relating to vibration. It was also reported that home owners tended to complain more than non-home owners. *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) proposed that this might reflect concern about property values or commitment to the neighbourhood rather than a real difference in the reactions of these two groups to aircraft noise. However, as has been suggested in the present review, concern about property values or property damage due to vibration may partially mediate the impact of noise on reaction. Home-owners may actually react more negatively to aircraft noise because of concern about property value, although home ownership versus rental is not a substantial predictor of reaction. Furthermore, any real or apparent influence of home ownership on reaction is likely to be seriously confounded by the influence of factors such as age, socio-economic status, education, self-judged capacity to complain and evaluations of likely efficacy of complaint.

In an attitudinal survey reported in Kinhill (1990), residents of areas facing a potential increase in noise levels were more likely to be dissatisfied (11% of residents in such areas) with their neighbourhoods than residents of high noise areas (10%). Dissatisfaction was less likely in residents expecting a reduction in noise levels, or residents of low noise areas (both 6%). However, these findings are difficult to interpret because there was a 17% overlap in the high noise and "going high" noise groups. Additionally, no further information was given regarding the current noise levels in areas facing either an increase or reduction in noise levels. Because noise levels are time consuming and expensive to measure and compute (Carter et al., 1996b), this is not surprising. No information regarding the statistical significance of the differences is given, and it is unlikely that the difference between the dissatisfaction amongst residents of areas facing a potential increase in noise levels (11%) and amongst residents of high noise areas (10%) was significant. Aircraft noise was the reason most commonly given for dissatisfaction, being mentioned by 50% of the respondents who reported being dissatisfied. It was recognised that the impact of noise on health, sleep, speech and social well-being could result in residential dissatisfaction (Kinhill, 1990).

Residents in areas of potential noise increase were also least likely to be sure whether they would still be living in the same area in the next three years and most likely to report that they would consider moving. Residents in areas of potential noise decrease were most likely to be sure and least likely to consider moving (Kinhill, 1990). Again the statistical significance of these differences is not reported in the study. However, it is reported that current and potential noise exposure accounted for only 3% of responses regarding the likelihood of moving. Work-related factors were mentioned more frequently.

The *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) includes numerous submissions regarding reactions to the noise, and these submissions themselves can be viewed as a part of reaction. As previously discussed people complained of disturbances to activities including sleep, conversation, and recreational activities. The Committee heard reports of increased tension and argument in families and teachers reported increased irritability and aggression in children. People reported feeling frustrated and powerless to change the situation. The potential of such perceived lack of control to worsen the impact of aircraft noise has been discussed in the present review in the context of learned helplessness. The Committee seemed to confuse the issue of whether there is a significant risk of an aircraft crashing and whether people fear that there is. Whilst it was reported that residents in the vicinity of the airport have a real fear of an aircraft crashing, the potential impact of this on reaction was not identified.

The DEAF "studies" also considered reaction to the noise and found that complaints of tension/anxiety/annoyance were the second most common of all complaints received (Senate Select Committee on Aircraft Noise in Sydney, 1995). As previously identified, problems which are reported to the Committee and to DEAF may not be caused by aircraft noise. However, scientific studies suggest that such problems may be caused by aircraft noise and that the complaints themselves may indeed be a part of reaction to aircraft noise.

Submissions to the *Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) are in keeping with evidence that aircraft noise may affect residential behaviour and the like. For example, Goldberg submitted that there were reports from teachers of families moving out of noise affected areas and/or moving their children to schools that were not noise affected. Submissions also suggested that noise affected institutions, such as schools and hospitals, were having difficulty recruiting staff, however no experimental data were presented to substantiate these claims.

Key issues in the prediction of long-term reaction is the extent to which the various reactions can be predicted from contours of noise exposure and the extent to which this prediction may change depending on the development of demand for and design of aircraft. Thus, predictions are likely to differ for exposure made up of more, though quieter, overflights versus exposure resulting from moves to larger heavier aircraft, which may produce louder noises and a different spread of noise due to their flatter flight path. These

issues cannot readily be addressed without accurate prediction of future aviation patterns.

## **5.5 IMPACT OF NOISE ON PSYCHOLOGICAL HEALTH**

It has been hypothesised that if noise causes annoyance and frustration, prolonged noise exposure might either cause or exacerbate mental illness (Cohen and Weinstein, 1982; Cohen et al., 1986; Evans and Cohen, 1987; Herridge and Chir, 1972). A recent review by Stansfeld (1992) produced a similar conclusion to earlier reviews (see for example McLean and Tarnopolsky, 1977): "noise exposure may lead to minor emotional symptoms, but the evidence of elevated levels of aircraft noise leading to psychiatric hospital admissions and psychiatric disorder in the community is contradictory". Noise level is related to annoyance, which in turn is related to psychiatric disorder.

### **5.5.1 METHODOLOGICAL CONCERNS WITH RELEVANT STUDIES**

Studies of the impact of noise on mental health have been plagued by a number of difficulties:

- any theoretical considerations are restricted to post hoc explanations, and this may be selectively explaining results after the event;
- no clear distinction is made between causation versus aggravation of mental illness;
- the concept of mental illness is not clearly defined, resulting in confusion with other health effects, such as irritability;
- a wide range of psychiatric variables are used, varying in specificity, place of contact with medical agencies, and use of psychotropic medicine;
- assessment of "casinos" has relied on the use of symptom checklists (self-report or psychiatrist) (for example, Tarnopolsky, Barker, Wiggins, and McLean, 1978), admissions to hospitals (Abey-Wickrama, A'Brook, Gattoni, and Herridge, 1969; Åhrlin and Ohrström, 1978; Gattoni and Tarnopolsky, 1973; Herridge and Chir, 1972; Jenkins, Tarnopolsky, and Hand, 1981; Kryter, 1990; McLean and Tarnopolsky, 1977; Meecham and Smith, 1977; Tarnopolsky et al., 1978; Tarnopolsky et al., 1980; Watkins et al., 1981), and use of medication (for example, Watkins et al., 1981). Each of these approaches have specific problems and all may result in only severe mental cases being given consideration. Further, the data collected using these methods are often retrospective raising concerns with accuracy of recall, although not a problem where hospital records are used; and
- many community studies of mental health effects of noise exposure have given inadequate consideration to the influence of confounding variables such as "noise sensitivity" and socio-economic status. For example, Stansfeld (1992) reported evidence suggesting a direct relationship between sensitivity and mental health, independent of noise

exposure (see also Stansfeld, Clark, Jenkins, and Tarnopolsky, 1985). Socio-economic status may influence private treatment versus hospitalisation and thus entry into public records. This would tend to underestimate hospital admissions in higher socio-economic, often lower noise, areas. Social support may influence admission. Gender and mental problems may influence socio-economic status and social support.

### 5.5.2 THE IMPACT OF NOISE ON PSYCHOLOGICAL HEALTH

A simple relationship between aircraft noise and psychiatric morbidity is yet to be detected, however there is evidence that some relationship exists.

In an early study of the records of 124,000 residents in the vicinity of London Heathrow airport (Abey-Wickrama et al., 1969), a higher rate of admissions to mental hospitals was detected in high than in low noise areas. However, the study design was questioned by other researchers (Chown, 1970) and the result could not be replicated in a later study with suitable controls for demographic factors such as age and gender (Gattoni and Tarnopolski, 1973). Further studies have found mental hospital admissions to be related to level of aircraft noise (Herridge and Chir, 1972: 31% more hospital admissions in high noise areas) and residence in noisy areas (Meecham and Smith, 1977: 29% more hospital admissions in high noise areas), but the effects of potential confounding variables were not accounted for and disconfirming studies are also available (for example, Tarnopolsky et al., 1980). Jenkins et al. (1981) studied 9000 admissions to three hospitals over 4 years to conclude that while admission rate correlated with noise exposure it was more closely related to non-noise factors. Reanalysis of these data, adjusting for unemployment and the percentage of people in rental accommodation (Kryter, 1985, 1990), produced a significant positive correlation between aircraft noise exposure and admission rate at two of the three psychiatric hospitals examined. Aircraft noise exposure above 58 Ldn was found to be predictive of an increase in psychiatric hospital admissions, with an increase to 70 Ldn being associated with a 40% increase in admissions.

Studies which have employed symptom checklists to determine "casinos" suggest that the relationship of noise exposure to psychiatric morbidity is an indirect one, via annoyance. Grandjean (1974a, 1974b) found no correlation between symptoms and exposure. Similarly, Tarnopolski et al. (1978), using the General Health Questionnaire (which assesses anxiety, personality disorder, and depressive, phobic, obsessional and other neuroses) corroborated by psychiatrists' diagnoses, also found no overall difference between the incidence of mental symptoms in 100 Ss living near Heathrow airport and 100 living in a quieter area (with road traffic noise controlled). However, mental symptoms were more prevalent in subjects who reported a greater annoyance with noise, and annoyance was related to noise levels as well as noise sensitivity (see also Tarnopolski and Morton-Williams, 1980). Knipschild (1976) found a high proportion of psychological and psychosomatic complaints in a high aircraft noise area. Van Kamp (1990) found no significant association between aircraft or traffic noise stratum and depression or social anxiety.

Evidence of higher consumption of tranquilisers and sleeping pills in high noise areas has been regarded as an indication of latent disease or mental disturbance in noise-exposed communities. In keeping with the view that annoyance mediates the relationship between noise exposure and mental health, Watkins et al. (1981) found increased use of psychotropic drugs by people who reported that they are highly annoyed by noise, in the absence of a relationship between medication use and noise exposure.

Preliminary data from a prospective traffic noise study parallels the findings regarding aircraft noise. Whilst no association was observed between noise level at baseline and later development of psychiatric disorder, noise sensitivity was found to be strongly related to psychiatric symptoms (Stansfeld et al., 1993). In a cross-sectional community study Relster (1975) found that there were more consultations for psychological problems in areas with high levels of road traffic noise compared to areas with lower levels. In a laboratory study, exposure to 90 dBA traffic noise produced significant increases in anxiety (as measured by the STAI-A-State Anxiety questionnaire) when presented both when subjects were or were not performing a calculation task, performance of which alone did not increase anxiety (Iwamoto et al., 1995).

Occupational studies have demonstrated an association between noise exposure and development of neurosis and irritability (Evans, 1982; Cohen et al., 1986). However, again confounding factors abound.

### 5.5.3 MODERATORS

It has been proposed that sensitivity, a relatively stable trait, might moderate (or mediate) any deleterious effects of noise exposure on mental health, possibly by increasing annoyance with noise. The relationships among noise annoyance, noise sensitivity and psychiatric illness have been found to be complex and not yet well differentiated (Stansfeld, 1988, 1992; Stansfeld et al., 1985; Tarnopolsky et al., 1980a, 1980b). Tarnopolsky et al. (1978) report a marked association between annoyance by aircraft noise and current psychiatric symptoms, and found noise sensitivity to be a powerful predictor of noise annoyance. They conclude that sensitivity to noise is a predisposing factor for psychiatric morbidity. The only prospective study of noise sensitivity and psychiatric disorder confirms this conclusion; noise sensitivity was found to be strongly related to psychiatric symptoms (Stansfeld et al., 1993).

Evidence regarding the role of sensitivity is not unambiguous. Noise sensitive subjects have been found to have more psychiatric symptoms, higher neuroticism scores and greater reactivity to other sensory stimuli, than subjects who are not noise sensitive (Stansfeld et al., 1985). It has thus been proposed that noise sensitivity may be a self-perceived indicator of vulnerability to stressors in general and may also be indirectly measuring a subclinical level of psychological morbidity (Berglund and Lindvall, 1995). Noise sensitivity may not indicate susceptibility to noise-induced mental illness, but rather the presence of mental illness (which may be exacerbated by noise exposure). Consistently with this hypothesis, the effect of noise sensitivity on psychiatric disorder was virtually eliminated when a measure of trait anxiety was included in the analysis (Stansfeld et al., 1993).



There are other potential modifiers of the noise-mental illness relationship. For example, people with low social support are perhaps more likely to be hospitalised for noise-related mental problems (Berglund and Lindvall, 1995).

#### 5.5.4 INDIRECT EFFECTS OF NOISE ON PSYCHOLOGICAL HEALTH

Noise-induced sleep disturbance may contribute to noise-related mental illness, since sleep is thought to be a prerequisite for good mental health (Hobson, 1989). Indeed, there is evidence that noise disturbed sleep can have deleterious long-term effects on psychosocial health and wellbeing. Ohrström (1991) found worse self-reported depression amongst individuals living in apartments facing a noisy street. Depression was found to be significantly related to sleep quality and reported noise annoyance (see also Ohrström, 1989). Various psychosocial symptoms, including feeling "very tired", "anxious/nervous", and "of wanting to be left alone", were more frequent in a noisy (72 dB LAeq) than in a quiet (52 dB LAeq) area. It was proposed that these symptoms may be linked to noise-induced sleep disturbances, but not to daily activity disturbances (see Berglund and Lindvall, 1995).

Noise-related illness may also be caused or aggravated by noise interference with speech intelligibility. Disturbances of speech communication have been associated with problems with concentration, fatigue, uncertainty and lack of self-confidence, irritation, misunderstandings, decreased working capacity, problems in human relations, and a number of reactions to stress (Berglund and Lindvall, 1995).

Noise may have a negative impact on mental health as a result of "learned helplessness". Exposure to aircraft noise is largely uncontrollable, except insofar as individuals can reduce the impact of the noise slightly by moving to a quieter room or closing doors and windows. Exposure to uncontrollable noise has often been found to produce learned helplessness in humans in the laboratory (for example, Hiroto and Seligman, 1975). Learned helplessness has been proposed, with considerable evidence, as an account of human depression (see Job and Barnes, 1995; Overmier and Helhammer, 1988; Seligman, 1975; 1991). Thus, observed relationships between noise exposure and depression (Ohrstrom, 1989; Stansfeld, 1992; Tarnopolsky et al., 1980) are not surprising.

It has been proposed that annoyance with noise represents a point on a continuum, the end of which is marked by mental illness. It has also been suggested that repeated or continue annoyance could mediate a negative impact of noise on mental health (see Berglund and Lindvall, 1995; Stansfeld, 1992). Ohrstrom (1993a) reported an association between noise annoyance and psychosocial well-being, although the relationship may reflect noise-induced sleep disturbance.

#### 5.5.5 COMMENTS FROM RECENT SYDNEY AIRPORT STUDIES

Kinhill (1990) discussed the effect of exposure to aircraft noise on mental health only in the context of admissions to both general and psychiatric



hospitals. Two of the studies cited considered mental hospital admissions (Abey-Wickrama et al., 1969; Meecham and Smith, 1977), however these were appropriately criticised for failure to account for confounding variables. The epidemiological study performed for the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) (Taylor and Lyle, 1990) also did not distinguish between general and psychiatric hospital admissions, probably for logistic reasons. Thus, it is not clear to what extent the finding that there were no consistent associations between admissions and noise levels applies to psychiatric admissions in particular.

The *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) comments on the Taylor and Lyle (1990) study but did not identify the failure to distinguish between mental and general health. The Committee mentioned two studies at Heathrow which showed a correlation between noise level and hospitalisation rates (Herridge and Chir, 1972; Meecham and Smith, 1977), without identifying the shortcomings of these studies such as the failure to control for confounding variables. However, Kryter's (1990) reanalysis of data collected around Heathrow in 1981, which controlled for confounding variables, demonstrated "statistically significant associations between psychiatric hospital admission rates and the level of exposure to aircraft noise" (Senate Select Committee on Aircraft Noise in Sydney, 1995, p150). In a submission to the Committee, Dr Soames Job commended Kryter's (1990) reanalysis and suggested that the weight of the evidence supported an effect of aircraft noise exposure on mental health. In its submission the Australian Medical Association also referred to the Kryter study, as well as to the findings of Stansfeld (1992) that subjects who are highly noise sensitive exhibit significantly more psychiatric symptoms. It was not identified that Stansfeld concluded there was no direct relationship of noise exposure with psychiatric symptoms, but rather that noise exposure was associated with annoyance, which in turn was related to psychiatric symptoms.

The DEAF "studies" found complaints of symptoms which could reflect mild depression. According to the submission of one psychotherapist, several new patients had been seen since the opening of the third runway, some of them suicidal. However, such reports are scientifically meaningless in the absence of baseline measurements to indicate the number of new (and suicidal) patients that could have been expected in the absence of the third runway opening.

## 5.6 ADAPTATION/HABITUATION TO NOISE EXPOSURE

Adaptation refers to a temporarily reduced sensory responsiveness with stimulus exposure. Habituation refers to a reduced response to the sensory input detected. Whether or not people habituate to noise remains a contentious issue (see Weinstein, 1982; Raw and Griffiths, 199). However, failure to observe habituation of reactions to noise in community studies may indicate that these studies were conducted after subjects had already adapted to noise exposure. Responses reported in community studies may be lower than initial responses, rather than accurately reflecting initial responses which could then be expected to habituate. Thus, it should not be expected

that the impacts of aircraft noise exposure some time following commencement of aircraft operations in a particular area will be lower than those suggested by the present literature review.

Available evidence suggests that some responses to community noise habituate whereas others do not. For example, habituation has been observed in the orienting response (Berglund and Lindvall, 1995), the fight/flight and stress responses for fluctuating noise (for example, Meyer-Falke et al., 1995; Vallet et al., 1983a, 1983b), peripheral vasoconstriction under some conditions (Ginsberg and Furedy, 1974; Jansen, 1969; but see Fruhstorfer and Hensel, 1980), and several indicators of sleep disturbance (body movements within each night and probability of awakening: Berglund and Lindvall, 1995). In contrast minimal habituation has been observed for body movements across nights (Ohrström, 1989; see also Ohrström, 1993c), shifts towards earlier sleep stages (Berglund and Lindvall, 1995), the cardiac response during sleep (Muzet and Ehrhart, 1978) and reaction to noise (dissatisfaction, annoyance etc.) (Griffiths and Raw, 1989; Weinstein, 1982). However, the perceived loudness of a continuous sound has been found to decrease with exposure time (Miskiewicz, Hellmann, and Scharf, 1995; for an earlier review see Scharf, 1991), with sensory adaptation being greater for low frequency sounds.

Generally, the claim that humans do not habituate to noise is based on the failure to observe a reduction in self-reported annoyance to noise over extended periods after a change in exposure (Griffiths and Raw, 1989; Weinstein, 1982). On the other hand, human laboratory studies show reductions in response to noise relatively early in the exposures (for example, Miskiewicz et al., 1995; Scharf, 1991; Vallet et al., 1983a, 1983b). For example, loudness adaptation has been found to occur within 3-6 minutes in the laboratory (Scharf, 1991). Since community studies have not examined responses following a change in noise within a time interval commensurate with those used in laboratory studies, it is possible that habituation had already occurred before the community studies were conducted. Thus studies of long-existing noise exposure should be viewed as studies of reaction after any adaptation or habituation.

Goldberg (1996) criticised the Draft EIS for presenting data from studies which have examined the effects of noise in areas with long-term noise exposure without considering adaptation, such that these data would underestimate the impacts which could be expected immediately following a change to noise exposure. There are several points to make in relation to this objection. Firstly, few studies of the impacts of noise in newly exposed areas are available, although this problem could perhaps have been made more explicit in the Draft EIS. This issue has been addressed in the present review. Secondly, evidence regarding habituation and adaptation is also scant. Available evidence suggests that habituation may not occur for all noise effects. Thirdly, post-habituation data is appropriate for predicting the impacts of noise some time after an increase in exposure levels, even if they underestimate immediate effects. The present review provides available data regarding the impact of noise in newly exposed areas, and recognises that even these data may reflect post-habituation/adaptation impacts. Evidence for adaptation and habituation themselves have also been considered.

## **5.7 COMBINED EFFECTS OF AIRCRAFT NOISE AND OTHER STRESSORS**

Exposure to aircraft noise seldom occurs in isolation and thus it is important to consider whether its impacts interact with other stressors, such that the impact of the noise and/or the other stressors is moderated (potentiated or ameliorated). Aircraft noise exposure is often associated with noise from other sources, such as ground transport or industry. Air pollution, especially from aircraft and road traffic exhausts, is also commonly experienced in conjunction with aircraft noise.

Research into the interactive effects of noise and other stressors has been insufficient to justify firm conclusions for any particular outcome. However, evidence supports the hypothesis that noise-induced hearing losses are exacerbated by combined exposure with ototoxic agents, including the asphyxiant carbon monoxide, which is present in road traffic exhaust fumes. Furthermore, combined exposure to aircraft noise and noise from other sources may potentiate hearing loss, sleep disturbance, and negative reaction. However, the manner in which noises interact to produce these outcomes is complex and not yet fully understood.

Many of the data presented in this review regarding the impacts of aircraft noise on health, performance and reaction have been gleaned in community studies, in which combined exposures occur naturally. Thus, these data provide a valid indication of the effects of aircraft noise which might be expected in a real world situation.

## 6

## VULNERABLE GROUPS AND LAND USES

## 6.1 SUMMARY OF VULNERABLE GROUPS

Inadequate research attention has been given to factors which moderate (ameliorate or potentate) the risk of negative consequences of noise exposure on health, performance and reaction. Where such data are available, its meaning is often ambiguous due to its correlational nature. Nonetheless, consideration of the existing evidence is worthwhile in terms of targeting noise mitigation measures toward critical groups, designing interventions to reduce their risks, or, if the opportunity arises, siting noise sources to avoid vulnerable groups. Both features of the noise and of the exposed individual moderate the impacts of the noise, but person factors will be the focus of the following section, since the features of aircraft noise are regarded as a given (but see earlier comments on changing aircraft fleets).

Vulnerable groups have been identified for a range of potential outcomes of aircraft noise. However, a non-specific vulnerability has been hypothesised for "people with reduced adaptability or reserve capacity such as the sick, the aged, people with impaired sleeping functions or those who are subject to other environmental strains" (Berglund and Lindvall, 1995, p140).

## 6.1.1 AUDITORY HEALTH

*Aural Discomfort and Pain*

Noise levels typically encountered in residential areas around airports are unlikely to cause aural pain in people with normal hearing. However, people with sensorineural hearing damage (possibly noise-induced) and/or hearing aid users could well experience pain at these levels. Some discomfort may be experienced regardless of hearing ability.

Noise-sensitivity also increases the likelihood of experiencing discomfort and pain.

*Hearing Loss*

The probability of suffering permanent hearing losses as a result of exposure to aircraft noise is increased amongst groups who are frequently exposed to high levels of non-aircraft noise, because this reduces the possibility of recovery between noise events. For example, individuals who work in noisy industries are more likely to suffer hearing losses due to aircraft noise. Exposure to aircraft noise increases the probability that their occupational exposure will have adverse effects on hearing.

Individuals who are simultaneously exposed to ototoxic agents either in the home or in occupational settings, are more likely to suffer noise-induced hearing losses than those who are not. A number of drugs which are ototoxic on their own have been found to potentate the effects of noise on hearing, including the aminoglycoside antibiotics and cis-platin. No

evidence is available regarding the effects of loop diuretics and available evidence regarding the effects of aspirin is inconsistent. However, it seems that chronic high doses of aspirin probably potentate the effects of noise. Asphyxiants, organic solvents, and metals, which are common in occupational settings are ototoxic on their own and potentate the effects of noise on hearing. Organic solvents are often encountered in the home (for example, glue, paint). Thus, people exposed to these chemicals in the workplace or as a result of pollution or smoking are at increased risk for noise-induced hearing loss. Residents of areas with a lot of road traffic are at particular risk because of the carbon monoxide and lead content in the air.

Risk of noise-induced hearing might also be increased in individuals with pathological changes to the middle ear or latent vitamin b deficiency.

Evidence that older individuals are more likely to suffer aircraft-noise-induced hearing losses is inconsistent. Some studies have not supported this contention while others suggest a synergistic effect of age and exposure. Males and females are equally likely to suffer noise-induced hearing losses. However, the risk is increased among people with lower socio-economic status.

### **6.1.2 NON-AUDITORY PHYSIOLOGICAL HEALTH**

#### *Balance*

Exposure to aircraft noise is most likely to upset balance in individuals who have unequal stimulation to the two sides of their vestibular systems (for example, people who have suffered unilateral deafferentation).

#### *Startle Reflex and Orienting Response*

Aircraft noise is more likely to cause startle in individuals who regard it as a signal for danger. Sonic booms also produce startle.

#### *Cardiovascular Health*

Both acute and chronic noise-induced effects on cardiovascular function are increased for people with additional exposure to non-aircraft noise. Thus, workers in noisy industries are at increased risk for cardiovascular problems.

Acute and chronic elevations of blood pressure are more likely amongst females and individuals with a family history of hypertension.

Noise-induced effects on cardiovascular health are also more likely amongst individuals who perceive aircraft noise to be uncontrollable or to be a signal for danger.

#### *Perinatal Health*

Data regarding the only researched potential moderating variable of the influence of aircraft noise exposure on perinatal health, sex, are inconsistent. One study revealed that the observed differences in birth weights between high and low areas mostly reflect differences amongst girls. However, a

much larger study found that the differences in birth weight were more often among boys.

### *General Health*

Individuals who regard the noise as uncontrollable may be more likely to be effected by the immunosuppressive effects of learned helplessness.

Noise sensitive individuals are also more likely to suffer noise-induced reductions in general health status.

## **6.1.3 PERFORMANCE AND ACTIVITY**

### *Sleep Disturbance*

It has been proposed that shift workers might be more at risk of aircraft-noise-induced sleep disturbances than the general population, because they sleep during the day, when there are more aircraft noise events and sleep tends to be lighter. However, data are insufficient to identify whether shift workers are at increased risk of noise-induced sleep disturbance over and above their exposure to noise when they are trying to sleep during the day. The possibility that shift workers suffer particularly from noise-induced sleep disturbances is also inadequate to abandon a curfew. Firstly, available data do not address the issue of whether the sleep of shift-workers during the day would be markedly improved by slightly reducing the intensity or number of noise events during the day. Secondly, it is not yet known whether any such improvement would be undermined by potentially increased disturbance during the nights when these workers are not on shift as a result of increased nighttime noise.

The influence of age on noise-induced sleep disturbances, depends on the nature of the disturbance. The probability of EEG responses and awakening as a result of noise increases with age. In contrast, children are more likely than adults to demonstrate a heart rate response for a given sound pressure level.

Women are probably more sensitive to noise-induced sleep disturbance than men.

Psychological variables can also influence the effect of noise on sleep. Evidence suggests that neuroticism and noise sensitivity may increase susceptibility to sleep disturbance. The one third of the population who are most noise sensitive are more likely to demonstrate a noise-induced reduction in subjective sleep quality.

### *Impairment of Voice Communication*

Noise-induced impairment of speech intelligibility may be particularly prevalent amongst certain groups; including the hearing impaired, the elderly, young children and people for whom the language being spoken is not their first.

There is a more pronounced masking effect of noise on speech discrimination for hearing impaired individuals, who often experience a loss of frequency resolution. Individuals who are not familiar with the spoken language, such as children in the process of language acquisition and second-language persons, may experience an exaggerated reduction of speech intelligibility due to noise. For these groups, a 5 to 10 dB larger signal-to-noise ratio is needed for acceptable speech intelligibility. In aircraft noise exposed areas, typically this may require an increased vocal effort which may strain the voice.

### *Interference with Tasks*

The impact of noise on task performance differs markedly for different groups. Noise may improve the performance of people who are tired (low arousal) because of sleep deprivation and/or strain, by raising their arousal to a more optimal level. In contrast, noise has been found to impair cognition and reading in children, especially those in higher school years.

Noise-sensitivity also increases the probability that noise exposure will interfere with task performance, and reduce productivity.

## **6.1.4 REACTION TO NOISE EXPOSURE**

Since reaction is to noise, noise is a major determinant of reaction. Around major airports a majority of the population will perceive noise as disturbing daily activities. Nonetheless, large individual variation in reaction exists.

The likelihood of a negative reaction to aircraft noise is increased by a number of psychological factors. Thus, people who have negative attitude to aircraft noise or its source (aircraft, the airport, airport authorities) are more likely to be annoyed or dissatisfied by it. The belief that vibration due to aircraft noise causes structural damage to the home is also relevant here. Similarly, individuals who are fearful of the health and/or safety impacts of aircraft noise and its source are more likely to react negatively to it. For example, someone who believes that aircraft noise adversely affects their health, or that an aircraft might crash on their home are more likely to find it disturbing.

Noise-sensitive individuals have been found to react more negatively to aircraft noise than those who are not noise-sensitive. Evidence pertaining to the relationship between reaction to noise and other personality traits, including Type A/B profile, neuroticism/extraversion, negative affect, locus of control and non-complaining attitude is less consistent. Perceived inability to predict, control or adapt to the noise also increases the risk of negative reaction to it.

Australian data suggest that older individuals are less likely than younger individuals to report negative reactions to the noise, although the effect of age is small. However, this may reflect differences in recall and reporting rather than a difference in reaction itself. There appears to be no effect of gender or socio-economic status on reaction to noise.

### 6.1.5 PSYCHOLOGICAL HEALTH

Psychological factors which have been associated with increased potential for deleterious effects of noise on mental health include, high trait neuroticism, or anxiety. Individuals with latent mental illness, are also more likely to demonstrate psychiatric morbidity as a result of exposure to noise.

Noise-sensitivity has also been found to be a risk factor for noise-induced psychiatric morbidity, possibly because it indicates a latent potential for mental illness.

Individuals who perceive the noise as uncontrollable are at increased risk of "learned helplessness" and depression.

Females are more likely than males to suffer depression and other psychiatric illnesses (for example, see Seligman, 1991). It is not yet known whether noise exposure interacts with this effect.

### 6.1.6 COMMENTS FROM RECENT SYDNEY AIRPORT STUDIES

Both the *Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) and the *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) isolated a number of groups as potentially vulnerable to the negative impact of aircraft noise. However, selection of these groups was based largely on intuition, rather than close examination of the potential impacts of aircraft noise, and the groups which have been found to be particularly vulnerable to them. Further, neither Kinhill (1990) nor the *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) distinguish clearly between vulnerability to a particular direct impact of aircraft noise and vulnerability to the consequences of such an impact.

Kinhill (1990) identifies young children, people with a poor command of English, shift workers, the elderly, the sick, and people who are at home a lot during the day as groups who are particularly vulnerable to the effects of noise.

The vulnerability of children was discussed mainly in terms of impaired speech intelligibility and consequent retardation of learning. Students are also identified as being vulnerable to noise-induced disturbance of educational activity. It must be explicitly recognised, however, that children are particularly vulnerable not just in virtue of engaging in educational activity, but because they require a stronger signal to noise ratio in order to achieve the same speech intelligibility as young adults. It was also reported that children have been shown to suffer noise-induced elevations in blood pressure. However, available data does not indicate that children are any more prone to this effect of noise exposure than adults, although it is conceivable that experience of this effect from a young age may result in serious problems later in life. It was argued that children seem somewhat immune to noise-induced hearing loss. However, failure to find hearing losses in children following noise exposure does not indicate that exposure has not had a negative impact. Exposure to aircraft noise may speed the



processes of presbycusis and socioacusis, but not be detectable as an immediate change in hearing acuity.

People with poor command of the English language were also presented as being more vulnerable than average to noise-induced speech disturbance (Kinhill, 1990). It was further hypothesised that this group and people of lower socio-economic status are more likely to be frustrated in any effort to overcome the problems potentially associated with aircraft noise exposure. However, overall socio-acoustic surveys have not supported a relationship between socio-economic status and reaction.

Shift-workers are identified as being particularly at risk of noise-induced sleep disturbance when they try to sleep during the day (Kinhill, 1990). No evidence is reported which resolves whether their increased risk is simply due to sleeping during non-curfew hours or whether their sleep is more easily disturbed, for example due to disruption of circadian rhythms.

Elderly people were presented as being at increased risk of noise-induced sleep disturbance, which may equate to greater susceptibility to negative health outcomes (Kinhill, 1990). It was also proposed that elderly people with impaired hearing may be especially prone to aural pain. However, it is hearing impairment rather than age which is central to this effect.

Patients of hospitals and nursing homes were considered to be at increased risk of noise-induced sleep disturbance (Kinhill, 1990). However, the point seems to be not that they are more likely to have sleep disrupted but that disruption is more likely to adversely effect health, due to the importance of sleep to recuperation.

Residents of noise affected areas who spend most of their day at home were also regarded as being more likely to suffer negative impacts of aircraft noise, presumably because of increased noise exposure (Kinhill, 1990). However, this claim would seem to rely on the assumption that individuals who are not at home are in an environment which is exposed to lower levels of aircraft noise. It not clear that this will be uniformly true. Further, available data suggests that the number of hours spent at home is not related to reaction. It is not yet known whether this is true of other noise outcomes.

The *Report of the Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) gives only limited consideration to vulnerable groups. Sleep loss was thought to be particularly problematic to children and the sick, again not because of these groups being more prone to disturbance but because of their being more likely to suffer negative consequences of it. The elderly were regarded as being particularly at risk of confusion and anxiety due to exposure throughout the day. This claim again depends on the unjustified assumption that people away from home have a lesser exposure to aircraft noise, as well as perhaps the assumption that elderly people are particularly liable to experience anxiety due to the noise. Some data in fact suggests that elderly react less to aircraft noise (for example, Hede and Bullen, 1982a), while meta-analysis indicates no relationship between age and reaction to noise (Fields, 1992a). The possibility that the sick are more adversely affected would require more careful investigation than it has received to date.

## 6.2 SENSITIVE LAND USES AND RECOMMENDED SOUND PARAMETERS

It is possible to specify sound parameters to minimise the likelihood of several potential outcomes of noise exposure. Unfortunately, available data are insufficient to provide such guidelines for all potential outcomes.

Different guidelines have been adopted by various authorities, and may not all be relevant to Australian conditions.

The following section provides guidelines for outcomes where relevant data are available, largely in terms of sound parameters. It is, however, critical to recognise that the impacts of noise are moderated by a wide range of non-acoustic variables.

In particular, health effects are often more closely related to reactions, such as annoyance, rather than noise exposure (for example, Hede and Bullen, 1982a; Graeven, 1974; Lercher, 1996; Neus et al., 1983; Nivison and Endresen, 1993; Otten et al., 1990; Stansfeld, 1992). The causal sequence in such relationships has not been clearly identified but is consistent with the view that health effects are caused by reaction, not noise exposure per se. This fact, combined with potential overreaction to the change in noise, raises the possibility that any health effects of the proposed Second Sydney Airport will be greater than might be predicted on the basis of data regarding unchanged aircraft noise exposure.

### 6.2.1 AUDITORY HEALTH

#### *Aural Discomfort and Pain*

Aural discomfort is experienced at sound pressure levels above 100-110 dB and acute pain begins at sound pressure levels above approximately 130 dB. However, lower levels than these are recommended to avoid discomfort and pain in among sensitive individuals, including the hearing impaired.

#### *Tissue Damage*

There is a risk of rupture of the tympanic membrane at sound pressure levels in excess of 130-140 dBA, regardless of sound duration.

#### *Hearing Loss (Impairment)*

On the basis of studies of workers continually exposed to noise during their working day it has been concluded that risk is negligible at noise exposure levels lower than 75 dB LAeq, 8h, but increases with increasing levels. Thus, risk should also be negligible with a four hour exposure to 78 dBA, a two hour exposure to 81 dBA, and a one hour exposure to 84 dBA.

Because aircraft noise tends to be intermittent, the risk it presents to hearing is lower still. However, the risk to hearing presented by aircraft noise may be increased by its low frequency component or concurrent exposure to other noise sources or ototoxic agents.

Exposure to aircraft noise may increase the risk of occupational hearing loss such that, the limit of safe exposure may be reduced to 70 dB LAeq averaged over a 24-h day.

Finally, it should be noted that the data on hearing loss which are presented above are based on many years of exposure.

### 6.2.2 PERFORMANCE AND ACTIVITY

#### *Sleep Disturbance*

Sleep disturbance is a critical effect of aircraft noise exposure in dwellings, hospitals and preschools. In order to avoid the negative effects of noise on sleep, the maximum sound pressure levels of an intermittent noise source such as aircraft should not exceed 45dBA indoors. A lower limit of 40dB L<sub>Amax</sub> is recommended in residential areas with low background noise levels or in the homes of particularly susceptible individuals.

"Safe" outdoor values should be determined on the basis of the magnitude of the sound attenuation from outdoors to indoors, with particular consideration to whether the exposed individuals prefer to sleep with open windows. Outdoor levels are generally from 5-15 dBA higher than indoor levels with the windows open (see Berglund and Lindvall, 1995).

#### *Impairment of Voice Communication*

In order to avoid impairment of voice communication, which is a critical effect of noise in dwellings, hospitals (including impaired detection of warning signals), schools and preschools, speech signals should always exceed background noise levels.

When the distance of the listener from the speaker is approximately two meters, relaxed conversation speech (54-55 dBA) is 100% intelligible only in background sound pressure levels of less than 45 dB LAeq, but reasonably intelligible in background sound pressure levels of 55 dBA. Slightly more effortful speech (60dBA) is fairly intelligible in background sound pressure levels around 65 dB LAeq.

For outdoor speech communication, the "inverse square law" applies. In order to remain intelligible the speech signal must increase by 3dBA for any doubling of speaker to listener distance, with background noise level constant. Inside, reverberation makes prediction of speech intelligibility more difficult.

For sensitive groups or when listening to complicated messages (at school, listening to foreign languages, telephone conversation) the speech signal should exceed background noise levels by at least 10 dBA, preferably 15 dBA. Thus, it is recommended that the sound pressure level should not exceed 35 dB LAeq in class rooms during teaching sessions, so that spoken messages can be heard and understood. In outdoor playgrounds background sound pressure levels should not exceed 55 dB LAeq.

For hearing impaired individuals inevitably the effect of noise depends on level of impairment, but generally the speech signal must exceed the background levels by about three to four decibels more than for individuals with normal hearing, to achieve equivalent speech intelligibility.

### 6.2.3 REACTION

Reaction is a critical impact of noise in dwellings, hospitals, schools, preschools and possibly work sites. To protect the majority of people from being seriously annoyed during the daytime, the sound pressure level from continuous noise in outdoor living areas should not exceed 55 dB LAeq. To protect the majority of people from being moderately annoyed during the daytime the sound pressure level outdoors should not exceed 50 dB LAeq.

These criterion sound pressure levels should be 5 to 10 dB lower during the evening and night than during the day.

It is critical that maximum sound pressure levels and the number of noise events over time be considered in predicting reaction to aircraft noise.

### 6.2.4 COMMENTS FROM RECENT SYDNEY AIRPORT STUDIES

*Proposed Third Runway Sydney (Kingsford Smith) Airport Draft Environmental Impact Statement* (Kinhill, 1990) identifies as "sensitive land uses" facilities where:

- speech communication is essential, for example for teaching, worship, theatre and meetings;
- listening or relaxation is important, for example in listening to music, watching television, or sleeping;
- exposure to noise places additional stress on people, in hospitals for example; and
- low vibration is necessary, for example where electron microscopes are used.

Recommendations of the former Department of Aviation for noise levels for particular land uses was presented in Kinhill (1990) as *Table 6.1*.

A number of submissions to the *Senate Select Committee on Aircraft Noise in Sydney* (Senate Select Committee on Aircraft Noise in Sydney, 1995) were relevant to the issue of sensitive land uses. For example, a number of complaints regarded interruption of church services (including funerals and wedding ceremonies) and fundraising activities at schools. Reported disturbance of educational activities has already been discussed, as has potential interference with recuperation due to noise-induced sleep loss. Medical staff also complained of difficulties obtaining patient histories or conducting therapies with constant interference by aircraft noise. Again, it must be recognised that whilst these submissions give an indication of feelings of some residents, they are of limited scientific merit.

**TABLE 6.1** LAND USES AND ASSOCIATED NOISE LEVELS (ANEF) WHICH ARE ACCEPTABLE, WHICH ARE ACCEPTABLE CONDITIONAL UPON INCLUSION OF SUITABLE NOISE CONTROL FEATURES IN THE BUILDING, AND WHICH ARE UNACCEPTABLE, IN THE VICINITY OF AUSTRALIAN AIRPORTS

Land use	ANEF		
	Acceptable	Conditional	Unacceptable
Education facilities			
adult	<20	20-25*	>25
primary	<20	20-25*	>25
secondary	<20	20-25*	>25
other	<20	20-25*	>25
Health facilities			
hospitals	<20	20-25*	>25
other	<20	20-25*	>25
Child care facilities	<20	20-25*	>25
Aged facilities			
accommodation	<20	20-25*	>25
day care	<20	20-25*	>25
Recreation facilities			
indoor	<25	25-30	>30
outdoor		No limits specified, uses vary	
Community facilities			
residential/neighbourhood	<25	25-30	>30
Houses, home units and flats	<20	20-25**	>25
Places of worship	<20	20-30*	>30
Hotels, motels and hostels	<25	25-30*	>30
Public buildings	<20	20-30*	>30
Commercial buildings	<25	25-35†	>35†
Light industrial buildings	<30	30-40	>40
Heavy industrial buildings		Acceptable in all ANEF zones	

\* An analysis of building noise reduction requirements should be made by an acoustic consultant and any necessary noise control features included in the design of the building.

\*\* Some people may find the area within the 20-25 ANEF contour interval to be unsuitable for residential use. Land use authorities may consider that the incorporation of noise control features in the construction of residences is appropriate.

† If the 35 ANEF contour is not included in ANEF drawings, this contour should be determined by interpolation.

Source: Kinhill Engineers, 1990.

## 6.3 RESEARCH NEEDS

### 6.3.1 OVERVIEW

Whilst extensive research provides evidence for some effects of aircraft noise on health, performance and reaction, further research is required before a full understanding of the effects of noise is reached.

This section provides an outline of what the authors consider to be future research needs with respect to the effects of aircraft noise on health. It contains only the views of the authors of this Technical Paper and is not intended to represent the Commonwealth Government's or the Department

of Transport and Regional Development's views, and is not endorsed by either of these entities.

### 6.3.2 RESEARCH NEEDS

Further research is required into the most reliable, valid and accurate measurement of noise and its health, performance and reaction outcomes. More thorough investigation of which noise index is most useful in predicting certain outcomes is also required. It may be the case that different noise indices are differentially effective in predicting different outcomes (see Job, 1993).

An important issue in the assessment of aircraft noise impact and the development of strategies for land use planning in the vicinity of airports is which of annoyance and dissatisfaction, or sleep disturbance is the most sensitive indicator of noise impact. (However, it should be noted that a composite index of reaction, which includes all these elements may provide a reasonable solution and has been used in some studies). It would assist in the evaluation of this question if contours of equal sleep disturbance could be developed and superimposed on maps of airports and their surrounds along with contours of equal annoyance and of noise exposure (for example, ANEF contours). There should be no technical difficulty in translating scenarios of various aircraft types and numbers into 'sleep disturbance contours' using the procedure developed by Passchier-Vermeer (1994). Application of contours may also facilitate the prediction of noise-induced sleep disturbances, particularly for shift workers. However corrections may be necessary depending on whether shiftworkers' susceptibility to noise-induced sleep disturbance is more, less or the same as for the general population.

There are many laboratory and cross-sectional community studies of the outcomes of exposure to aircraft noise. However, more longitudinal studies and long term studies of reaction to changes in noise levels are needed (see Lercher, 1996) to address several as yet unresolved issues. Firstly, such studies would provide an opportunity to disentangle the effects of noise from those of confounding factors such as socio-economic status (see Carter et al., 1993). The discovery of poorer health in high than in low noise areas may simply reflect an effect of lower socio-economic status in high noise areas. However, a change in noise levels provides the opportunity of a pseudo-experimental design in which noise level is the independent variable. By testing the same individuals twice, under different noise conditions, variance due to confounding and modifying variables is controlled. Secondly, longitudinal designs offer the opportunity of assessing cumulative effects of long-term exposure to noise and examining the influence of risk factors. That is, it may be possible to predict which individuals are likely to be most negatively effected by noise exposure. Such prediction is of clear practical importance in terms of appropriate use of noise mitigation measures. Finally, longitudinal designs may be employed to evaluate the influence of using a "survivor" population. For example, it might be examined whether there are differences between residents who choose to stay in a high noise area and those who choose to leave it. It would also be useful to determine whether individuals who move out of a high noise area subsequently suffer less deleterious effects of noise than those who remain in residence. Such a

study is currently underway in relation to the introduction of the third runway at Sydney Airport (see Carter et al., 1996a, 1996b; Job et al., 1996a, 1996b, 1996c, 1996c).

Community studies are required to substantiate findings for several potential outcomes of aircraft noise exposure, which have chiefly been examined in the laboratory. Similarly, the applicability of data regarding the effects of occupational noise to the prediction of the effects of aircraft noise should be evaluated. In particular, the study of noise-induced hearing impairment has largely been restricted to occupational and recreational (music) settings. These studies suggest that aircraft noise does not pose a significant risk to hearing, primarily because it is intermittent. However, the degree to which aircraft potentiates or accelerates hearing loss due to non-aircraft noise exposure (including occupational exposure) and due to ageing deserves further consideration.

The role of variables which mediate or moderate the influence the effects of exposure to aircraft noise, requires further investigation. For example, better understanding of the nature of, and causal role(s) of, noise sensitivity would allow increase the usefulness of the concept. Whilst, "noise sensitivity" is associated with a wide range of outcomes of noise exposure, including cardiovascular effects, general health effects, sleep disturbance, reaction and mental health effects, its usefulness as an indicator of risk will remain dubious until it is defined (or validated) and studied independently of these outcomes. Validation of self-reported sensitivity has occurred to some extent, but could be broadened to include numerous noise-reactivity measures. Furthermore, noise sensitivity is commonly comprised of more than one factor (Job and Hede, 1989; Bullen et al., 1991). The separate validation of each factor would be useful. Similarly, delineation of the causal role of attitude in reaction would be beneficial. Job (1993) and Lercher (1996) have suggested that further research into the role of Locus of Control, Type A versus Type B personality and learned helplessness would also be profitable.

Very few studies examine the effects of aircraft noise on blood pressure elevation in the field. Further research should correct this deficiency.

Further studies should examine hospital admissions with better control for potential confounding variables, such as age, gender, socio-economic status, and previous noise exposure.

Research based on a new procedure for assessing the impact of aircraft noise on sleep should be conducted in the vicinity of Australian airports. A novel procedure for predicting the average maximum number of awakenings and/or sleep stage changes per person per year due to night time aircraft noise has been proposed by Passchier-Vermeer (1994) and adopted as the basis for regulations by the Netherlands government. The procedure is based on dose/response relation (percentage awakening versus L<sub>Amax</sub> or SEL) derived from all the major field studies of aircraft noise and sleep reported to the time the procedure was developed, which agrees well with the more recent studies conducted in the US by Fidell and associates. The procedure also adopts a rule for estimating the effect of number of aircraft flyovers, and results in the calculation of an LA<sub>eq</sub> for all aircraft noise events overnight.

Prediction and potential regulation of the average number of aircraft noise-induced awakenings and changes in sleep stage distribution per year may be based on this LAeq.

Measured in terms of awakening, sleep disturbance is related to noise by a reliable dose-response function. However, it is important also to consider the time spent awake following awakening. Individuals who find it difficult to return to sleep following awakening are paradoxically likely to experience less awakenings, thus giving the impression of minimal sleep disturbance in spite of being awake for extended periods of time. Only polygraphic measures can provide an estimate of the time spent awake.

A number of potential risk factors for noise-induced sleep disturbance require further research attention. For example, Carter and colleagues (Carter and Hunyor, 1988, Hunyor, et al, 1992a; Carter, et al, 1992b) have recommended further research into the effects of noise on previously existing cardiac arrhythmias both in subjects with higher grade (more serious) arrhythmias, and utilising common environmental noises of sudden onset (such as noise from low flying military aircraft). Further, given the apparent importance of attitude in the noise source in determining reaction to the noise, it could be potentially important to consider the effect of this variable on noise-induced sleep disturbance. It is also critical to test the hypothesis that sick individuals are liable to suffer more as a result of noise-induced sleep disturbance due to the necessity of sleep for recuperation. Carter (1996a) has made other relevant suggestions for research on the effects of noise on sleep.

The mechanisms underlying overreaction to changes in noise exposure are also not yet fully understood. People who receive a sudden increase in noise exposure show a large increase in reaction to a level beyond that expected from the new exposure level (see Raw and Griffiths, 1990; Job, 1988a). Adaptation/habituation is unlikely to be the explanation of this effect, because adaptation/habituation of noise reaction is thought to be minimal (Weinstein, 1982). Research should focus on disentangling competing theories of (and therefore factors of practical relevance to the effect) (Brown, 1987; Raw and Griffiths, 1990; Job, 1988a).

Evaluation of the longer term effect of insulation of homes affected by Sydney Airport should be a priority.

Reaction to noise seems to have escalated in the last twenty years. This change is potentially due to greater publicity regarding the noise problem, greater awareness of the noise problem, greater concern with environmental issues in general, higher expectations about the local environment or greater expectation of political influence by (groups of) individuals. Careful evaluations of this effect and the reasons for it are required.

It would be of interest to examine the relationships between directly measured indices of fear of aircraft and/or aircraft noise and self-reported fear. There are a number of objectively measurable effects of fear of noise. For example, fear should be reflected in reduced habituation of the orienting and startle responses, greater vasoconstriction and possibly greater elevation of blood pressure. It would be profitable to compare subjects who report high versus no fear in surveys in terms of these indices of fear.



Given the practical importance of identifying which groups are particularly at risk for various effects of noise exposure, further research should be aimed at identifying risk factors. A number of potentially vulnerable groups, including children, the aged, and the ill, and shiftworkers have been proposed. However, examination of such hypotheses has been scant and restricted to only a few potential noise exposure outcomes. Thus, for example it is unclear to what degree the sleep disturbances suffered by shift workers are in fact due to aircraft noise exposure rather than disruption of circadian rhythms due to sleeping during the day. Nor is it clear whether they would benefit overall from a reduction daytime aircraft noise exposure. As suggested by Kinhill (1990), research should be directed toward an understanding of the particular risks faced by supposedly "vulnerable" groups.

# References

## REFERENCES

- Abel, S.M., and Haythornthwaite, C.A. (1984). The progression of noise-induced hearing loss: A survey of workers in selected industries in Canada. *Journal of Otolaryngology*, 13, 1-36.
- Abel, S.M., Krever, M., and Alberti, P.W. (1990). Auditory detection, discrimination and speech processing in ageing, noise-sensitive and hearing-impaired listeners. *Scandinavian Audiology*, 19, 43-54.
- Abey-Wickrama, I., A'Brook, M.F., Gattoni, F.E.G., and Herridge, C.F. (1969). Mental-hospital admissions and aircraft noise. *Lancet*, 2, 1275-1277.
- Acton, W.I. (1967). A review of hearing damage risk criteria. *Annals of the Occupational Hygiene*, 10, 143-153.
- Acton, W.I. (1970). Speech intelligibility in a background noise and noise induced hearing loss. *Ergonomics*, 13, 546-554.
- Ader, R. and Cohen, N. (1993). Psychoneuroimmunology: Conditioning and stress. *Annual Review Psychology*, 44, 53-85.
- Ahrlin, U., and Ohrström, E. (1978). Medical effects of environmental noise on humans. *Journal of Sound and Vibration*, 59, 79-87.
- Alexandre, A. (1974). Decision criteria based on spatio-temporal comparisons of surveys on aircraft noise. In W.D. Ward (ed.), *Noise as a Public Health Problem*. Washington, DC, U.S. Environmental Protection Agency (EPA 550/9.73.008), pp. 619-627.
- Altena, K. (1990). Noise, interruption of sensorimotor rhythms during sleep or wakefulness and adverse effects on health. In B. Berglund and T. Lindvall (eds.), *Noise as a Public Health Problem. Vol. 5: New Advances in Noise Research—Part II*. Stockholm: Swedish Council for Building Research, D2, 1990, pp. 393-401.
- Altena, K. Noise annoyance and loss of value. (1987). In H.S. Koelega (ed.), *Environmental Annoyance: Characterization, Measurement, and Control*. Amsterdam: Elsevier, pp. 399-407.
- Altura, B.M. (1979). Sudden-death ischemic heart disease and dietary magnesium intake: Is the target site coronary vascular smooth muscle? *Medical Hypotheses*, 5, 843-848.
- Altura, B.M. (1993). Extraaural effects of chronic noise exposure on blood pressure, microcirculation and electrolytes in rats: Modulation by  $Mg^{2+}$ . In H. Ising and B. Kruppa (eds.), *Noise and Disease*. Stuttgart: Gustav Fischer, pp. 81-90.
- Andersson, K., and Lindvall, T. (eds.) (1988). *Health Effects of Community Noise. Evaluation of the Nordic Project on "The Health Effects of*

*Community Noise*". Copenhagen, Denmark: Nordic Council of Ministers, Miljörapport No. 6.

Ando, Y., and Hattori, H. (1973). Statistical studies on the effects of intense noise during human fetal life. *Journal of Sound and Vibration*, 27, 101-110.

Andrén, L. (1982). Cardiovascular effects of noise. *Acta Medica Scandinavica*, 65, 1-45.

Andrén, L., Hansson, L., and Björkman, M. (1981). Haemodynamic effects of noise exposure before and after beta-selective and non-selective beta-adrenoreceptor blockade in patients with essential hypertension. *Science*, 61, 895-915.

Andrén, L., Hansson, L., Björkman, M., and Jonsson, A. (1980). Noise as a contributory factor in the development of elevated arterial pressure. *Acta Medica Scandinavica*, 207, 493-398.

Andrén, L., Hansson, L., Björkman, M., Jonsson, A., and Borg, K. (1979). Haemodynamic and hormonal changes induced by noise. *Acta Medica Scandinavica, Suppl.* 625, 13-18.

Andrén, L., Lindstedt, G., Björkman, M., Borg, K., and Hansson, L. (1982). Effects of noise on blood pressure and 'stress' hormones. *Clinical Science*, 62, 137-141.

Andres, W.S., Kerrigan, M.E., and Bird, B.T. (1975). Hearing and para-airport children. *Aviation, Space and Environmental Medicine*, 46, 740-742.

Aniansson, G. (1974). Methods for assessing high frequency hearing loss in everyday listening situations. *Acta Oto-Laryngologica, Suppl.* 320.

Anthony, A., and Ackerman, E. (1955). Effects of noise on the blood eosinophil levels and adrenals of mice. *Journal of Acoustical Society of America*, 27, 1144-1149.

Anthony, A., Ackerman, E., and Lloyd, J.A. (1959). Noise stress in laboratory rodents; I. Behavioural and endocrine response of mice, rats and guinea pigs. *Journal of the Acoustical Society of America*, 31, 1430-1437.

Arguelles, , A.E., Ottone, J.P., and Chekherdemian, M. (1962). Pituitary adrenal stimulation by sound of different frequencies. *Journal of Clinical Endocrinology*, 22, 846-852.

Arguelles, A.E., Martinez, M.A., Pucciarelli, E., and Disisto, M.V. (1970). Endocrine and metabolic effects of noise in normal, hypertensive and psychotic subjects. In B.L. Welch and A.S. Welch (eds.), *Physiological Effects of Noise*. New York: Plenum, pp. 43-55.

Aro, S. (1984). Occupational stress, health related behavior, and blood pressure: A 5-year follow-up. *Preventive Medicine*, 13, 333-348.

- Arvidsson, O., and Lindvall, T. (1978). Subjective annoyance from noise compared with some directly measurable effects. *Archives of Environmental Health*, 33, 159-166.
- Atherley, G.R.C., Gibbons, S.L., and Powell, J.A. (1970). Moderate acoustic stimuli: The interrelation of subjective importance and certain physiological changes. *Ergonomics*, 13, 536-545.
- Atherley, G.R.C., Noble, W.G., and Sugden, D.B. (1967). Foundry noise and hearing in foundrymen. *Annals of Occupational Hygiene*, 10, 255-261.
- Atrens, D. (1994). The questionable wisdom of a low-fat diet and cholesterol reduction. *Social Science and Medicine*, 39, 43-447.
- Aubree, D. (1973). *Etude de la gêne due bruit de train*. C.S.T.B., Paris.
- Avery, G.C. (1982). Comparison of telephone complaints and survey measures of noise annoyance. *Journal of Sound and Vibration*, 82, 215-225.
- Axelsson, A. (1991). Leisure noise exposure in adolescents and young adults. *Journal of Sound and Vibration*, 151, 447-453.
- Axelsson, A., and Jerson, T. (1985). Noisy toys: A possible source of sensorineural hearing loss. *Paediatrics*, 76, 574-578.
- Axelsson, A., and Lidén, G. (1985). Buller och bullerskador [Noise and Noise Impairment]. In G. Lidén (ed.), *Audiologi [Audiology]*. Stockholm: Almqvist and Wiksell.
- Axelsson, A., and Lindgren, F. (1978). Hearing in pop musicians. *Acta Otolaryngol*, 85: 225-231.
- Babisch, W., and Gallacher, J.E.J. (1990). Traffic noise, blood pressure and other risk factors: The Caerphilly and Speedwell collaborative heart disease studies. In B. Berglund and T. Lindvall (eds.), *Noise as a Public Health Problem. Vol. 4: New Advances in Noise Research—Part 1*. Stockholm: Swedish Council for Building Research, D1, 1990, pp. 315-326.
- Babisch, W., Elwood, P.C., and Ising, H. (1993). Road traffic noise and heart disease risk: Results of the epidemiological studies in Caerphilly, Speedwell and Berlin. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 260-267.
- Babisch, W., Fromme, H., Beyer, A., and Ising, H. (1996). Elevated catecholamine levels in urine in traffic noise exposed subjects. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2153-2158.
- Babisch, W., Gallacher, J.E.J., Elwood, P.C., and Ising, H. (1988). Traffic noise and cardiovascular risk. The Caerphilly study, first phase. Outdoor noise levels and risk factors. *Archives of Environmental Health*, 43, 407-414.

Bailey, P. (1983). Hearing for speech: The information transmitted in normal and in impaired hearing. In M.E. Lutman and M.P. Haggard (eds.), *Hearing Science and Hearing Disorders*. London: Academic Press, pp. 1-34.

Bartley, S and Chute, E (1947). *Fatigue and impairment in man*. New York: McGraw Hill.

Bauer, P., Körpert, K., Neuberger, M., Raber, A., and Schwetz, F. (1991). Risk factors for hearing loss at different frequencies in a population of 47 388 noise-exposed workers. *Journal of the Acoustical Society of America*, 90, 3086-3098.

Baughn, W. L. (1973). *Relation between daily noise-exposure and hearing loss based on the evaluation of 6,835 industrial noise exposure cases*. Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory, Report AMRL-TR-73-53.

Becker, A.B., Warm, J.S., Dember, W.N, and Hancock, P.A. (1995). Effects of jet engine noise and performance feedback on perceived workload in a monitoring task. Special Issue: Pilot workload Contemporary issues. *International Journal of Aviation Psychology*, 5, 49-62.

Belojevic, G., Ohrström, E., and Rylander, R. (1992). Effects of noise on mental performance with regard to subjective noise sensitivity. *International Archives of Occupational and Environmental Health*, 64, 293-301.

Benkö, E. (1959). Narrowing of the visual fields for objects and colours in the case of chronic brain damage. *Ophthalmologica*, 138, 449-456.

Benkö, E. (1962). Further information about the narrowing of the visual fields caused by noise damage. *Ophthalmologica*, 143, 76-80.

Beranek, L.L. (1947). The design of speech communication systems. *Proceedings of the Institute of Radio Engineers*, 35, 880-890.

Bergamini, L., Bergamasco, B., Benna, P., Covacich, A., and Gilli, M. (1976). Effect of road noise on the central nervous system. In G. Rossi and M. Vigone (ed.), *International Congress on Man and Noise*. Turin: Minerva Medica, pp. 142-156.

Berglund, B (1996). *Aircraft Noise and Health*. Presented at the Second Airport Regions Conference, Helsinki-Vanraa Airport, Finland.

Berglund, B. and Lindvall, T. (eds.)(1995). Community Noise. *Archives of the Center for Sensory Research*, 2, 1-195.

Berglund, B. (1990). Loudness scaling in environmental psychoacoustics. In E. Ozimek, (Ed.), *Subjective and Objective Evaluation of Sound*. Singapore: World Scientific Publishing, pp. 3-14.

Berglund, B., and Berglund, U. (1986). *Horstyrkan hos ljud från högspänningsledningar [The loudness of power line noises]*. Stockholm: Naturvårdsverket, Report No 3035.

- Berglund, B., and Job, R.F.S. (1996). Theory and method in perceptual evaluation of complex sound. In H. Fastl, S. Kuwano and A. Schick (Eds.), *Recent Trends in Hearing Research*. Oldenburg, Germany: Bibliotheks- und Informations system der Universit Oldenburg, 215-240.
- Berglund, B; Berglund, U and Lindvall, T (1975a). A study of response criteria in populations exposed to aircraft noise. *Journal of Sound and Vibration*, 41, 33-39.
- Berglund, B., Berglund, U., and Lindvall, T. (1975). Scaling loudness, noisiness and annoyance of aircraft noise. *Journal of the Acoustical Society of America*, 57, 930-934.
- Berglund, B., Berglund, U., and Lindvall, T. (1976). Scaling loudness, noisiness and annoyance of community noises. *Journal of the Acoustical Society of America*, 60, 1119-1125.
- Berglund, B., Berglund, U., and Lindvall, T. (1980). Loudness separation of community noise. In J.V. Tobias, G. Jansen, and W.D. Ward (eds.), *Noise as a Public Health Problem*. Rockville, MD: ASHA Reports 10, pp. 349-354.
- Berglund, B., Berglund, U., and Lindvall, T. (1986). *On the meaning of annoyance*. Transactions of the Acoustical Society of Japan, No. N86-10-5.
- Berglund, B., Berglund, U., Goldstein, M., and Lindvall T. (1981). Loudness (or annoyance) summation of combined community noises. *Journal of the Acoustical Society of America*, 70, 1628-1634.
- Berglund, B., Hassmén, P., and Job, R.F.S. (1996). Sources and effects of low-frequency noise. *Journal of the Acoustical Society of America*, 99, 2985-3002.
- Berglund, B., Preis, A., and Rankin, K. (1990). Relationship between loudness and annoyance for ten community sounds. *Environment International*, 16, 523-531.
- Berglund, U. (1981). Loudness and annoyance from community noise. In A. Schick (ed.), *Akustik zwischen Physik und Psychologie*. Stuttgart, Germany: Klett-Cotta, pp. 27-32.
- Bergman, M. (1980). *Aging and the Perception of Speech*. Baltimore, MD: University Park Press.
- Berry, B., and Thiessen, C.J. (1970). Effects of impulsive noise on sleep. Ottawa: National Research Council of Canada, NRC 11597.
- Bertoni, D., Franchini, A., et al. xxx(1993). Reactions of people to urban traffic noise in Modena, Italy. In *Proceedings of Noise as a Public Health Problem, Vol2*, INRETS, Lyon, 593-596.
- Bitter, C., and Willigers, L.H.J. Experiencing sound insulation measures against aircraft noise in residential areas. A comparative study. Ministerie van Volksgezondheid en Milienhygiene, ICG-LL-HR-14-03, 1980.

- Björkman, M., Åhrlin, U., and Rylander, R. (1992). Aircraft noise and average versus maximum levels. *Archives of Environmental Health*, 47, 326-329.
- Björkman, M. (1988). Maximum noise levels in road traffic noise. *Journal of Sound and Vibration*, 127, 583-587.
- Björkman, M. (1991). Community noise annoyance: Importance of noise levels and the number of noise events. *Journal of Sound and Vibration*, 151, 497-503.
- Björkman, M., Levein, B., Rylander, R., Åhrlin, U., and Ohrström, E. (1986). Störningar i Uddevalla före och efter trafikomläggningen. [Annoyance in Uddevalla before and after change of traffic streams]. Gothenburg, Sweden: Department of Environmental Hygiene, University of Gothenburg, No 17.
- Blois, R., Debilly, G., and Mouret, J. Daytime noise and its subsequent sleep effects. In J.V. Tobias, G. Jansen and W.D. Ward (eds.)(1980). *Noise as a Public Health Problem*. Rockville, MD: ASHA Reports 10, pp. 425-432.
- Bly, S., Goddard, M., and McLean, J. (1993). A review of the effects of noise on the immune system. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 2, pp. 509-512.
- Bohne, B. Mechanisms of noise damage in the inner ear. In D. Henderson, R.P. Hamernik, D.S. Dosanjh and J.H. Mills (eds.)(1976). *Effect of Noise on Hearing*. New York, NY: Raven, pp. 41-67.
- Borg, E. and Møller, A.R. (1978). Noise and blood pressure: Effect of lifelong exposure in the rat. *Acta Physiologica Scandinavica*, 103, 340-342.
- Borsky, P.N. Review of community response to noise. In J.V. Tobias, G. Jansen, and W.D. Ward (eds.)(1980). *Noise as a Public Health Problem*. Rockville, MD: ASHA Reports 10, pp. 453-474.
- Botsford, J.H. (1969). Using sound levels to gauge human response to noise. *Sound and Vibration*, 3, 16-28.
- Bradley, J.S. and Jonah, H. (1979). The effects of site selected variables on human response to traffic noise, *Journal of Sound and Vibration*, 66, 589-604.
- Bradley, J.S. (1994). On dose-response curves of annoyance to aircraft noise. In S. Kuwano (ed.), *Inter-Noise 94. Noise Quantity and Quality*. Poughkeepsie, NY: Noise Control Foundation, Vol. 1, pp. 235-238.
- Bradley, J.S. (1996). Determining acceptable limits for aviation noise. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2541-2546.
- Brandenberger, G., Follenius, M., and Tremolieres, C. (1970). Failure of noise exposure to modify patterns of plasma cortisol in man. *European Journal of Applied Psychology*, 36, 239-246.



Brandenberger, G., Follenius, M., Wittersheim, G., and Salame, P. with Sieoni, M. and Reinhardt, B. (1980). Plasma catecholamines and pituitary adrenal hormones related to mental task demand under quiet and noise conditions. *Biological Psychology*, 10, 239-252.

Brennan, F.X., Job, R.F.S., Watkins, L.R., and Maier, S.F. (1992). Total plasma cholesterol levels of rats are increased following three sessions of tailshock. *Life Sciences*, 50, 645-650.

Broadbent, D.E. (1957). Effects of noise on behaviour. In C.M. Harris (ed.), *Handbook of Noise Control*. New York: McGraw-Hill, pp. 10-34.

Broadbent, D.E. (1971). *Decision and Stress*. New York: Academic Press.

Broadbent, D.E. (1972). Individual differences in annoyance by sound. *Sound*, 6, 56-61.

Broadbent, D.E. (1981). The effects of moderate levels of noise on human performance. In J. Tobias and E. Schubert (ed.), *Hearing: Research and Theory*. New York: Academic Press, Vol. 1.

Bronzhaft, A.L. and McCarthy, D.P. (1975). The effects of elevated train noise on reading ability. *Environment and Behaviour*, 7, 571-527.

Brown, A.L. (1987). Responses to an increase in road traffic noise. *Journal of Sound and Vibration*, 117, 69-79.

Brown, A.L., Hall, A., and Kyle-Little, J. (1985). Response to a reduction in traffic noise exposure. *Journal of Sound and Vibration*, 98, 235-246.

Brown, J.J., Brummett, R.E., Fox, K.E., and Bendrick, T.W. (1980). Combined effects of noise and kanamycin. *Archives of Otolaryngol*, 106, 744-745.

Brown, R. (1991). Sleep and resistance to infection. Paper presented at the *Inaugural Australian Psychophysiology Conference, Sydney, Australia*.

Brown, R., Pang, G., Husband, A.J., and King, M.G. (1989). Suppression of immunity to influenza virus infection in the respiratory tract following sleep disturbance. *Regional Immunology*, 2, 321-325.

Brown, R., Pang, G., Husband, A.J., and King, M.G. (1989a). Suppression of immunity to influenza virus infection in the respiratory tract following sleep disturbance. *Regional Immunology*, 2, 321-325.

Brown, R., Price, R.J., King, M.G., and Husband A.J. (1989b). Interleukin-1 B and muramyl dipeptide can prevent decreased antibody response associated with sleep deprivation. *Brain, Behavior, and Immunity*, 3, 320-330.

Bryan, M.E. (1976). Low frequency noise annoyance. In W. Tempest (Ed.), *Infrasound and Low Frequency Vibration*. London: Academic Press, pp. 65-96.

- Buchta, E. (1993). A review of the penalty for impulse noise. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 420-427.
- Buchta, E. (1996). Annoyance caused by shooting noise- Determination of the penalty for various weapon calibers. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2495-2500.
- Bullen, R.B. (1984). The effects of aircraft noise: Current knowledge and future research. *Bulletin of the Australian Acoustical Society*, 12, 75-79.
- Bullen, R.B., and Hede, A.J. (1983). Time-of-day corrections in measures of aircraft noise exposure. *Journal of Acoustical Society of America*, 73, 1624-1630.
- Bullen, R.B., and Hede, A.J. (1986). Comparison of the effectiveness of measures of aircraft noise exposure by using social survey data. *Journal of Sound and Vibration*, 108, 227-245.
- Bullen, R.B., and Job, R.F.S. (1985). Re-analysis of data presented in "Community Reponse to Blasting" by Fidell et al. [*J. Acoust. Soc. Am.* 74, 888-893 (1983)]. *Journal of the Acoustical Society of America*, 78, 799-800.
- Bullen, R.B., Hede, A.J., and Job, R.F.S. (1991). Community reaction to noise from an artillery range. *Noise Control Engineering Journal*, 37, 115-128.
- Bullen, R.B., Job, R.F.S., and Burgess, D.H. (1985). *Reaction to Aircraft Noise on RAAF Bases*. National Acoustic Laboratories Commissioned Report No.7. Australian Government Publishing Service, Canberra.
- Buntin, J. (1989). *Criteria for acceptable aircraft noise exposure in classrooms*. Newport Beach, California: Intervix.
- Burns, W. (1973). *Noise and Man*. London: John Murray, 2nd ed.
- Burns, W., and Robinson, D.W. (1970). *Hearing and Noise in Industry*. London: Her Majesty's Stationery Office.
- Caille, E.J., and Bassano, J.L. (1977). Deformation du sommeil et du comportement en environnement sonore simulé. *Collection recherche environnement*, 3, 39-80.
- Cantrell, R.W. (1974). Prolonged exposure to intermittent noise: Audiometric, biochemical, motor, psychological and sleep effects. *Laryngoscope*, 84, 1-55.
- Carter, N.L. and Beh, H.C. (1989). The effect of intermittent noise on cardiovascular functioning during vigilance task performance. *Psychophysiology*, 26, 548-559.
- Carter, N.L. and Hunyor, S.N. (1988). Traffic noise and cardiac arrhythmias. *Proceedings of the Fifth International Congress on Noise as a Public Health Problem, Stockholm*, Vol. 2.

Carter, N.L. and Ingham, P. (1995). *A Laboratory Study of the Effects of Background Noise Level and Number of Truck Noise Events on Sleep*. National Acoustic Laboratories Commissioned Report No. 124.

Carter, N.L. (1995) Environmental noise, sleep, and health. *Proceedings of the 15th International Congress on Acoustics, Trondheim, Norway, Vol. II*, 33-36.

Carter, N.L. (1996). Approaches to the study of noise induced sleep disturbance. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2277-2282.

Carter, N.L. (1996b). Transportation noise, sleep, and possible after-effects, *Environmental International* 22, 105-116.

Carter, N.L., and Hunyor, S.N. (1991). A field study of traffic noise and cardiac arrhythmia during sleep. In: *Technical Papers: 4th Western Pacific Regional Acoustics Conference*. Brisbane, Australia: Queensland Department of Environment and Heritage, pp. 165-172.

Carter, N.L., Crawford, G., Kelly, Hunyor, S. (1993). Environmental noise during sleep and sympathetic arousal assessed by urinary catecholamines. In Vallet, M. (ed.) *Noise as a Public Health Problem, Vol 1*, 51.

Carter, N.L., Good, T, Brown, R, Pang, G and Clancy, R (1995). *Traffic Noise, Slow Wave Sleep and Immune Response in Night Shift Workers*. National Acoustic Laboratories, Sydney. Preliminary Report, August.

Carter, N.L., Hunyor, S.N., Crawford, G., Kelly, D., and Smith, A.J.M. (1994b). Environmental noise and sleep - A study of arousals, cardiac arrhythmia and urinary catecholamines, *Sleep*, 17, 298-307.

Carter, N.L., Hunyor, S.N., Ingham, P., and Tran, K. and (1992a). A field study of the effects of traffic noise on arrhythmia during sleep. *Journal of Sound and Vibration*, 169, 211-227.

Carter, N.L., Ingham, P., and Tran, K. (1992b). Overnight traffic noise measurements in bedrooms and outdoors, Pennant Hills Road, Sydney-comparison with criteria for sleep, *Acoustics Australia*, 20, 49-55.

Carter, N.L., Job, R.F.S., Peplow, P., Taylor, R., and Morrell, S. (1996a). Community response to major changes in runway configuration, operating procedures and aircraft noise at Sydney airport. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2311-2316.

Carter, N.L., Job, R.F.S., Taylor, R., Peplow, P., and Morrell, S. (1996b). Progress report on Sydney Airport Health Studies. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2165-2170.

Carter, N.L., Peplow, P., Taylor, R., Job, R.F.S, Jenkins, A., Morrell, S., Brown, and R., Pang, G. (1993). *Proposal for Studies of the Effects of Aircraft Noise from Sydney (Kingsford Smith Airport) on Health*. Sydney Airport Health Studies Committee, Report prepared for the Federal Airports Corporation.

Cartwright, L.B. and Thompson, R.N. (1975). The effects of broadband noise on the cardiovascular system in normal resting adults. *American Industrial Hygiene Association Journal*, 9, 653-658.

Cavatorta, A., Falzoi, M., Romanelli, A., Cigala, F., Ricco, M., Bruschi, G., Franchini, I., and Borghetti, A. (1987). Adrenal response in the pathogenesis of arterial hypertension in workers exposed to high noise levels. *Journal of Hypertension*, 5, 463-466.

Cederlöf, R., Jonsson, E., and Sörensen, S. (1967). On the influence of attitudes to the source on annoyance reactions to noise: A field experiment. *Nordisk Hygienisk Tidskrift*, 48, 46-59.

Ceypek, T., and Kuzniarz, J.J. (1974). Hearing loss due to impulse noise: A field study. In W. Ward (ed.), *Noise as a Public Health Problem*. Washington DC: US Environmental Protection Agency (Report EPA 550/9-73-0008), pp. 219-228.

CHABA. (1988). Committee on Hearing, Bioacoustics and Biomechanics. Working group on speech understanding. Speech understanding and aging. *Journal of the Acoustical Society of America*, 83, 859-895.

Chiles, W.D., and West, D. (1972). Residual performance effects of simulated sonic booms introduced during sleep. Oklahoma City, OK: Federal Aviation Administration, Civil Aeromedical Institute (FAA-AM-72-19).

Chowns, R.H. (1970). Mental-hospital admissions and aircraft noise. *Lancet*, 1(7644):467.

Clark, W.W. (1991). Recent studies of temporary threshold shift (TTS) and permanent threshold shift (PTS) in animals. *Journal of the Acoustical Society of America*, 90, 155-163.

Coblentz, A., Martel, A., and Ignazi, A. (1990). Effects of fetal exposition to aircraft noise on the birthweight of children. *Proceedings of the Human Factors Society 34th Annual Meeting*.

Cofer, C.N., and Appley, M.H. (1964). *Motivation: Theory and Research*. New York: Wiley.

Cohen, A. (1974). Industrial noise and medical absence, and accident record data on exposed workers. In W. Ward (Ed.), *Noise as a Public Health Problem*. Washington DC: US Environmental Protection Agency (Report EPA 550/9-73-0008), pp. 441-453.

Cohen, A., Anticaglia, J.R., and Jones, H.H. (1970). Noise-induced hearing loss: Exposures to steady-state noise. *Archives of Environmental Health*, 20, 614-623.

Cohen, A., Kylin, B., and LaBenz, P.J. (1966). Temporary threshold shifts in hearing from exposure to combined impact/steady-state noise conditions. *Journal of the Acoustical Society of America*, 40, 1371-1380.

- Cohen, S. and Spacapan, S. (1984) The social psychology of noise. In D.M. Jones and A.J. Chapman (eds.). *Noise and Society*. Chichester, UK: Wiley, 221-245.
- Cohen, S. and Weinstein, N.D. (1981). Nonauditory effects of noise on behavior and health. *Journal of Social Issues*, 37, 36-70.
- Cohen, S. (1980). Aftereffects of stress on human performance and social behavior: A review of research and theory. *Psychological Bulletin*, 88, 82-108.
- Cohen, S., and Lezak, A. (1977). Noise and inattentiveness to social cues. *Environment and Behavior*, 9, 559-572.
- Cohen, S., and Weinstein, N. (1982). Nonauditory effects of noise on behavior and health. In G.W. Evans (ed.), *Environmental Stress*. New York, NY: Cambridge University Press, pp. 45-74.
- Cohen, S., Evans, G.W., Krantz, D.S., and Stokols, D. (1980). Physiological, motivational, and cognitive effects of aircraft noise on children: Moving from the laboratory to the field. *American Psychologist*, 35, 231-243.
- Cohen, S., Evans, G.W., Stokols, D., and Krantz, D.S. (1986). *Behavior, Health, and Environmental Stress*. New York, NY: Plenum Press.
- Cohen, S., Glass, D.C., and Singer, J.E. (1973). Apartment noise, auditory discrimination, and reading ability in children. *Journal of Experimental Social Psychology*, 9, 407-422.
- Coles, R.R.A., and Rice, C.G. (1970). Towards a criterion for impulse noise in industry. *Annals of the Occupational Hygiene*, 13, 43-50.
- Coles, R.R.A., Garinther, G.R., Hodge, D.C., and Rice, C.G. (1968). Hazardous exposure to impulse noise. *Journal of the Acoustical Society of America*, 43, 336-343.
- Collins, P.W.P. (1988). Synergistic interactions of gentamicin and pure tones causing cochlear hair cell loss in pigmented guinea pigs. *Hearing Research*, 36, 249-260.
- Corcoran, B.W.J. (1967). Noise and loss of sleep. *Quarterly Journal of Experimental Psychology*, 14, 178-182.
- Corso, J.F. (1992). Support for Corso's hearing loss model relating aging and noise exposure. *Audiology*, 31, 162-167.
- Danielson, R., Henderson, D., Gratton, M.A., Bianchi, L., and Salvi, R. (1991). The importance of "temporal pattern" in traumatic impulse noise exposures. *Journal of the Acoustical Society of America*, 90, 209-218.
- Dankittikul, W., Izumi, K., Yano, T., Kurosawa, K., and Yamashita, T. (1993). Cross-cultural comparison of community responses to road traffic noise in Japan and Thailand. In M. Vallet (ed.) *Noise as a Public Health Problem*, Vol

2, Nice, France: Institut National de recherche sur les Transports et leur Securite, 197-200.

Davis, H. (1973). Some comments on "mpairment to hearing from exposure to noise", by K.D. Kryter *Journal of the Acoustical Society of America*, 53, 1237-1239.

Davis, R.C., Buchwald, A.M., and Frankman, R.W. (1955). Autonomic and muscular responses and their relation to simple stimuli. *Psychological Monographs*, 69, No. 45.

Davis, R.C., Buchwald, A.M., and Frankmann, R.W. (1955). Autonomic and muscular responses, and their relation to simple stimuli. *Psychological Monograph: General and Applied*, 69: No. 405.

de Jong, R.G. and Miedema, H.M.E. (1995). Comparing results of community response surveys. In M. Newman (ed.), *Proceedings of the 15th Internaltional Congress on Acoustics, Trondheim, Norway*, 61-64.

de Jong, R.G., Opmeer, C.H.J.M., and Miedema, H.M.E. (1995). Annoyance caused by environmental pollutants in the Netherlands. In M. Newman (ed.), *Proceedings of the 15th Internaltional Congress on Acoustics, Trondheim, Norway*, 65-68.

Dement, W., and Kleitman, N. (1957). Cyclic variations in EEG and their relation to eye movements, body mobility and dreaming. *Electroencephalografy and Clinical Neurophysiology*, 9, 673-689.

Deutsche Forschungsgemeinschaft. (1974). *An Interdisciplinary Investigation of the Effects of Aircraft Noise on Man*. Boppard, Germany: Bold, Vol. 3.

DeVany, A.S. (1976). An economic model of airport noise pollution in an urban environment. In S.A.Y. Lin (ed.) *Theory and Measurem,ent of Economic Externalities*. New York, N.Y.: Academic Press, 205-214.

Di Nisi, J., Muzet, A., Ehrhart, J., and Libert, J.P. (1990). Comparison of cardiovascular responses to noise during waking and sleeping in humans. *Sleep*, 13, 108-120.

di Cantogno, L.V., Dallerba, R., Teagno, P.S., Cocola, L. (1976). Urban traffic noise, cardiocirculatory activity and coronary risk factors. *Acta Otolaryngologica*, 339 (Suppl.), 208-213.

Diamond, I.D., and Rice, C.G. (1987). Models of community reaction to noise from more than one source. In H.S. Koelega (ed.) *Environmental Annoyance: Character-ization-Measurement, and Control*. Amsterdam, The Netherlands: Elsevier, pp. 301-312.

Diamond, I.D., and Walker, J.G. (1986). An international study of the influence of residual noise on community disturbance due to aircraft noise. In R. Lotz (ed.), *Inter-Noise 86*. New York, NY: Noise Control Foundation, Vol. II, pp. 941-946.

Dickinson, P., and Hegley, N. (1989). Open air concert noise control in New Zealand. In G.C. Maling (ed.), *Inter-Noise 89*. New York, NY: Noise Control Foundation, pp. 745-750.

Dickson, E.D.D., and Chadwick, D.L. (1955). Observations on disturbances of equilibrium and other symptoms induced by jet engine noise. *Journal of Laryngology and Otolaryngology*, 65, 154-165.

Dieroff, H.-G. (1961b). Über die gehörschädigende Wirkung der Schlagimpulse im Industrielärm. *Archiv für Ohren-, Nasen-, und Kehlkopfheilk*, 178, 503-515.

Dieroff, H.-G. (1964). Die Schalleitungsschwerhörigkeit als Lärmschutz. [Sound transmission deafness as noise protection.] *Zeitschrift für Laryngologie, Rhinologie und Otologie*, 43, 690-698.

Dieroff, H.-G. (1974). Hearing damage caused by very short, high-intensity impulse noise. In: *Noise as a Public Health Problem*. Washington DC: US Environmental Protection Agency, Report EPA 550/9-73.008, pp. 229-234.

Dobbs, M.E. (1972). Behavioural responses to auditory stimulation during sleep. *Journal of Sound and Vibration*, 20, 467-476.

Dodson, H.C., Bannister, L.H., and Douek, E.E. (1982). The effects of combined gentamicin and white noise on the spiral organ of young guinea pigs. *Acta Otolaryngol*, 94, 193-202.

DORA. (1980). *Aircraft Noise and Sleep Disturbance*. London: Directorate of Operational Research and Analysis, Final Report, No. 8008.

Duquesnoy, A.J. (1983). Effect of a single interfering noise or speech source up on the binaural sentence intelligibility of aged persons. *Journal of the Acoustical Society of America*, 74, 739-743.

Dyckner, T., and Wester, P.O. (1983). Effect of magnesium on blood pressure. *British Medical Journal*, 286, 1847-1849.

Eberhardt, J.L. (1982). Disturbance by road traffic noise of the sleep of young and elderly males as recorded in the home. In W.P. Koella (ed.), *Sleep 1982: The 6th European Congress of Sleep Research*. Basel, Switzerland: Kaeger, pp. 298-300.

Eberhardt, J.L. (1987). *The Influence on Sleep of Noise and Vibrations Caused by Road Traffic*. Lund: University of Lund, Doctoral dissertation.

Eberhardt, J.L. (1988). The influence of traffic noise on sleep. *Journal of Sound and Vibration*, 127, 449-455.

Eberhardt, J.L., and Akselsson, K.R. (1987). The disturbance by road traffic noise of the sleep of young male adults as recorded in the home. *Journal of Sound and Vibration*, 114, 417-434.

Eberhardt, J.L., Stråle, L.-O., and Berlin, M.H. (1987). The influence of continuous and intermittent traffic noise on sleep. *Journal of Sound and Vibration*, 116, 445-464.

Edmonds, L.D., Layde, P.M., and Erikson, J.D. (1979). Airport noise and teratogenesis. *Archives of Environmental Health*, 34, 243-247.

Ehrenstine, W and Muller-Limmroth, W (1975). Changes in sleep patterns caused by shift work and traffic noise. In P Colquhoun, S Folkard, P Knauth, and J Rutenfranz (Eds) *Proceedings of the International Symposium on Night and Shiftwork: Experimental Studies on Shiftwork*. Opladen: Westdeutscher Verlag; 1975, pp 48-56.

Ehyai, A., and Freemon, F.R. (1987). Progressive optic neuropathy and sensorineural hearing loss due to chronic glue sniffing. *Journal of Neurology, Neurosurgery and Psychiatry*, 46, 349-351 (1983).

Environmental Impact Reports Pty. Ltd. (1979) *Aircraft Flyover and Mortality*.

Etholm, B., and Egenberg, K.E. (1964). The influence of noise on some circulatory functions. *Acta Oto-Laryngology*, 58, 208-213.

Evans, G.W. and LePore, S.J. (1993). Nonauditory effect of noise on children. *Children's Environments*, 10, 31-51.

Evans, G.W. (1990). The nonauditory effects of noise on child development. In B. Berglund, U. Berglund, J. Karlsson and T. Lindvall (eds.), *Noise as a Public Health Problem. Vol. 4: New Advances in Noise Research—Part II*. Stockholm: Swedish Council for Building Research, D1, 1990, pp. 425-453.

Evans, G.W. (ed.)(1982). *Environmental Stress*. New York, NY: Cambridge University Press.

Evans, G.W., and Cohen, S. (1987). Environmental stress. In D. Stokols and I. Altman (eds.), *Handbook of Environmental Psychology*. New York: Wiley, Vol. 1, pp. 571-610.

Evans, G.W., Hygge, S., and Bullinger, M. (1995). Chronic noise and psychological stress. *Psychological Science*, 6, 333-338.

Evans, G.W., Bullinger, M., Hygge, S., Gutman, G., and Aziz, N. (1994). Chronic noise exposure and children: Cardiovascular and neuroendocrine processes. In: *Abstract Guide of the 23rd International Congress of Applied Psychology*. Madrid, Spain: International Association of Applied Psychology.

Faculty Of Medicine (Twenty-eight Members Of), University Of Sydney. Submission to The Senate Select Committee On Aircraft Noise In Sydney, 1995.

Fairfield Residents Against Airport Noise (1996). *Badgery's Creek Aiport: Reasons Against, Version 14*.



- Fastl, H. (1985). Loudness and annoyance of sounds: subjective evaluation and data from ISO 532B. In: *Inter-Noise 85*. Vol. II. Dortmund, Germany: Federal Institute for Occupational Safety, Vol. II, pp. 1403-1406.
- Fastl, H., and Yamada, Y. (1986). Cross-cultural study on loudness and annoyance of broadband noise with a tonal component. In A. Schick, H. Höge and G. Lazarus-Mainka (eds.), *Contributions to the Psychological Acoustics IV*. Oldenburg: Bibliotheks- und Informationssystem der Universität Oldenburg (BIS), pp. 341-353.
- Fastl, H., Markus, D., and Nitsche, V. (1985). Zur Lautheit und Lästigkeit von Fluglärm. In: *Fortschritte der Akustik, DAGA 85*. Bad Honnef: DPG-GmbH, pp. 227-230.
- Favino, A., Maugeri, U., Kauchtschischvili, G., Robustelli Della Cuna, G., and Nappi, G. (1973). Radioimmunoassay measurements of serum cortisol, thyroxine, growth hormone and leuteinising hormone with simultaneous electroencephalographic changes during continuous noise in man. *The Journal of Nuclear Biology and Medicine*, 17, 119-122.
- Fearn, R.W., and Hanson, D.R. (1984). Hearing damage in young people using headphones to listen to pop music. *Journal of Sound and Vibration*, 96, 147-149.
- Fechter, L.D. (1993). Effects of acute styrene and simultaneous noise exposure on auditory function in the guinea pig. *Neurotoxicology and Teratology*, 15, 151-155.
- Fechter, L.D., Young, J.S., and Carlisle, L. (1988). Potentiation of noise induced threshold shifts and hair cell loss by carbon monoxide. *Hearing Research*, 34, 39-48.
- Ferris, K. (1966). The temporary effects of 125 c.p.s. octave-band noise on stapedectomised ears. *Journal of Laryngology and Otology*, 80, 579-582.
- FICON (1992). *Final Report: Airport Noise Assessment Methodologies and Metrics*. Washington, D.C.
- Fidell, S. (1996). Some policy and regulatory implications of recent findings of field studies on noise-induced sleep disturbance. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2261-2265.
- Fidell, S., and Jones, G. (1975). Effects of cessation of late night on an airport community. *Journal of Sound and Vibration*, 42, 411-427.
- Fidell, S., Barber, D.S., and Schultz, T.J. (1991). Updating a dosage-effect relationship for the prevalence of annoyance due to general transportation noise. *Journal of the Acoustical Society of America*, 89, 221-233.
- Fidell, S., Horonjeff, R., Schultz, T.J., and Teffeteller, S. (1983). Community response to blasting. *Journal of the Acoustical Society of America*, 74, 888-893.

Fidell, S., Howe, R.R., Tabachnik, B.G., Pearsons, K.S., and Sneddon, M.D. (1995b). *Noise-induced Sleep Disturbance in Residences Near Two Civil Airports*. National Aeronautics and Space Administration (NASA) Contractor Report 198252.

Fiddel, S., Pearsons, K., Howe, R., Tabachnick, B., Silvati, L., and Barber, D.S. (1994). *Noise-Induced Sleep Disturbance In Residential Settings*. BBN Contractor Report, USAF Material Command Armstrong Laboratory Report AL/OE-TR-1994-0131.

Fidell, S., Pearsons, K., Tabachnik, B., Howe, R., Silvati, L., and Barber, D.S. (1995a). Field study of noise-induced sleep disturbance. *Journal of the Acoustical Society of America*, 98, 1025-1033.

Fiddel, S., Teffeteller, S., Horonjeff, R.D., and Green, P.M. (1979). Predicting annoyance from the detectability of low level sounds. *Journal of the Acoustical Society of America*, 66, 1427-1434.

Fields, J.M. (1983). Variability in individuals responses to noise: community differences. In R. Lawrence (ed.), *Inter-Noise 83. Noise Control: The International Scene*. New York, NY: Noise Control Foundation, pp. 965-968.

Fields, J.M. (1984). The effect of numbers of noise events on people's reactions to noise: an analysis of existing survey data. *Journal of the Acoustical Society of America*, 75, 447-467.

Fields, J.M. (1985). *Research on the effect of noise at different times of day: models, methods and findings*. Hampton, USA: National Aeronautics and Space Administration, Langley Research Center, NASA Contractor Report CR-3888.

Fields, J.M. (1986). *The relative effect of noise at different times of day*. Hampton, USA: National Aeronautics and Space Administration, Langley Research Center, NASA Contractor Report CR-3965.

Fields, J.M. (1990). A quantitative summary of non-acoustical variables' effects on reactions to environmental noise. In: *Noise Con 90*. Poughkeepsie, NY: Noise Control Foundation, pp. 303-308.

Fields, J.M. (1991). *An updated catalog of 318 social surveys of residents' reactions to environmental noise (1943-1989)*. Contractor Report CR-187553. Hampton, USA: National Aeronautics and Space Administration, Langley Research Center, NASA.

Fields, J.M. (1992). *Effect of personal and situational variables on noise annoyance: With special reference to en route noise*. Contractor Report CR-189670. Hampton, USA: National Aeronautics and Space Administration, Langley Research Center, NASA.

Fields, J.M. (1993a). Theories and evidence on the effect of ambient noise on reactions to major noise sources. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, pp. 412-419.

- Fields, J.M. (1993b). Effects of personal and situational variables on noise annoyance in residential areas. *Journal of the Acoustical Society of America*, 93, 2753-2763.
- Fields, J.M. (1994). *A review of an updated synthesis of noise/annoyance relationships*. Hampton, USA: National Aeronautics and Space Administration, Langley Research Center, NASA Contractor Report CR 1944950.
- Fields, J.M. (1996a) *An analysis of residents' reactions to environmental noise sources within an ambient noise context*. Contract Report NAS1-19061. Federal Aviation Administration, National Air and Space Administration.
- Fields, J.M. (1996b). Measuring residents' reactions to noise with a magnitude scale. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2383-2388.
- Fields, J.M. (1996c). Progress toward the use of shared noise reaction questions. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2389-2394.
- Fields, J.M., and Powell, C.A. (1994). *A community survey of noise annoyance conducted under controlled helicopter noise exposure conditions*. Hampton, USA: National Aeronautics and Space Administration, Langley Research Center, NASA TM-86400, USA-235x.
- Fields, J.M., and Walker, J.G. (1982). Comparing the relationship between noise level and annoyance in different surveys. A railway noise vs. aircraft and road traffic comparison. *Journal of Sound and Vibration*, 81, 51-80.
- Finegold, L.S., Harris C.S., and von Gierke, H.E. (1994). Community annoyance and sleep disturbance: updated criteria for assessing the impacts of general transportation noise on people. *Noise Control Engineering Journal*, 42, 25-30.
- Finke, H.-O. (1980). *Akustische Kennwerte für die Messung und Beurteilung von Geräuschimmissionen und deren Zusammenhang mit der subjektiven Gestörtheit*. Braunschweig, Germany: Dissertation of Technical University,.
- Finkelman, J.M., Zeitlin, L.R., Romoff, R.A., Friend, M.A., and Brown, L.S. (1979). Conjoint effect of physical stress and noise stress on information processing performance and cardiac response. *Human Factors*, 21, 1-6.
- Finkle, A.L. and Poppen, J.R. (1948). Clinical effects of noise mechanical vibrations of a turbo-jet engine on man. *Journal of Applied Psychology*, 1, 183-204.
- Fisch, L. (1981). Aircraft noise and hearing impairment in children. *British Journal of Audiology*, 15, 231-240.
- Flanagan, J.L. (1972). *Speech Analysis, Synthesis and Perception*. Berlin, Germany: Springer-Verlag.

- Fletcher, J.L. (1972). *Effects of non-occupational exposure on a young adult population, Memphis State University*. Report for NIOSH, DHEW, HSM 099-71-52.
- Folch, J., Ojeda, F., and Esquivel, P. (1991). Rise in thymocyte number and thymulin serum level induced by noise. *Immunology Letters*, 30, 301-306.
- Follenius, M., Brandenberger, G., Lecornu, C., Simeoni, M., and Reinherdt, B. (1980). Plasma catecholamines and pituitary adrenal hormones in response to noise exposure. *European Journal of Applied Physiology*, 43, 253-261.
- Frankenhaeuser, M., and Lundberg, U. (1977). The influence of cognitive set on performance and arousal under different noise loads. *Motivation and Emotion*, 1, 139-149.
- French, N.R., and Steinberg, J.C. (1947). Factors governing the intelligibility of speech sounds. *Journal of the Acoustical Society of America*, 19, 90-119.
- Frerichs, R.R., Beeman, B.L., and Coulson, A.H. (1980). Los Angeles airport noise and mortality - Faulty analysis and public policy. *American Journal of Public Health*, 70, 357-362.
- Friedmann, J. and Globus, G. (1974). *Effects of cessation of late night landing noise on sleep electrophysiology in the home*. NASA Report 132543.
- Fruhstorfer, B. and Hensel, H. (1980). Extra-auditory responses to long-term intermittent noise stimulation in humans. *Journal of Applied Physiology*, 49, 985-993.
- Fruhstorfer, B., Fruhstorfer, H., and Grass, P. (1984). Daytime noise and subsequent night sleep in man. *European Journal of Applied Physiology*, 53, 159-163.
- Fruhstorfer, B., Pritsch, M.G., and Fruhstorfer, H. (1988). Effects of daytime noise load on the sleep-wake cycle and endocrine patterns in man: I. 24 hours neurophysiological data. *International Journal of Neuroscience*, 39, 197-209.
- Fuchs, G.L., Verzini, A.M., Skarp, A.H.O. (1996). The effects of low frequency noise on man- Two experiments. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2137-2140.
- Gabrielsson, A., Johansson, B., Johansson, B., Lindblad, A.C., and Persson, L. (1974). *Assessment of comfort and discomfort levels for pure tone. A methodological study*. Stockholm: Karolinska Institute, Technical Audiology, Report TA No. 74.
- Galambos, R., Rosenberg, P.E., and Glorig, A. (1953). The eyeblink response as a test for hearing. *Journal of Speech Hearing Disorder*, 18, 373-378.

- Gallo, R., and Glorig, A. (1964). Permanent threshold shift changes produced by noise exposure and aging. *American Industrial Hygiene Association Journal*, 25, 237-245.
- Galloway, W.J., and Bishop, D.E. (1970). Noise forecasts: evolution, evaluation, extensions, and land use interpretations. Rep. FAA-NO-70-9. Washington, DC: Federal Aviation Administration.
- Gamberale, F. (1985). The perception of exertion. *Ergonomics*, 28, 299-308.
- Gamberale, F., Goldstein, M., Kjellberg, A., Liska, L., and Löfstedt, P. (1982). Upplevd ljudstyrka och störningsgrad hos lågfrekvent ljud. [Perceived loudness and annoyance of low frequency noise.] *Arbete and Hälsa*, 1984:2. [National Board of Occupational Safety and Health, Solna, Sweden] (In Swedish).
- Gattoni, F., and Tarnopolsky, A. (1973). Aircraft noise and psychiatric morbidity: Preliminary communication. *Psychological Medicine*, 3, 516-520.
- Ginsberg, S. and Furedy, J.J. (1974). Stimulus repetition, change and assessments of sensitivities and relationships among an electrodermal and two plethysmographic components of the orienting reaction. *Psychophysiology*, 11, 35-43.
- Gjestland, T., and Oftedal, G. (1980). Assessment of noise annoyance: The introduction of a threshold level in Leq calculations. *Journal of Sound and Vibration*, 69, 603-610.
- Gjestland, T., Granoien, I.L.N., and Liasjo, K.H. (1995a). Community response to noise from a short-term military aircraft exercise. In M. Newman (ed.), *Proceedings of the 15th International Congress on Acoustics, Trondheim, Norway*, 109-112.
- Gjestland, T., Liasjo, K.H., and Granoien, I.L.N. (1995b). Community response to noise from short-term military aircraft exercise. *Journal of Sound and Vibration*, 182, 221-228.
- Glass, D.C., and Singer, J.E. (1972). *Urban Stress. Experiments on Noise and Social Stressors*. New York, NY: Academic Press.
- Globus, G., Friedmann, J., Cohen, H., Pearsons, S.K., and Fidell, S. (1974). The effects of aircraft noise on sleep electrophysiology as recorded in the home. In: *Noise as a Public Health Problem*. Washington DC: US Environmental Protection Agency, Report EPA 550/9-73.008, pp. 587-591.
- Glorig, A., and Nixon, J.C. (1962). Hearing loss as a function of age. *Laryngoscope*, 72, 1596-1610.
- Glorig, A., Grings, W., and Summerfield, A. (1958). Hearing loss in industry. *Laryngoscope*, 68, 447-465.

Goldberg, J.L. (1996). A change in operation mode at Sydney Kingsford-Smith Airport: Why it led to an aircraft noise disaster. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2317-2320.

Goldstein, M. (1994). Low-frequency components in complex noise and their perceived loudness and annoyance. *Arbete and Halsa* 1994, 2 (Work and Health; Scientific journal issued by National Institute of Occupational Health, S-171 84 Solna, Sweden).

Graeven, D. B. (1974). The effects of airplane noise on health: An examination of three hypotheses. *Journal of Health and Social Behaviour*, 15, 336-343.

Grandjean, E. (1974a). A working group for the socio-psychological survey on aircraft noise: Social survey on the effects of aircraft noise around three airports in Switzerland. In: *International Congress on Noise as a Public Health Problem*. Bern: Federal Air Office, pp. 645-654.

Grandjean, E. (1974b). *Sozio-psychologische Untersuchungen von Fluglarm*. Bern: Eidgenössisches Luftamt, Bundeshaus.

Grandjean, E., Graf, P., Lauber, A., Meier, H.P., and Muller, R. (1973). A survey of aircraft noise in Switzerland. *Proceedings of the International Congress of Noise as a Public Health Problem, Dubrovnik, Yugoslavia*, 645-660.

Gratton, M.A., Salvi, R.J., Kamen, B.A., and Saunders, S.S. (1990). Interaction of cisplatin and noise on the peripheral auditory system. *Hear Research Newsletter*, 50, 211-224.

Green, D.M. (1993). A theory of community noise. In A. Schick (ed.), *Contributions to Psychological Acoustics*. BIS: Oldenberg, 459-471.

Green, D.M. (1995). Weber's law in auditory intensity discrimination. In C.-A. Possamai (ed.), *Fechner Day 95*. Cassis, France: International Society for Psychophysics, pp. 1-20.

Green, K.B., Pasternack, B.S., and Shore, R.E. (1982a). Effects of aircraft noise on reading ability of school-age children. *Archives of Environmental Health*, 37, 24-31.

Green, K.B., Pasternack, B.S., and Shore, R.E. (1982b). Effects of aircraft noise on hearing ability of school-age children. *Archives of Environmental Health*, 37, 284-289.

Greifahn, B. (1991). Environmental noise and sleep. Review- Need for further research. *Applied Acoustics*, 32, 255-268.

Greifahn, B. (1977). Long-term exposure to noise. Aspects of adaptation, habituation and compensation. *Waking and Sleeping*, 1, 383-386.

Greifahn, B. (1986). A critical load for nocturnal high-density road traffic noise. *American Journal of Industrial Medicine*, 9, 261-269.

Griefahn, B. (1989). Cardiac responses caused by shots of tanks during sleep. *Journal of Sound and Vibration*, 128, 109-119.

Griefahn, B. (1990). Präventivmedizinische Vorschläge für den Nächtlichen Schallschutz. *Zeitschrift für Lärmbekämpfung*, 37, 7-14.

Griefahn, B., and Gros, E. (1983). Disturbances of sleep—interaction between noise, personal and psychological variables. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano, Italy: Centro Ricerche e Studi Amplifon, pp. 895-904.

Griefahn, B., and Gros, E. (1986). Noise and sleep at home, a field study on primary and after-effects. *Journal of Sound and Vibration*, 105, 373-383.

Griefahn, B., and Jansen, G. (1978). EEG-responses caused by environmental noise during sleep. Their relationships to exogenic and endogenic influences. *The Science of the Total Environment*, 10, 187-199.

Griefahn, B., Jansen, G., and Klosterkötter, W. (1976). *On the problem of noise-induced sleep disturbances—A review of sleep literature*. Berlin, Germany: Umweltbundesamt, Report No. 4.

Griffin, M.J. (1990). *Handbook of Human Vibration*. London: Academic Press.

Griffiths, I. D., and Langdon, F. J. (1968). Subjective response to road traffic noise. *Journal of Sound and Vibration*, 8, 16-32.

Griffiths, I.D., and Raw, G.J. (1986). Community and individual response to changes in traffic noise exposure. *Journal of Sound and Vibration*, 111, 209-217.

Griffiths, I.D., and Raw, G.J. (1989). Adaptation to changes in traffic noise exposure. *Journal of Sound and Vibration*, 132, 331-336.

Guilleminault, C., and Stoohs, R. (1995). Arousal, increased respiratory efforts, blood pressure and obstructive sleep apnoea. *Journal of Sleep Research*, 4, Suppl 1, 117-124.

Gunn, W.J. (1987). The importance of the measurement of annoyance in prediction of effects of aircraft noise on health and well-being of noise-exposed communities. *Developments in Toxicological and Environmental Science*, 15, 237-256.

Gunn, W.J. (1987). The importance of the measurement of annoyance in prediction of effects of aircraft noise on the health and well-being of noise-exposed communities. In H.S. Koelega (ed.), *Environmental Annoyance: Characterization, Measurement, and Control*. Amsterdam, The Netherlands: Elsevier, pp. 237-256.

Gunn, W.J., Petterson, H.P., Cornog, J., Klaus, P., and Connor, W.K. (1975). *A model and plan for a longitudinal study of community response to aircraft noise*. Hampton, USA: National Aeronautics and Space Administration, NASA TMX-72690.

Gunn, W.J., Shigehisa, T., and Shepherd, W.T. (1977). Annoyance response to spectrally modified recorded aircraft noise during television-viewing. *Journal of Auditory Research*, 17, 241-249.

Guski, R. (1983). First steps toward the concept of quietness and its psychological and acoustical determinants. In R. Lawremce (ed.), *Inter-Noise 83. Noise Control: The International Scene*. New York, NY: Noise Control Foundation, pp. 843-846.

Haider, M., Kundi, E., Groll-Knapp, E., and Koller, M. (1990). Interactions between noise and air pollution. *Environment International*, 16, 593-601.

Hall, F.L. (1984). Community response to noise: is all noise the same? *Journal of the Acoustical Society of America*, 76, 1161-1168.

Hall, F.L., Birnie, S.E., Taylor, S.M., and Palmer, J.E. (1981). Direct comparison of community response to road traffic noise and to aircraft noise. *Journal of the Acoustical Society of America*, 70, 1690-1698.

Hall, F.L., Taylor, M., and Birnie, S.E. (1985). Activity interference and noise annoyance. *Journal of Sound and Vibration*, 103, 237-252.

Hallpike, C.S. (1967). The loudness recruitment phenomenon: A clinical contribution to the neurology of hearing. In A.B. Graham (ed.), *Sensorineural Hearing Processes and Disorders*, pp. 489-499.

Hallpike, C.S., and Hood, J.D. (1959). Observations upon the neurological mechanism of the loudness recruitment phenomenon. *Acta Otolaryngologica*, 50, 472-486.

Hamernik, R.P., Ahroon, W.A., and Hsueh, K.D. (1991). The energy spectrum of an impulse: Its relation to hearing loss. *Journal of the Acoustical Society of America*, 90, 197-204.

Hamernik, R.P., Turrentine, G., Roberto, M., Salvi, R., and Henderson, D. (1984). Anatomical correlates of impulse noise-induced mechanical damage in the cochlea. *Hearing Research*, 13, 229-247.

Hanson, E.K.S., Sceellekens, J.M.H., Veldman, J.B.P., and Mulder, L.J.M. (1991). Psychomotor and cardiovascular consequences of mental effort and noise. *Human Movement Science*, 12, 607-626.

Harris, C.S. (1974). The effects of different types of acoustic stimulation on performance. In: *International Congress on Noise as a Public Health Problem*. Washington DC: US Environmental Protection Agency, Report EPA 550/9-73-008, pp. 389-403.

Harris, J.D. (1965). Pure-tone acuity and the intelligibility of everyday speech. *Journal of the Acoustical Society of America*, 37, 824-830.

Hebb, D.O. (1955). Drives and the C.N.S. (Conceptual Nervous System). *Psychological Review*, 62, 243-254.



- Hede, A.J. and Bullen, R.B. (1982a). Aircraft noise in Australia: a survey of community reaction. *National Acoustic Laboratories Report No. 88* Australian Government Publishing Service, Canberra ACT.
- Hede, A.J., and Bullen, R.B. (1982b). Community reaction to noise from a suburban rifle range. *Journal of Sound and Vibration*, 82, 39-49.
- Hellman, R.P. (1982). Loudness, annoyance and noisiness produced by single-tone-noise complexes. *Journal of the Acoustical Society of America*, 72, 62-73.
- Hellman, R.P. (1985). *Contribution of tonal components to the overall loudness, annoyance and noisiness of noise. Relation between single tones and noise spectral shape*. Washington DC: National Aeronautics and Space Administration, NASA Contractor Report 3892.
- Hellman, R.P., and Meiselman, C.H. (1990). Loudness relators for individuals and groups in normal and impaired hearing. *Journal of the Acoustical Society of America*, 88: 2596-2606.
- Hellström, P.A. (1991). The effects on hearing from portable cassette players: A follow-up study. *Journal of Sound and Vibration*, 151, 461-469.
- Hellström, P.A., and Axelsson, A. Sound levels, hearing habits and hazards of using portable cassette players. *Journal of Sound and Vibration*, 127, 521-528 (1988)..
- Hellström, P.A., Dengerink, H.A., and Axelsson, A. (1992). Noise levels from toys and recreational articles for children and teenagers. *British Journal of Audiology*, 26: 267-270.
- Henkin, R.I., and Knigge, K.M. (1963). Effect of sound on the hypothalamic-pituitary-adrenal axis. *American Journal of Physiology*, 204, 710-714.
- Herridge, C.F., and Chir, B. (1972). Aircraft noise and mental hospital admissions. *Sound*, 6, 32-36.
- Hinchcliffe, R. (1959). The threshold of hearing as a function of age. *Acustica*, 9, 303-308.
- Hiroto, D.S. and Seligman, M.E.P. (1975). Generality of learned helplessness in man. *Journal of Personality and Social Psychology*, 31, 311-327.
- Hobson, J.A. (1989). *Sleep*. New York, NY: Scientific American Library (W.H. Freeman and Co.).
- Hockey, R. (1979). Stress and the cognitive components of skilled performance. In V. Hamilton and D.M. Warburton (eds.), *Human Stress and Cognition*. New York, NY: Wiley, pp. 141-177.
- Hofman, W.F., and Liefing, B.J. (1992). The effects of traffic noise on ultradian sleep periodicity. *Journal of Sleep Research*, 1992;1, Supp. 1:98.

Hofman, W.F., Kumar, A., and Tulen, J.H.M. (1995). Cardiac reactivity to traffic noise during sleep in man. *Journal of Sound and Vibration*, 179, 577-589.

Holmberg, K., Landstrom, U., Kjellberg, A., and Tesarz, M. (1996). Measurement and analyses of temporal variations in noise and the relation to noise annoyance. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2521-2524.

Horio, K., Sakamoto, H., and Matsui, K. (1972). Adrenocortical response to noise exposure. In: *Proceedings of the Joint Meeting of International Societies for Hygiene, Preventive and Social Medicine* (Vienna, October 20-November 7, 1972) Vienna, Sonderdruck Reprint, pp. 1-4.

Horne, J. (1990). *Why We Sleep*. New York: Oxford University Press.

Horne, J.A., Pankhurst, F.L., Reyner, L.A., Hume, K., and Diamond, I.D. (1994). A field study of sleep disturbance: effects of aircraft noise and other factors on 5,742 nights of actimetrically monitored sleep in a large sample. *Sleep*, 17, 146-159.

Horonjeff, R.D., Fidell, S., Teffeteller, S.R., and Green, D.M. (1982). Behavioral awakening as functions of duration and detectability of noise intrusions in the home. *Journal of Sound and Vibration*, 184, 327-336.

Houtgast T., and Steeneken, H.J.M. (1983). Experimental verification of the STI: A valid basis for setting indoor noise level criteria. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano, Italy: Centro Ricerche e Studi Amplifon, Vol. 1, pp. 477-487.

Houtgast, T. (1980). Indoor speech intelligibility and indoor noise level criteria. In J.V. Tobias, G. Jansen, and W.D. Ward (eds.), *Noise as a Public Health Problem*. Rockville, MD: ASHA Reports 10, pp. 172-183.

Houtsma, A.J.M., Durlach, N.I., and Braida, L.D. (1980). Intensity perception XI. Experimental results on the relation of intensity resolution to loudness matching. *Journal of the Acoustical Society of America*, 68, 807-813.

Howarth, H.V.C., and Griffin, M.J. (1990). Subjective response to combined noise and vibration: Summation and interaction effects. *Journal of Sound and Vibration*, 143, 443-454.

Humes, L.E., Dirks, D.D., Bell, T.S., Ahlstrom, C., and Kincaid, G.E. (1986). Application of the Articulation Index and the Speech Transmission Index to the recognition of speech by normal-hearing and hearing-impaired listeners. *Journal of Speech Hearing Research*, 29, 447-462.

Hygge, S. (1993). Classroom experiments on the effects of aircraft, traffic, train, and verbal noise on long-term recall and recognition in children aged 12-14 years. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 2, pp. 531-534.

Hygge, S. (1994). *Classroom experiments on the effects of aircraft, road traffic, train, and verbal noise presented at 66 dBA Leq, and of aircraft and*

road traffic noise presented at 55 dBA Leq, on long-term recall and recognition in children aged 12-14 years. Gävle, Sweden: Royal Institute of Technology, Report to the Swedish Environmental Protection Agency.

Hygge, S., Bullinger, M., and Evans, G.W. (1994). The Munich Airport Noise Study: Cognitive effects on children from before to after the change over of airports. *Abstract Guide from the 23rd International Congress of Applied Psychology, Madrid, Spain, July, 1994*. Gävle, Sweden: Royal Institute of Technology, Report to the Swedish Environmental Protection Agency.

Hygge, S., Evans, G.W., and Bullinger, M. (1993). The Munich Airport Noise Study: Psychological, cognitive, motivational, and quality of life effects on children. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 301-308.

Hygge, S., Evans, G.W., and Bullinger, M. (1996). The Munich airport noise study: Cognitive effects on children from before to after the changeover of airports. *Proceedings of Inter-noise '96, Liverpool, U.K.*, 2189-2194.

Hygge, S., Rönnerberg, J., Larsby, B., and Arlinger, S. (1992). Normal-hearing and hearing-impaired subjects' ability to just follow conversation in competing speech, reversed speech, and noise backgrounds. *Journal of Speech and Hearing Research*, 35, 208-215.

IEC Publication 537 (1976). *Frequency Weighting for the Measurement of Aircraft Noise (D-weighting)*. Geneva, Switzerland: International Electrotechnical Commission.

Irwin, M.R., Segal, D.S., Hauger, R.L., and Smith, T.L. (1989). Individual behavioral and neuroendocrine differences in responsiveness to audiogenic stress. *Pharmacology, Biochemistry and Behavior*, 32, 913-917.

Ishii, E.K. (1993). Department of Epidemiology, University of Pittsburgh, Personal communication.

Ising, H. (1981). Interaction of noise-induced stress and Mg decrease. *Artery*, 9, 205-211.

Ising, H. (1983). *Stressreaktionen und Gesundheitsrisiko bei Verkehrslärmbelastung*. Berlin: Dietrich Reimer [Wa Bo Lu Berichte 2/1983].

Ising, H., Babisch, W., Gandert, J., and Scheuermann, B. (1988). Hörschaden bei jugendlichen Berufsanfängern aufgrund von Freizeitlärm und Musik. *Zeitschrift für Lärmbekämpfung*, 35, 35-41.

Ising, H., Babisch, W., Kruppa, B., Lindthammer, A., and Wiens, D. (1996). Subjective work noise- A major risk factor in myocardial infarction. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2159-2163.

Ising, H., Bertschat, F., Ibe, K., Stoboy, V., Goossen, C., and Hengst, G. (1986). Stress-induced Ca/Mg shifts and vascular response in animals and men; comparison to electrolyte alterations in myocardial infarction patients. *Magnesium-Bulletin*, 8: 95-103.

Ising, H., Havestadt, C., and Neus, H. (1985). Health effects of electrolyte alterations in humans caused by noise stress. In: *Inter-Noise 85*. Dortmund, Germany: Bundesanstalt für Arbeitsschutz, Vol. II, pp. 973-976.

Ising, H. and Rebentisch, E. (1993). Comparison of acute reactions and long term extra-aural effects of occupational and environmental noise exposure. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp 280-287.

ISO (1982). *Acoustics-Description and measurement of environmental noise - Part 1: Basic quantities and procedures*. Geneva, Switzerland: International Organization for Standardization, International Standard, ISO 1996-1:1982(E).

ISO. (1989). *Acoustics-Audiometric test methods. Part 1: Basic pure tone air and bone conduction threshold audiometry*. Geneva, Switzerland: International Organization for Standardization, International Standard ISO 8253-1989.

ISO. (1990). *Acoustics-Determination of occupational noise exposure and estimation of noise-induced hearing impairment*. Geneva, Switzerland: International Organization for Standardization, International Standard ISO 1999, 1990(E).

Iwamoto, M., Ishi, F., Yoneda, J., Morie, T., and Harada, N. (1995). A physiological response (plasma cyclic AMP) and a psychological response (STAI-A-Atate) to noise exposure and/or calculation task. *Journal of Sound and Vibration*, 186, 599-605.

Jakobsen, J., and Plovsing, B. (1996). Combined assessment of noise from shooting and training areas. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2443-2446.

Jansen, G. (1962). Vegetative Lärmwirkungen bei Industriearbeitern [Vegetative effects of noise on industrial workers]. *Zeitschrift für Lärmbekämpfung*, 6, 126-128.

Jansen, G. (1969). Effects of noise on physiological state. In W.D. Ward and J. Fricke (ed.), *Noise as a Public Health Hazard*. Washington DC: American Speech Hearing Association, ASHA Report No. 4, pp. 89-98.

Jenkins, L., Tarnopolsky, A., and Hand, D. (1981). Psychiatric admissions and aircraft noise from London Airport: four-year, three-hospitals' study. *Psychological Medicine*, 11, 765-782.

Jirkova, H., and Kromarova, B. (1965). Studies on the influence of noise on the general health of workers in large engineering works, an attempt at evaluation. *Prac. Lekarstov*, 17, 147-148.

Job, R.F.S. and Barnes, B.W. (1995). Stress and consumption: Inescapable shock, neophobia and finickiness about drinking quinine-adulterated water. *Behavioral Neuroscience*, 109, 106-116.

- Job, R.F.S., Topple, A., Carter, N.L., Peploe, P., Taylor, R., and Morrell, S. (1996b). Test-retest reliability of psychological scales (sensitivity and attitude) related to community reaction to noise. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2413-2418.
- Job, R.F.S., Topple, A., Carter, N.L., Peploe, P., Taylor, R., and Morrell, S. (1996c). Public reactions to changes in noise levels around Sydney Airport. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2419-2424.
- Job, R.F.S. (1988a). Community response to noise: A review of factors influencing the relationship between noise exposure and reaction. *Journal of the Acoustical Society of America*, 83, 991-1001.
- Job, R.F.S. (1988b). Over-reaction to changes in noise exposure: The possible effect of attitude. *Journal of Sound and Vibration*, 126, 550-552.
- Job, R.F.S. (1991). Reliability and stability of noise reaction scales. *Transportation Research Record*, 1312, 101-108.
- Job, R.F.S. (1993). Psychological factors of community reaction to noise. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 48-59.
- Job, R.F.S. (1995). Measuring annoyance and other personal reactions to noise. In M. Newman (ed.), *Proceedings of the 15th International Congress on Acoustics, Trondheim, Norway*, 287-290.
- Job, R.F.S. (1996). A model of human reaction to noise. In S Pandalai (Ed.). *Current Topics in Acoustical Research*. Trivandrum, India: Council of Scientific Information, 635-650.
- Job, R.F.S., and Bullen, R.B. (1985). *Social Survey Methodology: A Review of the Assessment of Community Noise Reaction in Dose/Response Studies*. National Acoustic Laboratories Report 106. Canberra: Australia Government Publishing Service.
- Job, R.F.S., and Bullen, R.B. (1987). The effects of a face to face interview versus a group administered questionnaire in determining reaction to noise. *Journal of Sound and Vibration*, 116, 161-168.
- Job, R.F.S., and Hede, A.J. (1989). Community reaction to noise from power stations. In G.C. Maling, Jr. (ed.), *Inter-Noise 89*. New York, NY: Noise Control Foundation, pp. 865-868.
- Job, R.F.S., Bullen, R.B., and Burgess, D.H. (1991). Noise induced reaction in a work community adjacent to aircraft runways: The Royal Australian Airforce. In A. Lawrence (ed.), *Inter-Noise '91: The Cost of Noise*. Poughkeepsie, NY: Noise Control Foundation, pp. 895-898.
- Job, R.F.S., Peploe, P., and Cook R. (1995). Factors influencing reaction to individual impulsive events experienced in the home. In M. Newman (ed.), *Proceedings of the 15th International Congress on Acoustics, Trondheim, Norway*, 295-298.

Job, R.F.S., Kenny, D., Carter, N.L., Taylor, R., Morrell, S., and Peploe, P. (1996a). Personality, coping and stress reactions. *Proceedings (Edited Abstracts) of the International Congress on Stress and Health (Sydney, Australia, October, 1996)*. D. Kenny (Ed.). Sydney, NSW: University of Sydney, 124.

Job, R.F.S., Topple, A., Hatfield, J., Carter, N.L., Peploe, P., and Taylor, R. (1996d). General scales of community reaction to noise (affect and dissatisfaction) are more stable than scales of annoyance. *Proceedings of the Fourth International Congress on Sound and Vibration, June 24-27, St Petersburg, Russia*.

Johansson, B. (1952). A noise and hearing survey in Swedish iron ore mines. *Jarkontorets Annals*, 136, 468.

Johansson, B., Kylin, B., and Langfy, M. (1967). Acoustic reflex as a test of individual susceptibility to noise. *Acta Oto-Laryngologica*, 64, 256-262.

Johnson, A.-C., Juntunen, L., Nylen, P., Borg, E., and Hoglund, G. (1988). Effect of interaction between noise and toluene on auditory function in the rat. *Acta Otolaryngol*, 105, 56-63.

Johnson, L.C., Townsend, R.E., and Naitoh, P. (1973). Prolonged exposure to noise as a sleep problem. *Proceedings of the International Congress on Noise as a Public Health Problem, Dubrovnik, 1973*. U.S. E.P.A. Report 550/9-73-008, 559-574.

Jonah, B.A., Bradley, J.S., and Dawson, N.E. (1981). Predicting individual subjective responses to traffic noise. *Journal of Applied Psychology*, 66, 490-501.

Jones, D.M. and Davies, D.R. (1984). Individual and group differences in the response to noise. In D.M. Jones and A.J. Chapman (eds.) *Noise and Society*. Chichester, UK: Wiley. 125-153.

Jones, D.M. Performance effects. In D.M. Jones and A.J. Chapman (eds.)(1984). *Noise and Society*. Chichester, UK: Wiley, 155-184.

Jones, D.M., and Chapman, A.J. (eds.)(1984). *Noise and Society*. Chichester, UK: Wiley.

Jones, N. and Tauscher, J. (1978). Residence under airport landing patterns as a factor in health. *Archives of Environmental Health*, 33, 10-12.

Jurriens, A.A., Griefahn, B., Kumar, A., Vallet, M., and Wilkinson, R. (1983). An essay in European research collaboration: Common results from the project on traffic noise and sleep in the home. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano: Centro Ricerche e Studi Amplifon, Vol. 2, pp. 929-937.

Kahn, M.S., Johansson, O., and Sundback, U. (1996). Evaluation of annoyance response to engine sounds using different rating methods. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2517-2520.

Karagodina, I.L., Soldatkina, S.A., Vinokur, I.L., and Klimukhin, A.A. (1969). Effect of aircraft noise on the population near airports, *Hygiene and Sanitation*, 34, 182-187.

Kastka, J. and Hangartner, M. (1986). Machen hassliche Strassen den Verkehrslärm lastiger? Eine umweltpsychologische Analyse zum Einfluss architektonisch gestalterischer Elemente auf die Störwirkung von Verkehrslärm auf die Anwohner. *Arcus*, 1, 23-29.

Kastka, J., and Paulsen, R. (1991). Felduntersuchung zur Wirkung von Lärm und Erschütterung für verschiedene Quellen. In: *Deutsche Physikalische Gesellschaft: Fortschritte der Akustik-DAGA '91*. Bad Honnef: DPG GmbH, pp. 441-444.

Kastka, J., Mau, U., Muth, T., and Siegmann, S. (1996). Standings and results of the research on aircraft noise- Longitudinal study at Dusseldorf airport 1987-1995. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 305-310.

Katz, J. (ed.)(1994). *Handbook of Clinical Audiology*. Baltimore, ML: Williams and Wilkins, 4th ed.

King, P.F. (1941). Hearing conservation in aircrew and group support personnel. In J.C. Guignard and P.F. King (eds.), *Aeromedical Aspects of Vibration and Noise*. Paris: NATO/AGARD, pp. 204-241.

King, P.F., Coles, R.R.A., Lutman, M.E., and Robinson, D.W. *Assessment of Hearing Disability. Guidelines for Medical Practice*. London: Whurr Publishers (1992)..

Kinhill, Pty Ltd. (1990). *Proposed third Runway Sydney (Kingsford Smith) Airport: Draft Environmental Impact Statement*. Parramatta: Macarthur Press.

Kitte, G., and Kieroff, H.G. (1971). Zur Problematik der Farbsinnänderung unter Lärmimmission [On the problem of changes in colour detection due to noise exposure]. *Klinische Monatsblätter für Augenheilkunde*, 158, 732-739.

Kjellberg, A., and Goldstein, M. (1985). Loudness assessment of band noise of varying bandwidth and spectral shape. An evaluation of various frequency weighting networks. *Journal of Low Frequency Noise and Vibration*, 4, 12-26.

Klein, K., and Gröbl, M. (1969). Über hämodynamische Reaktionen unter akustischen Reizen [Hemodynamic reactions to acoustic stimuli]. *Wiener Klinische Wochenschrift*, 81, 705-709.

Klosterkötter, W. (1974). New experiences on noise effects. *Kampf dem Lärm*, 4, 3-11.

Klumpp, R.G., and Webster, J.C. (1963) Physical measurements of equally speech-interfering navy noises. *Journal of the Acoustical and Society of America*, 35, 1328-1338.

Knipschild, P. (1976). *Medische gevolgen van vliegtuiglawaai*. Amsterdam: Coronel Laboratorium, Doctoral Dissertation.

Knipschild, P., Meijer, H., and Salle, H. (1981). Aircraft noise and birthweight. *International Archives of Occupational and Environmental Health*, 48, 131-136.

Knipschild, P.V. (1977a). Medical effects of aircraft noise: community cardiovascular survey. *International Archives of Occupational and Environmental Health*, 40, 185-190.

Knipschild, P.V. (1977b). Medical effects of aircraft noise: general practice survey. *International Archives of Occupational and Environmental Health*, 40, 191-196.

Knipschild, P.V., and Oudshoorn, N. (1977). Medical effects of aircraft noise: drug survey. *International Archives of Occupational and Environmental Health*, 40, 197-200.

Konecni, V.J. (1975). The mediation of aggressive behaviour: Arousal level versus anger and cognitive labeling. *Journal of Personality and Social Psychology*, 32, 706-712.

Konishi, T., and Kelsey, E. (1968). Effect of cyanide on cochlear potentials. *Acta Oto-Laryngologica*, 65, 381-399.

Korn, T.S. (1954). Effect of psychological feedback on conversational noise reduction in rooms. *Journal of the Acoustical and Society of America*, 26, 793-794.

Korte, C., and Grant, R. (1980). Traffic noise, environmental awareness, and pedestrian behavior. *Environment and Behavior*, 12, 408-420.

Korte, C., Ypma, I., and Toppen, A. (1975). Helpfulness in Dutch society as a function of urbanization and environmental input level. *Journal of Personality and Social Psychology*, 32, 996-1003.

Kryter, K.D. (1960). Damage risk criteria for hearing. In L.L. Beranek (ed.), *Noise Reduction*. New York, NY: McGraw-Hill, pp. 495-513.

Kryter, K.D. (1962). Methods for the calculation and use of the articulation index. *Journal of the Acoustical Society of America*, 34, 1689-1697.

Kryter, K.D. (1970). *The Effects of Noise on Man*. New York, NY: Academic Press.

Kryter, K.D. (1982). Community annoyance from aircraft and ground vehicle noise. *Journal of the Acoustical Society of America*, 72, 1212-1242.

Kryter, K.D. (1983). Response of K.D. Kryter to modified comments by T.J. Schultz on K.D. Kryter's paper "Community annoyance from aircraft and ground vehicle noise" [*J. Acoust. Soc. Am.* 72, 1243-1252 (1982)]. *Journal of the Acoustical Society of America*, 73, 1066-1068.



Kryter, K.D. (1985). *The Effects of Noise on Man*, 2nd. ed New York: Academic Press.

Kryter, K.D. (1990). Aircraft noise and social factors in psychiatric hospital admission rates: a re-examination of some data. *Psychological Medicine*, 20, 395-411.

Kryter, K.D. (1991). Effects of nosocosis and industrial and gun noise on hearing of U.S. adults. *Journal of the Acoustical Society of America*, 90, 3196-3201.

Kryter, K.D. (1994). *The Handbook of Hearing and the Effects of Noise. Physiology, Psychology, and Public Health*. New York: Academic Press.

Kryter, K.D., Ward, W.D., Miller, J.D., and Eldredge, D.H. (1966). Hazardous exposure to intermittent and steady state noise. *Journal of the Acoustical Society of America*, 39, 451-463.

Kryter, K.D., Williams, C., and Green, D.M. (1962). Auditory acuity and the perception of speech. *Journal of the Acoustical Society of America*, 34, 1217-1223.

Kugler, J., Kalveram, K.T., and Lange, K.W. (1990). Acute, not chronic, exposure to unpredictable noise periods affects splenic lymphocytes and plasma corticosterone in the mouse. *International Journal of Neuroscience*, 51, 233-234.

Kumar, A., Tulen, J.H.M., Hofman, W.F., van Diest, R., and Jurriens, A.A. (1983). Does double glazing reduce traffic noise disturbance during sleep? In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano, Italy: Centro Ricerche e Studi Amplifon, Vol. 2, pp. 939-950.

Kundi, M., Weninger, U., Stidl, H.-G., and Haider, M. (1984). Effects of combined exposures to steady-state and impulse noise on inner ear functions. In O. Manninen (ed.), *Combined Effects of Environmental Factors*. Tampere, Finland: Keskupaino Central Printing House, pp. 169-178.

Kup, W. (1965). Der Einfluss des Lebensalters auf Entstehung und Progredienz der Lärmschwerhörigkeit. [The influence of age on the development of progression of noise deafness] *HNO [Hals-Nasen-Ohrenärzte]*, 13, 268-272.

Kurra, S., Maekawa, Z.I., and Morimoto, M. (1995). A prediction model for annoyance against transportation noise sources. In M. Newman (ed.), *Proceedings of the 15th International Congress on Acoustics, Trondheim, Norway*, 165-168.

Kuwano, S., Namba, S., and Miura, H. (1989). Advantages and disadvantages of A-weighted sound pressure level in relation to subjective impression of environmental noises. *Noise Control Engineering Journal*, 33, 107-115.

Labiale, G. (1983). Laboratory study of the influence of noise level and vehicle number on annoyance. *Journal of Sound and Vibration*, 90, 361-371.

Lambert, J., and Vallet, M. (1994). *Study Related to the Preparation of a Communication on a Future EC Noise Policy*. Bron Cedex, France: INRETS, LEN report no. 9420.

Lambert, J., Champelovier, P., and Vernet, I. (1996). Annoyance from high speed train noise: A social survey. *Journal of Sound and Vibration*, 193, 21-28.

Lambert, J., Simonnet, F., and Vallet, M. (1984). Patterns of behaviour in dwellings exposed to road traffic noise. *Journal of Sound and Vibration*, 92, 159-172.

Lampert, B.L., and Henderson, T.L. (1973). *Occupational noise and hearing, 1968-1972*. Cincinnati, OH: National Institute for Occupational Safety and Health, NIOSH Technical Information.

Landale, N. and Guest, A. (1985). Constraints, satisfaction and residential mobility. *Demography*, 22:2, 298-303.

Langdon, F.J. (1976). Noise nuisance caused by road traffic in residential areas. *Journal of Sound and Vibration*, 47, 243-282.

Langdon, F.J. (1987). Some residual problems in noise nuisance: a brief review. In H.S. Koelega (ed.), *Environmental Annoyance: Characterization, Measurement, and Control*. Amsterdam, The Netherlands: Elsevier, pp. 321-331.

Langdon, F.J., and Buller, I.B. (1977). Road traffic noise and disturbance to sleep. *Journal of Sound and Vibration*, 50, 13-28.

Langdon, F.J., and Griffiths, I.D. (1982). Subjective effects of traffic noise exposure. II: Comparisons of noise indices, response scales, and the effects of changes in noise levels. *Journal of Sound and Vibration*, 83, 171-180.

Lazarus, H. (1986). Prediction of verbal communication in noise—a review (part 1). *Applied Acoustics*, 19, 439-464.

Lazarus, H. (1987). Prediction of verbal communication in noise—a development of generalized SIL curves and the quality of communication (part 2). *Applied Acoustics*, 20, 245-261.

Lazarus, H. (1990). New methods for describing and assessing direct speech communication under disturbing conditions. *Environment International*, 16, 373-392.

Lee, K., Hicks, G., and Nino-Marcia, G. (1991). Validity and reliability of scales to assess fatigue. *Psychiatric Research*, 36, 291-298.

Lehman, G. (1959). Nachweis und Bedeutung der vegetativen Larmbelastung. *Internationales Journal für Prophylaktische Medizin und Sozialhygiene*, 6, 1-3.

Lehmann, G. (1955). Untersuchungen der nervösen Larmbelastung. *Karl-Arnold Festschrift*. Opladen, Köln.

Lehmann, G., and Tamm, J. (1956). Über Veränderungen der Kreislaufdynamik des ruhenden Menschen unter Einwirkung von Geräuschen [Changes of circulatory dynamics of resting men under the effects of noise]. *International Zeitschrift für angewandte Physiologie einschliesslich Arbeitsphysiologie*, 16, 217-227.

Lercher, P. and Kofler, W. (1993). Adaptive behavior to road traffic noise, blood pressure and cholesterol. In M. Vallet (ed.), *Noise as a Public Health Problem*, Vol 2. Arcuil Cedex: INRETS, 465-468.

Lercher, P. and Widmann, U. (1993). Factors determining community response to road traffic noise. In M. Vallet (ed.) *Noise as a Public Health Problem*, Vol 2, Nice, France: Institut National de recherche sur les Transports et leur Securite, 201-204.

Lercher, P. (1996). Environmental noise and health: An integrated research perspective. *Environment International*, 22, 117-129.

Lercher, P. (1996). Road traffic noise, self-medication, and prescriptions: A community study. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2171-2176.

Leventhall, H.G. (1988). Low frequency noise in buildings—internal and external sources. *Journal of Low Frequency Noise and Vibration*, 7, 74-85.

LeVere, T.E., Bartus, R.T., and Hart, F.D. (1972).

LeVere, T.E., Morlock, G.W., and Hart, F.D. (1975). Waking performance decrements following minimal sleep disruption: The effects of habituation during sleep. *Physiological Psychology*, 13, 147-154.

Levi, L. (1966). Life stress and urinary excretion of adrenalin and noradrenalin. In W. Raab (ed.) *Prevention of Ischaemic Heart Disease*. Springfield: Charles E. Thomas.

Lindberg, S., and Backteman, O. (1988). Loudness of impulse and community noises. *Journal of Low Frequency Noise and Vibration*, 7, 98-103.

Linden, W. (1987). Effect of noise distraction during mental arithmetic on phasic cardiovascular activity. *Psychophysiology*, 24, 328-333.

Lindvall, T., and Radford, E.P. (eds.) (1973). Measurement of annoyance due to exposure to environmental factors. *Environmental Research*, 6, 1-36.

Lockett, M.F., and Marwood, J.F. (1973). Sound deprivation causes hypertension in rats. *Fed. Proc.*, 32(11):2111.

Loeb, M. (1986). *Noise and Human Efficiency*. New York: Wiley.

Lukas, J.S. (1972a). Awakening effects of simulated sonic booms and aircraft noise on men and women. *Journal of Sound and Vibration*, 20, 457-466.

Lukas, J.S. (1972b). Effects of aircraft noise on human sleep. *American Industrial Hygiene Association Journal*, 33, 298-303.

Lukas, J.S. (1975). Noise and sleep: a literature review and a proposed criterion for assessing effect. *Journal of the Acoustical Society of America*, 58, 1232-1242.

Lukas, J.S. (1977). *Measures of noise level. Their relative accuracy in predicting objective and subjective responses to noise during sleep*. Washington DC: U.S. Environmental Protection Agency, EPA-Report 600/1-77-010.

Lukas, J.S., and Dobbs, M.E. (1972). *Effects of aircraft noise on the sleep of women*. Washington, DC, National Aeronautics and Space Administration, NASA Contractor Report CR-2041.

Lukas, J.S., Dobbs, M.E., and Kryter, K.D. (1971). *Disturbance of human sleep by subsonic jet aircraft noise and simulated sonic booms*. Washington, DC: National Aeronautics and Space Administration, NASA Contractor Report CR-1780, 1-68.

Lundberg, U., and Frankenhaeuser, M. (1978). Psychophysiological reactions to noise as modified by personal control over noise intensity. *Biological Psychology*, 6, 51-59.

Lutman, M.E., and Haggard, M.P. (eds.)(1983). *Hearing Science and Hearing Disorders*. London: Academic Press.

MacLaren, D., Gibson, H., Parry-Billings, M., and Edwards, R.A. (1989). A review of metabolic and physiological factors in fatigue, 17, 29-66.

Maier, S.F. and Seligman, M.E.P. (1976). Learned Helplessness: Theory and Evidence. *Journal of Experimental Psychology: General*, 105, 3-46.

Manninen, O. (1983). A review of exposure combinations including noise: The meaning of complex exposure. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano, Italy: Centro Ricerche e Studi Amplifon, Vol. 1, pp. 637-659.

Manninen, O. (1993). Synopsis of studies on combined effects. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 511-516.

Manninen, O. Interaction studies on environmental factors: Recent findings. In B. Berglund, U. Berglund, J. Karlsson and T. Lindvall T. (eds.)(1990). *Noise as a Public Health Problem*. Vol. 5: *New Advances in Noise Research-Part II*. Stockholm Sweden: Swedish Council for Building Research, D2, 1990, pp. 209-231.

Martin, A. (1976). The equal energy concept applied to impulsive noise. In D. Henderson, R.P. Hamernik, D.S. Dosanjh and J.H. Mills (eds.), *Effects of Noise on Hearing*. New York: Raven Press, pp. 421-449.

Martin, R.H., Gibson, E.S., and Lockington, J.N. (1975). Occupational hearing loss between 85 and 90 dBA. *Journal of Occupational Medicine*, 17, 13-18.

- Maschke, C., Breinl, S., Grimm R., and Ising, H. (1993). The influence of nocturnal aircraft noise on sleep and on catecholamine secretion. In H. Ising and B. Kruppa (eds.), *Noise and Disease*. Stuttgart: Gustav Fischer, pp. 402-407.
- Mathews Jr., K.E., and Canon, L. Environmental noise level as a determinant of helping behavior. *Journal of Personality and Social Psychology*, 3, 571-577 (1975).
- Matsui, K., and Sakamoto, H. (1971). The understanding of complaints in a noisy workshop. *Ergonomics*, 14, 95-102.
- Mazzetti, O. (1997). Examining the psychological health effects of aircraft noise on adults and children living under the flight path in Sydney. Unpublished report from the University of Western Sydney, Nepean.
- McDonald, N.J. and Ronayne, T. (1989). Jobs and their environment: The psychological impact of work in noise. *Irish Journal of Psychology*, 10, 39-55.
- McFadden, D., and Plattsmier, H.S. (1983). Aspirin can potentiate the temporary hearing loss induced by intense sounds. *Hearing Research*, 9, 295-316.
- McGrath, J.J. (1963). Irrelevant stimulation and vigilance performance. In D.N. Buckner and J.J. McGrath (eds.), *Vigilance: A Symposium*. New York: McGraw-Hill.
- McKennel, A.C., and Hunt, E.A. (1961). *Noise annoyance in central London*. London: British Central Office of Information. U.K. Government Survey Report SS 332.
- McKennell, A.C. (1963). *Aircraft Noise annoyance around London (Heathrow) Airport*. London: British Central Office of Information. U.K. Government Survey Report SS. 337.
- McKennell, A.C. (1973). Psycho-social factors in aircraft noise annoyance. *Proceedings of the International Congress of Noise as a Public Health Problem, Dubrovnik, Yugoslavia*, 627-644.
- McKennell, A.C. (1978). Annoyance from Concorde flights around Heathrow. *Proceedings of the Third International Congress on Noise as a Public Health Problem, Freiburg, West Germany*.
- McKennell, A.C. (1980). Annoyance from concorde flights round Heathrow. In G. Rossi (ed.), *Noise as a Public Health Problem*. Rockville, Maryland: ASHA Reports 10, pp. 562-579.
- McLean, E.K., and Tarnopolsky. (1977). A. Noise, discomfort and mental health: a review of the socio-medical implications of disturbance by noise. *Psychological Medicine*, 7, 19-62.
- Meecham, W.C. and Shaw, N. (1979). Effects of jet noise on mortality rates. *British Journal of Audiology*, 13, 77-80.

Meecham, W.C., and Smith, H.G. (1977). Effects of jet aircraft noise on mental hospital admissions. *British Journal of Audiology*, 11, 81-85.

Melamed, S. (1995) *First International Symposium on Work Environment and Cardiovascular Disease, Copenhagen*.

Melamed, S., Harari, G., and Green, M.S. (1993). Type A behavior, tension, and ambulatory cardiovascular reactivity in workers exposed to noise stress. *Psychosomatic Medicine*, 55, 185-192.

Meloni, T., and Krüger, H. (1990). Wahrnehmung und Empfindung von kombinierten Belastungen durch Lärm und Vibration. (Zeitschrift kombinierten Belastungen durch Lärm und Vibration). *Zeitschrift für Lärmbekämpfung*, 37, 170-175.

Meyer, R.E, Aldrich, T.E., and Easterly, C.E. (1989). Effect of noise and electromagnetic fields on reproductive outcome. *Environmental Health Perspectives*, 81, 193-200.

Meyer-Falke, A., Lanzendorfer, A., and Jansen, G. (1995). Psycho-physiological effects of impulsive noise on man: contrast in the reactions to artificial and realistic noise. In M. Newman (ed.), *Proceedings of the 15th International Congress on Acoustics, Trondheim, Norway*, 199-202.

Michalak, R., Ising, H., and Rebentisch, E. (1990). Acute circulatory effects of military low altitude flight noise. *International Archives of Occupational and Environmental Health*, 62, 365-372.

Michelson, W. (1980). Long and short range criteria for housing choice and environmental behavior. *Journal of Social Issues*, 36, 135-149.

Miedema, H. (1993). Response functions for environmental noise. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 428-433.

Miedema, H.M.E. (1987). Annoyance from combined noise sources. In H.S. Koelega (ed.), *Environmental Annoyance: Characterization, Measurement, and Control*. Amsterdam: Elsevier, pp. 313-320.

MIL Research Ltd. (1971). *Second Survey of Aircraft Noise Annoyance around London (Heathrow) Airport*. London: Her Majesty's Stationary Office.

Miller, G.A. (1947). The masking of speech. *Psychological Bulletin*, 44, 105-129.

Miller, G.A., and Licklider, J.C.R. (1950) The intelligibility of interrupted speech. *Journal of the Acoustical Society of America*, 22, 167-173.

Miller, J.D., Rosthenberg, S.J., and Eldredge, D.H. (1971). Preliminary observations on the effects of exposure to noise for seven days on the hearing and inner ear of the chinchilla. *Journal of the Acoustical Society of America*, 50, 1199-1203.

- Mills, J.H., and Lilly, D.J. (1971). Temporary threshold shifts produced by pure tones and by noise in the absence of an acoustic reflex. *Journal of the Acoustical and Society of America*, 50, 1556-1558.
- Mirmiran, M., and Van Someren, E. (1993). The importance of REM sleep for brain maturation. *Journal of Sleep Research*, 2, 188-192.
- Miskiewics, A., Hellmann, R., and Shcarf, B. (1995). Frequency and temporal effects in loudness adaptation. In M. Newman (ed.), *Proceedings of the 15th International Congress on Acoustics, Trondheim, Norway*, 203-206.
- Moch, A. (1984). Type A and type B behaviour pattern, task type and sensitivity to noise. *Psychological Medicine*, 14, 643-646.
- Moch-Sibony, A. (1984). Aspects cognitifs des stress de l'environnement. [Cognitive aspects of environmental stress.]. *Le Travail Humain*, 47, 155-165.
- Mohler, U. (1988). Community response to railway noise: A review of social surveys. *Journal of Sound and Vibration*, 120, 321-332.
- Mohr, G.C., Cole, J.N., Guild, E., and von Gierke, H.E. Effects of low frequency and infrasonic noise on man. *Aerospace Medicine*, 36, 817-824 (1965)..
- Moldofsky, H., Lue, F.A., Davidson, J.R., and Gorczynski, R.M. (1989). Effects of sleep deprivation in human immune functions. *FASEB Journal* 3, 1972-1977.
- Moldofsky, H., Lue, F.A., Eisen, J., Keystone, E., and Gorczynski, R.M. (1986). The relationship of interleukin-1 and immune function to sleep in humans. *Psychosomatic Medicine*, 48, 309-318.
- Molinie, J. (1916). Reflexes oculaires d'origine auditive. *Revue de Laryngologie, Otologie, Rhinologie*, 1, 358-393.
- Moller, A.R. (1961). Network model of the middle ear. *Journal of the Acoustical Society of America*, 33, 168-176.
- Morata, T.C. (1989). Study of the effects of simultaneous exposure to noise and carbon disulfide on workers' hearing. *Scandinavian Audiology*, 18, 53-58.
- Morata, T.C., Dunn, D.E., Kretschmer, L.W., Lemasters, G.K., and Santos, U.P. (1991). Effects of simultaneous exposure to noise and toluene on workers' hearing and balance. In L. Fechter (ed.), *Proceedings of the Fourth International Conference on the Combined Effects of Environmental Factors*. Baltimore, MD: Johns Hopkins University, Center for Environmental Health Sciences, pp. 81-86.
- Morell, S., Taylor, R., and Lyle, D. (in press). A review of health effects of aircraft noise.

Moscicki, E., Elkins, E., Baum, H., and McNamara, P. (1985). Hearing loss in the elderly: An epidemiologic study of the Framingham Heart Study Cohort. *Ear and Hearing*, 6, 184-190.

Moskovic, J.I. and Ettema, J.H. (1977a). Extra-auditory effects in short-term exposure to aircraft and traffic noise. *International Archives of Occupational and Environmental Health*, 40, 165-173.

Moskovic, J.I. and Ettema, J.H. (1977b). Extra-auditory effects in long-term exposure to aircraft and traffic noise. *International Archives of Occupational and Environmental Health*, 40, 177-184.

Mounier-Kuhn, P., Gaillard, J., Martin, H., and Bonnefoy, J. (1960). Influence de l'état antérieur de l'oreille sur la constitution de la surdité par traumatisme sonore. *Acta Oto-Rhino-Laryngologica Belgica*, 14, 176-185.

Muijser, H., Hoogendijk, E.M.G., and Hooisma, J. (1988). The effects of occupational exposure to styrene on high-frequency hearing thresholds. *Toxicology*, 49, 331-340.

Muller, F., Schmidt, A., and Paulsen, R. (1996). The influence of stimulus range on the judgements of loudness and annoyance. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2095-2098.

Murphy, K. (1969). Differential diagnosis of impaired hearing in children. *Developmental Medicine and Child Neurology*, 11, 561-568.

Murray, B.J., and Avery, G. (1984). *Survey of community reaction to overpressure from blasting*. Wilkinson-Murray Report No W4244.

Muzet, A., and Ehrhart, J. (1980). Habituation of heart rate and finger pulse responses to noise in sleep. In J.V. Tobias, G. Jansen and W.D. Ward (eds.), *Noise as a Public Health Problem*. Rockville, Maryland: ASHA Reports 10, pp. 401-404.

Muzet, A., and Olivier-Martin, N. (1973). Périodicité du Sommeil Paradoxal au Cours du Nuits Normales ou Perturbées par le Bruit. *Journal of Physiology*, 67, 209A.

Muzet, A., Naitoh, P., Johnson, L.C., and Townsend, R.E. (1974). Body movements in sleep during 30-day exposure to tone pulse. *Psychophysiology*, 1, 27-34.

Nabelek, A.K., and Robinson, P.K. (1961). Monaural and binaural speech perception in reverberation for listeners of various ages. *Journal of the Acoustical Society of America*, 71, 1242-1248x.

Nagai, N., Matsumoto, M., Yamasumi, Y., Shiraishi, T., Nishimura, K., Matsumoto, K., Miyashita, K., and Takeda, S. (1989). Process and emergence on the effects of infrasonic and low frequency noise on inhabitants. *Journal of Low Frequency Noise and Vibration*, 8, 87-99.



Naganuma, Y., Konishi, T., Marakami, M., Hongou, K., Yamatani, M., and Okada T. (1991). Age-related changes of auditory event-related potential (P300) in children *No to hattatsu [Brain & Development]*, 32, 194-199.

Namba, S., and Kuwano, S. (1961). Psychological study on Leq as a measure of loudness of various kinds of noises. *Journal of the Acoustical Society of Japan*, 5, 135-148x.

Narang, P.P., Butler, K.R., Schull, J.L., and Job, R.F.S. (1995). *Sound insulation of residences exposed to aircraft noise*. Report to the Department of Transport, Canberra. Australian Government Publishing Service, Sydney.

Neuberger, M., Korpert, K., Raber, A., Schwetz, P., and Bauer, P. (1992). Hearing loss from industrial noise, head injury and ear disease. *Audiology*, 31, 45-57.

Neuberger, M., Schwetz, F., Raber, A., Korpert, K., and Bauer, P. (1990). Zur Prophylaxe der Lärmschwerhörigkeit-medizinische Aspekte einer Analyse der Daten von 260917 Lärmarbeitern. In E. Baumgartner (ed.), *Lärm, Gehörermüdung und -erholung. Tagungsbericht 1989 der Österreichischen Gesellschaft für Arbeits-medicin*. Wien-München-Bern: W. Maudrich, pp. 75-81.

Neus, H., Ruddel H., and Schulte, W. (1983). Traffic noise and hypertension. The Bonn traffic noise study. In Rossi, G. (ed.) *Noise as a Public Health Problem: proceedings of the Fourth International Congress, Milano, Italy*, 694-698.

Neus, H., Ruddel H., and Schulte, W. (1990). Traffic noise and hypertension. An epidemiological study on the role of subjective reactions. *International Archives of Occupational and Environmental Health*, 51, 223-229x.

Niemeyer, W. (1967). Speech discrimination in noise-induced deafness. *International Audiology*, 42, 42-47.

Niveson, M.E. (1992). *The Relationship between Noise as an Experimental and Environmental Stressor, Physiological Changes, and Psychological Factors*. Bergen, Norway: Department of Biological and Medical Psychology, University of Bergen. Doctoral thesis.

Nivison, M.E. and Endresen, I.M. (1993). An analysis of the relationships among environmental noise, annoyance and sensitivity to noise and the consequences for health and sleep. *Journal of Behavioral Medicine*, 16, 257-276.

Nixon, C.W., Harris, C.S., and von Gierke, H.E. (1966). *Rail test to evaluate equilibrium in low-level wideband noise*. Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory, AMRL-TR-66-86.

Nixon, J.C., and Glorig, A. (1961). Noise-induced permanent threshold shift at 2000 cps and 4000 cps. *Journal of the Acoustical Society of America*, 33, 904-908.

Nuttall, A.L.(1984). Dynamic aspects of guinea pig inner hair cell receptor potentials with transient asphyxia. *Hearing Research*, 16, 1-16.

Ogle, C.W., and Lockett, M.F. (1968). The urinary changes induced in rats by high pitched sounds (20 kcyc/sec.). *Journal of Endocrinology*, 42, 253-260.

Ohrström, E. (1991). Psycho-social effects of traffic noise exposure. *Journal of Sound and Vibration*, 151, 513-517.

Ohrström, E., Bjorkman, M., and Rylander, R. (1988). Noise annoyance with regard to physiological sensitivity, subjective noise sensitivity and personality variables. *Psychological Medicine*, 18, 605-613.

Ohrström, E. and Skanberg, A.-B. (1996). A field survey on effects of exposure to noise and vibration from railway traffic, Part I: Annoyance and activity disturbance. *Journal of Sound and Vibration*, 193, 39-47.

Ohrström, E. (1982). *On the Effects of Noise with Special Reference to Subjective Evaluation and Regularity*. Gothenburg, Sweden: University of Gothenburg, Doctoral Dissertation.

Ohrström, E. (1983). Sleep disturbances—After effects of different traffic noises. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano, Italy: Centro Ricerche e Studi Amplifon, Vol. 2, pp. 917-928.

Ohrström, E. (1989). Sleep disturbance, psycho-social and medical symptoms—a pilot survey among persons exposed to high levels of road traffic noise. *Journal of Sound and Vibration*, 133, 117-128.

Ohrström, E. (1993a). Longterm effects in terms of psycho-social wellbeing, annoyance and sleep disturbance in areas exposed to high levels of road traffic noise. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 209-212.

Ohrström, E. (1993b). Research on noise and sleep since 1988: Present state. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 331-338.

Ohrström, E. (1993c). Effects of low levels from road traffic noise during night—A laboratory study on number of events, maximum noise levels and noise sensitivity. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 359-366.

Ohrström, E. (1996). Community reactions to noise and vibrations from railway traffic. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2339-2344.

Ohrström, E., and Bjorkman, M. (1983). Sleep disturbance before and after traffic noise attenuation in an apartment building. *Journal of Acoustical Society of America*, 73: 877-879.

Öhrström, E., and Björkman, M. (1988). Effects of noise-disturbed sleep—a laboratory study on habituation and subjective noise sensitivity. *Journal of Sound and Vibration*, 122, 277-290.

Öhrström, E., and Rylander, R. (1982). Sleep disturbance effects of traffic noise—a laboratory study on after effects. *Journal of Sound and Vibration*, 84, 87-103.

Öhrström, E., and Rylander, R. (1990). Sleep disturbance by road traffic noise—a laboratory study on number of noise events. *Journal of Sound and Vibration*, 143, 93-101.

Öhrström, E., Björkman, R., and Rylander, M. (1990). Effects of noise during sleep with reference to noise sensitivity and habituation. *Environment International*, 16, 477-482.

Okada, H., Takeuchi, S., Sugiyama, Y., Iwase, S., Mano, T., & Watanabe, T. (1993). Relationship between K-complex-related blood pressure change and muscle sympathetic nerve activity in humans. *Autonomic Nervous System*, 30, 78-84.

Olivier-Martin Schneider, N. (1973). *Évaluation Subjective du Sommeil Normal ou Perturbé par le Bruit. Relations avec certains Indicateurs Physiologiques et Traits de Personnalité*. Lyon, France: Thesis.

Ollerhead, J.B., Jones, C.J., Cadoux, R.E., Woodley, A., Atkinson, B.J., Horne, A., Pankhurst, F., Reyner, L., Hume, K.I., Van, F., Watson, A., Diamond, I.D., Egger, P., Holmes, D., and McKean, J. (1992). *Report of a field study of aircraft noise and sleep disturbance*. London: Department of Safety, Environment and Engineering.

Ollerhead, J.B. (1973). Noise; how can the nuisance be controlled? *Applied Ergonomics*, 4, 130-138.

Ollerhead, J.B. (1980). Accounting for time of day and mixed source effects in the assessment of community noise exposure. In J.V. Tobias, G. Jansen and W.D. Ward (eds.), *Noise as a Public Health Problem*. Rockville, Maryland: ASHA Reports 10, pp. 556-561.

Osada, Y., Tsumashima, S., Yoshida, K., Asano, M., Ogawa, S., Hirokawa, A., Nakamura, K., and Maruta, K. (1969). Sleep impairment caused by short time exposure to continuous and intermittent noise. *Bulletin of the Institute of Public Health (Tokyo)*, 18, 1-9.

Osada, Y., Tsunashima, S., Yoshida, K., Asano, M., Ogawa, S., Hirokawa, A., Nakamura, K., and Haruta, K. (1968). Experimental study on the influence of noise on sleep. *Bulletin of the Institute of Public Health (Tokyo)*, 17, 208-217.

Osada, Y., Yoshida, K., Ogawa, S. (1972). Physiological effects of aircraft noise, especially of level and number of exposure. *Bulletin of the Institute of Public Health*, 21, 51-59.

Otten, H., Schulte, W., and von Eiff, A.W. Traffic noise, blood pressure and other risk factors: The Bonn traffic noisy study. In B. Berglund, U. Berglund, J. Karlsson and T. Lindvall (eds.), *Noise as a Public Health Problem. Vol. 4: New Advances in Noise Research—Part I*. Stockholm: Swedish Council for Building Research, D1:1990, pp. 327-335 (1990).

Otto, Von E. (1970). Einfluss von Schallreizen auf EEG-Aktivitat, Herzperiodendauer und atemmechanische Messwerte im Schlaf. *Dt Gesundh Wes*, 25, 1661-1668.

Overmier, J.B. and Hellhammer, D.H. (1988). The Learned Helplessness Model of Human Depression. *Animal Models of Psychiatric Disorders*, 2, 177-202.

Overmier, J.B. and R. Murison (1989). Post-stress effects of danger and safety signals on gastric ulceration in rats. *Behavioral Neuroscience*, 103, 1296-1301.

Page, R.A. (1977). Noise and helping behavior. *Environment and Behavior*, 9, 311-334.

Palmblad, J., Kantell, K., Strander, H., Froberg, J., Karlsson, C-G., Levi, L., Ganstrom, M., and Unger, P. (1976). Stressor exposure and immunological response in man: interferon-producing capacity and phagocytosis. *Journal of Psychosomatic Research*, 20, 193-199.

Parizet, E., Daumier, S., and Milland, E. (1996). Road noise subjective evaluation in cars. *Proceedings of Inter-noise '96, Liverpool, U.K.*, 2237-2240.

Parker, D.E. (1976). Effects of sound on the vestibular system. In W. Tempest (ed.), *Infrasound and low frequency vibration*. London: Academic Press, 151-185.

Parrot, J., Petiot, J.C., Lobreau, J.P., and Smolik, H.J. (1992). Cardiovascular effects of impulse noise, road traffic noise, and intermittent pink noise at LAeq = 75dB, as a function of sex, age, and level of anxiety: A comparative study. I. Heart rate data. *International Archive of Occupational and Environment Health*, 63, 477-484.

Passchier-Vermeer, W. (1974). Noise induced hearing loss from exposure to intermittent and varying noise. In: *Noise as a Public Health Problem*. Washington DC: U.S. Environmental Protection Agency, Report EPA 550/9.73.008, pp. 169-200.

Passchier-Vermeer, W. (1993). *Noise and Health*. The Hague. Health Council of the Netherlands Publication No. A93/02E.

Passchier-Vermeer, W. (1994). *Sleep Disturbance Due To Nighttime Aircraft Noise*. Leiden, TNO Institute Of Preventative Health Care, TNO Report PG 94.077

- Pearsons, K.S., Barber, D.S., Tabachnick, B.G., and Fidell, S. (1995). Predicting noise-induced sleep disturbance. *Journal of the Acoustical Society of America*, 97, 331-338.
- Pearsons, K.S., Benett, R.L., and Fidell, S. (1976). *Speech levels in various environments*. Washington DC: Office of Resources and Development, US Environmental Protection Agency (Bolt, Beranek and Newman Inc., Report No. 3281).
- Pearsons, K.S., Fidell, S., Bennett, R.L., Friedmann, J., and Globus, G. (1974). *Effect of cessation of late-night landing noise on sleep electrophysiology in the home*. United States-NASA Report CR-132543, 1-28.
- Peeters, A.L., de Jong, R.G., and Tukker, J.C. (1981). *Annoyance by railroad traffic noise in living areas*. Delft, The Netherlands: IMG-TNO nr D60.
- Peploe, P., Cook, P., and Job, R.F.S. (1993). *Evaluation of the APL criterion for community noise annoyance caused by noise*. National Acoustic Laboratories Commissioned Report No.79. Chatswood, NSW: Australian Hearing Services.
- Peterson, E.A., Augenstein, J.S., Hazelton, C.L., Hetrich, D., Levene, R.M., and Tanis, D.C. (1984). Some cardiovascular effect of noise. *Journal of Auditory Research*, 24, 35-62.
- Peterson, E.A., Augenstein, J.S., Tanis, D.C., and Augenstein, D.G. (1981). Noise raises blood pressure without impairing auditory sensitivity. *Science*, 211, 1450-1452.
- Pickett, J.M. (1959). Low frequency noise and methods for calculating speech intelligibility. *Journal of the Acoustical Society of America*, 31, 1259-1263.
- Pimentel-Souza, F., Carvalho, J.C., Siqueira, A.L., Alvares, P.A.S., and Rodrigues, C.J.S. (1996). Noise and sleep quality in two hospitals in the city of Belo Horizonte, Brazil. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 226xxx-2270.
- Plomp, R. (1986). Signal-to-noise ratio model for the speech-reception threshold of the hearing impaired. *Journal of Speech and Hearing Research*, 29, 146-154.
- Pollack, I. (1952). The information of elementary auditory displays. *Journal of the Acoustical Society of America*, 24, 745-749.
- Ponomarenko, I.I. (1966). The influence of noise of different intensity levels and spectral compositions on some physiologic functions of adolescents. *Gigenda truda i professional'nye zabdevaniya*, 10, 32.
- Powell, C.A. (1978). *Annoyance due to the Interaction of Community Noise Sources*. George Washington University (USA). Doctoral dissertation.
- Powell, C.A. (1979). *A summation and inhibition model of annoyance response to multiple community noise sources*. Hampton, USA: National

Aeronautics and Space Administration, Langley Research Center, NASA Technical Paper 1479.

Preis, A. (1996). Measurement of annoyance components. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2289-2294.

Preis, A., and Berglund, B. (1994). Perceptual processing of environmental sound. In: *Inter-Noise 94. Noise—Quantity and Quality*. Poughkeepsie, NY: Noise Control Foundation, Vol. 2, pp. 797-802.

Prince, M.M., and Matanoski, G.M. (1991). Problems in ascertaining the combined effects of exposure: Results of an occupational cohort study of the joint effects of noise and smoking on hearing acuity. In L. Fechter (ed.), *Proceedings of the Fourth International Conference on the Combined Effects of Environmental Factors*. Baltimore: Johns Hopkins University, Center for Environmental Health Sciences, pp. 87-91.

Pryor, G.T., Dickinson, J., Howd, R.A., and Rebert, C.S. (1983). Transient cognitive deficits and high-frequency hearing loss in weanling rats exposed to toluene. *Neurobehavioral Toxicology and Teratology*, 5, 53-57.

Pryor, G.T., Rebert, C.S., and Howd, R.A. (1987). Hearing loss in rats caused by inhalation of mixed xylenes and styrene. *Journal of Applied Toxicology*, 7, 55-61.

Pulles, T., Biesiot, W., and Stewart, R. (1990). Adverse effects of environmental noise on health: An Interdisciplinary approach. In B. Berglund, U. Berglund, J. Karlsson, and T. Lindvall (eds.), *Noise as a Public Health Problem, Vol. 4: New Advances in Noise Research. Part I*. Stockholm: Swedish Council for Building Research, D1, 1990, pp. 337-348.

Rasmussen, K.B. (1979). Annoyance from simulated road traffic noise. *Journal of Sound and Vibration*, 65, 203-214.

Raw, G.J., and Griffiths, I.D. (1985). The effect of changes in aircraft noise exposure. *Journal of Sound and Vibration*, 101, 273-275.

Raw, G.J., and Griffiths, I.D. (1990). Subjective response to changes in road traffic noise: A model. *Journal of Sound and Vibration*, 141, 43-54.

Ray, R.L., Brady, J.V., and Emurian, H.H. (1984) Cardiovascular effects of environmental noise on health: An interdisciplinary approach. *Environment International*, 16, 437-445.

Rebert, C.S., and Becker, E. (1986). Effects of inhaled carbon disulfide on sensory-evoked potentials of Long-Evans rats. *Neurobehavioral Toxicology and Teratology*, 8, 533-541.

Rehm, S. and Jansen, G. (1978). Aircraft noise and premature birth. *Journal of Sound and Vibration*, 59, 133-135.

Rehm, S. (1983). Research on extraaural effects of noise since 1978. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano, Italy: Centro Richerche e Studi Amplifon, Vol. 1, pp. 527-547.

Reijneveld, S.A. (1994). The impact of the Amsterdam aircraft disaster on reported annoyance by aircraft noise and on psychiatric disorders. *International Journal of Epidemiology*, 23, 333-340.

Relster, E. (1975). *Traffic Noise Annoyance*, Polytechnik Vorlag, Lyngby.

Rey, P. (1974). La surdit  professionnelle. *Sozial Praventivmedizin*, 19, 177-183.

Rice, C.G. (1991). Human response to impulse noise. In J. Busing (ed.), *The effects of noise. Research review*. Brussels: CEC-Commission of the European Communities, CEC Report D 1992-0157-8, pp. 5-8.

Rice, C.G. (1996). Human response effects of impulsive noise, *Journal of Sound and Vibration*, 190, 525-543.

Rice, C.G., and Izumi, K. (1984). Annoyance due to combinations of noise sources. In: *Acoustics '84*. Liverpool, UK: Institute of Acoustics, pp. 287-294.

Rice, C.G., and Martin, A.M. (1973). Impulse noise damage risk criteria. *Journal of Sound and Vibration*, 28, 359-367.

Rice, C.G., and Robinson, D.W. (1995). Quantifying the annoyance potential of environmental noise. In M. Newman (ed.), *The 15th International Congress of Acoustics (ICA'95)*. Trondheim, Norway: Acoustical Society of Norway, Vol. II, pp. 263-266.

Riesz, R.R. (1928). Differential intensity sensitivity of the ear for pure tones. *Physical Review*, 31, 867-875.

Robinson, D. W. (1971). *Occupational Hearing Loss*. New York: Academic Press.

Roethlisberger, FS and Dickson WJ (1939). *Management of the Worker*. Cambridge, MA: Harvard University Press.

Rohrmann, B. (1983a). Comparison of noisiness functions from different noise sources. Methodological problems and substantive results. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano: Centro Ricerche e Studi Amplifon, pp. 1095-1104.

Rohrmann, B. (1983b). Psychologische Kriterien zur "erheblichkeit" von Belastungen. In A. Schick and K.P. Walcher (Hg.), *Beitr ge zu einer Bedeutungslehre des Schalls*. Bern: Haupt, pp. 139-150.

Rohrmann, B. (1984) *Psychologische forschung und umweltpolitische Entscheidungen: Das Beispiel Larm*. Opladen, Germany: West-deutscher Verlag.

Rohrmann, B. (1986). Comparability problems in the design of social-scientific research on environmental stressors. In A. Schick, H. Hoge and G. Lazarus-Mainka (eds.), *Contributions to Psychological Acoustics (IV)*. Oldenburg, Germany: Bibliotheks- und Informationssystem der Universit t Oldenburg (BIS), pp. 285-298.

Rohrmann, B. (1990b). Partizipation und Protest. In I. Kruse, C.F. Graumann, and E.D. Lantermann (Hg.): *Ökologische Psychologie—Ein Handbuch in Schlüsselbegriffen. [Ecological Psychology – A Handbook on Key Concepts.]* München: Psychologie-Verlags-Union, pp. 645-653.

Rohrmann, B. (1991). The influence of noise on housing decisions. In A. Schick, J. Hellbrück and E. Weber (eds.), *Contributions to Psychological Acoustics (V)*. Oldenburg, Germany: Bibliotheks- und Informationssystem der Universität Oldenburg (BIS), pp. 75-86.

Rohrmann, B., Schümer, R., Schümer-Kohrs, A., Finke, H.-O., and Guski, R. (1973). An interdisciplinary study on the effects of aircraft noise on man. In US Environmental Protection Agency (ed.), *Noise as a Public Health Problem*. Washington, DC: EPA, pp. 765-776.

Romero, J. and Lloso, D. (1995). Perception and acoustic conditions in secondary spanish schools. In M. Newman (ed.), *Proceedings of the 15th International Congress on Acoustics, Trondheim, Norway*, 271-274.

Rosecrans, J.A., Watzman, N., and Buckley, J.P. (1966). The production of hypertension in male albino rats subjected to experimental stress. *Biochemical Pharmacology*, 15, 1707-1718.

Rosen, S., Bergman, M., Plester, D., El-Mofty, A., and Satti, M.H. (1962). Presbycusis study of a relatively noise-free population in the Sudan. *Transactions of the American Otologists Society*, 50, 135-151.

Rosenblith, W.A., and Stevens, K.N. (1953). *Handbook of Acoustic Noise Control. Noise and Man*. Wright Patterson Air Force Base, OH: Report WADC, TR-52-204, Vol. 2.

Rostolland, D. (1985). Intelligibility of shouted voice. *Acustica*, 57, 103-121.

Rostolland, D. (1982). Acoustic features of shouted voice. *Acustica*, 50, 118-125.

Roth, A. (1970). Untersuchungen über die gehörschädigende Wirkung von Industrielärm unterhalb der Grenznormative [Investigation of the damage to hearing by industrial noise below the standard level]. *Zeitschrift für die gesamte Hygiene und ihre Grenz*, 16, 760-763.

Rotter, J.B. (1966). Generalized expectancies for internal versus external locus of control. *Psychological Monographs*, 80, 1-28.

Rovekamp, A.J.M. (1983). Physiological effects of environmental noise on normal and more sound-sensitive human beings. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano, Italy: Centro Ricerche e Studi Amplifon, Vol. 1, pp. 605-614.

Royal Prince Alfred Hospital Medical Board. (1995). Submission To The Senate Select Committee On Aircraft Noise In Sydney, 1995.



- Royster, J.D., Royster, L.H., and Killion, M.C. (1991). Sound exposures and hearing threshold of symphony orchestra musicians. *Journal of the Acoustical Society of America*, 89: 2793-2803.
- Rylander, R. and Lundquist, B. (1996). Annoyance caused by noise from heavy weapon shooting ranges. *Journal of Sound and Vibration*, 192, 199-206.
- Rylander, R., Björkman, M., Åhrlin, U., and Berglund, K. (1980). Aircraft noise annoyance contours: importance of overflight frequency and noise level. *Journal of Sound and Vibration*, 69, 583-595.
- Rylander, R., Sjöstedt, E., and Björkman, M. (1977). Laboratory studies on traffic noise annoyance. *Journal of Sound and Vibration*, 52, 415-421.
- Rylander, R., Sørensen, S., and Kajland, A. (1976). Traffic noise exposure and annoyance reactions. *Journal of Sound and Vibration*, 47, 237-242.
- Rylander, R., Sørensen, S., Andrae, B.O., Chatelier, G., Espmark, Y., Larsson, T., and Thackray, R.I. (1974). Sonic boom exposure effects—A field study on humans and animals. *Journal of Sound and Vibration*, 33, 471-486.
- Sabadin, A., Suncic, S., Hrasovec, B., and Verhovnik, V. (1991). Verkehrslärm und unterbewusste Wahrnehmung des Wohnumfeldes. *Wissenschaft Umwelt*, 3/4, 153-157.
- Salvi, R.J., Boettcher, F.A., Spongr, V., and Bancroft, B.R. (1991). Combined effects of salicylates and noise: Hearing loss and hair cell loss. In L. Fechter (ed.), *Proceedings of the Fourth International Conference on the Combined Effects of Environmental Factors*. Baltimore, MD: Johns Hopkins University, Center for Environmental Health Sciences, pp. 97-100.
- Sandberg, U. (1993). Noise emissions of road vehicles—effect of regulations. Status report of an I-INCE working party In P. Chappelle and G. Vemier (eds.), *Proceedings of Inter-Noise 93*. Poughkeepsie, NY: Noise Control Foundation, Vol. 1. pp. 45-50.
- Sanden, A. and Axelsson, A. (1981). Comparison of cardiovascular responses in noise resistant and noise-sensitive workers. *Acta Otolaryngologica*, 377 (Suppl.), 95-100.
- Sarafino, E.P. (1994). *Health Psychology: Biopsychosocial Interactions*. 2nd. Ed. Wiley, New York, NY.
- Sato, T. (1993) A path analysis of the effect of vibration on road traffic noise in annoyance. In M. Vallet (ed.) *Noise as a Public Health Problem, Vol 2*, Nice, France: Institut National de recherche sur les Transports et leur Securite, 197-200.
- Sattler, M.A. and Rott, J.A.A. (1996). Social survey on traffic noise for the city of Porto Alegre, Brazil. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2371-2374.

Scharf, B. (1991). Loudness adaptation measured by the method of successive magnitude estimation. In G.A. Schneider and S.J. Bolanowski (eds.), *Ratio Scaling of Psychological Magnitudes*. Hillsdale, N.J.: Erlbaum.

Scharf, B., Hellman, R., and Bauer, J. (1977). *Comparison of Various Methods for Predicting Loudness and Acceptability of Noise*. Washington, D.C.: U.S. Environmental Protection Agency, Rep. EPA 550/9-77-01.

Schell, L.M. (1981). Environmental noise and human prenatal growth. *American Journal of Physical Anthropology*, 56, 63-70.

Schick, A. (ed.) (1981). *Akustik zwischen Physik und Psychologie*. Stuttgart: Klett-Cotta.

Schmeck, K. and Poustka, F. (1993). Psychiatric and psychophysiological disorders in children living in a military jet-fighter training area. In M. Vallet (ed.) *Noise as a public Health Problem*, Vol 2. Arcueil Cedex, France: INRETS, 477-480.

Schneider, E.J., Mutchler, J.E., Hoyle, H.R., Ode, E.H., and Holder, B.B. (1970) The progression of hearing loss from industrial noise exposures. *American Industrial Hygiene Association Journal*, 31 (May-June): 368-376.

Schomer, P. D. (1981). *Community Reaction to Impulse Noise: Initial Army Survey*. Champaign, IL: U.S. Army Construction Engineering Research Laboratory. Technical Report N-100.

Schomer, P.D. and Sias, J.W. (1996). A comparative study of human response to blast noise and sonic booms. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2489-2494.

Schulte-Fortkamp, B. (1996). Combined methods to investigate effects of noise exposure and subjective noise assessment. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2351-2356.

Schultz, T.J. (1978). Synthesis of social surveys on noise annoyance. *Journal of the Acoustical Society of America*, 64, 377-405.

Schultz, T.J. (1982). Comments on K.D. Kryter's "Community annoyance from aircraft and ground vehicle noise". *Journal of the Acoustical Society of America*, 72, 1243-1252.

Schümer, R., and Zeichart, K. (1989). Strukturanalysen zur Reaktion auf Verkehrslärm. *Zeitschrift für Lärmbekämpfung*, 36, 12-18 (Teil 1: Untersuchungsansatz), 41-48 (Teil 2: Ergebnisse).

Schümer-Kohrs, A., and Schümer, R. (1974). Der sozialwissenschaftliche Untersuchungsteil. In: *DFG-Forschungsbericht Fluglärnwirkungen*. Boppard, Germany: Boldt.

Schwartz, S., and Jansen, G. (1990). Critical assessment of the methodological approaches for evaluating non-auditory physiological noise effects. Consequences for the continuation of noise research. In B. Berglund and T. Lindvall (eds.), *Noise as a Public Health Problem*. Vol. 4: New

*Advances in Research—Part 1*. Stockholm: Swedish Council for Building Research, D1, 1990, pp. 373-379.

Schwetz, F., Raber, A., Neuberger, M., Körpert, K., and Bauer, P. (1992). Impulshaltiger Lärm und Gehör, eine Studie aus Serieneuntersuchungen in Lärmbetrieben. *HNO [Hals-Nasen-und Ohrenärzte]*, 40, 10-15.

Seligman, M.E.P. (1975). *Helplessness: On Depression, Development and Death*. Freeman, San Francisco.

Seligman, M.E.P. (1991). *Learned Optimism*. Milson's Point: Random House Australia.

Selye, H. *The Stress of Life*. New York: McGraw-Hill (1956)..

Senate Select Committee on Aircraft Noise in Sydney (1995). *Falling on Deaf Ears— Report of the Senate Select Committee on Aircraft Noise in Sydney*. Commonwealth of Australia.

Seshagiri, B.V. (1979). *Impulsive noise from forging operations: Reactions of some communities in Ontario*. Canadian Ministry of Environment Report.

Sieber, W.J., Rodin, J., Larson, L., Ortega, S., and Cummings, N. (1992). Modulation of human natural killer cell activity by exposure to uncontrollable stress. *Brain, Behavior, and Immunity*, 6, 141-156.

Siegel, J.M., and Steele, C.M. (1980). Environmental distraction and interpersonal judgements. *British Journal of Social and Clinical Psychology*, 19, 23-32.

Slob, A., Wink, A. and Radder, J.J. (1973). The effect of acute noise exposure on the excretion of corticosteroids, adrenalin and noradrenalin in man. *Internationale Archive Arbeitsmedizin*, 31, 225-235.

Smith, A.W. (1989). A review of the effects of noise on human performance. *Scandinavian Journal of Psychology*, 30, 185-206.

Smith, R., Oyung, R., Gregory, K., Miller, and Rosekind, M. (1996). Evaluating sleep disturbance: A review of methods. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2073-2078.

Smoorenburg, G.F. (1992). Speech reception in quiet and noisy conditions by individuals with noise-induced hearing loss in relation to their tone audiogram. *Journal of the Acoustical Society of America*, 91, 421-437.

Solberg, S. (1996). Total noise rating at Oslo Airport Gardermoen. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2501-2504.

Sorensen, S., and Magnussen, J. (1979). Annoyance caused by noise from shooting ranges. *Journal of Sound and Vibration*, 82, 437-442.

Spoor, A. (1967). Presbycusis values in relation to noise induced hearing loss. *International Audiology*, 6, 48-57.

Spreng, M. (1975). Physiological and psycho-physical aspects of the threshold of discomfort and pain in hearing. *Zeitschrift für Hörschulakustik [J. audiol. Tech.]*, 14, 14-29.

Stansfeld, S.A. and Shine, P. (1993). Noise sensitivity and psychophysiological responses to noise in the laboratory. In M. Vallet (ed.), *Noise as a Public Health Problem*, Vol 2, Arcueil Cedex, France: INRETS, 481-484.

Stansfeld, S.A. (1988). Sensitivity to Noise—Source of Error or Stable Personal Characteristic? In: *Proceedings from an International Conference "Il rumore urbano e il governo del territorio"*, Modena, Italy, 1-2-3 Marzo, pp. 57-64.

Stansfeld, S.A. (1992). Noises, noise sensitivity and psychiatric disorder: epidemiological and psychophysical studies. *Psychological Medicine*, Monograph Suppl. 22.

Stansfeld, S.A., Clark, C.R., Jenkins, L.M., and Tarnopolsky, A. (1985). Sensitivity to noise in a community sample: I. Measurement of psychiatric disorder and personality. *Psychological Medicine*, 15, 243-254.

Stansfeld, S.A., Gallacher, J., Babisch, W., and Elwood, P. (1993). Road traffic noise, noise sensitivity and psychiatric disorder: Preliminary prospective findings from the Caerphilly study. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 3, pp. 268-273.

Stassen, T. (1980). Untersuchungen zur subjektiven Lastigkeit von Lärm und ihre Erfassung durch physikalische Geräuschkennwerte. In: *DAGA '80*. Berlin: Verein Deutsche Ingenieure, pp. 611-614.

Steffen, T.N., Nixon, J.C., and Glorig, A. (1963). Stapedectomy and noise. *Laryngoscope*, 73, 1044-1060.

Steinicke, G. (1957). *The impact of noise on sleep in man*. Research Report of the Economic and Transport Ministry of North Rhine-Westfalia (No. 416). Köln, Germany: West Deutscher Verlag.

Stevens, S.S. (1975). *Psychophysics: Introduction to its Perceptual, Neural and Social Prospects*. New York: Wiley and Sons.

Stevens, S.S., and Davis, H. (1938). *Hearing*. New York: Wiley.

Stevenson, D.C., McKellar, N.R. (1989). The effect of traffic noise on sleep of young adults in their homes. *Journal of the Acoustical Society of America*, 85, 768-771.

Stone, G.F., Freeman, T.W., and Craig, R.L. (1971). Noise control and hearing conversation in large steam-electric generating stations. *American Industrial Hygiene Association Journal*, 32, 123-131.

Struwe, Jansen, Schwarze, Nitzche and Notbohm (1995). Hearing loss induced by leisure noise: subjective evaluation and audiometric assessment. *Proceedings of the 15th International Congress on Acoustics*, Trondheim, Norway.

Sulkowski, W. (1974). Some epidemiological data on noise-induced hearing loss in Poland, its prophylaxis and diagnosis. In: *Noise as Public Health Problem*. Washington, DC: US Environmental Protection Agency, Report EPA 550/9-73.008, pp. 139-156.

Sulkowski, W. (1979). Clinical usefulness of audiometry and electronystagmography in the diagnosis of chronic carbon disulphide poisoning. *Medical Practice*, 30, 135.

Sullivan, M.J., Rarey, K.E., and Conolly, R.B. (1989). Ototoxicity of toluene in rats. *Neurotoxicology and Teratology*, 10, 525-530.

Suter, A.H. (1992). Noise sources and effects- a new look. *Sound and Vibration*, Jan, 18-38.

Suzuki, S., Kawada, T., Sato, T., Naganuma, S., Ogawa, M., and Aoki, S. (1993). Decrease in stage REM, as a most sensitive indicator of all-night noise exposure. In M. Vallet (ed.), *Noise as a Public Health Problem*. Arcueil Cedex, France: INRETS, Vol. 2, pp. 579-582.

Taffala, R.J., Evens, G.W., and Chen, A. (1988). Noise and human performance: The potential role of effort. *Proceedings of the Fifth International Congress on Noise as a Public Health Problem*, Vol.3, 95-100.

Talbott, E.O., Brink, L.L., Burks, C., Palmer, C., Engberg, R., Cioletti, M., and Ingman, C. (1996). Occupational noise exposure, use of hearing protectors over time and the risk of high blood pressure. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2131-2136.

Tarnopolsky, A. and Morton-Williams, J. (1980). *Aircraft Noise and Prevalence of Psychiatric Disorders*. Social and Community Planning research, 35, Northhampton Square, London, EC1.

Tarnopolsky, A., Barker, S.M., Wiggins, R.D., and McLean, E.K. (1978). The effect of aircraft noise on the mental health of a community sample: a pilot study. *Psychological Medicine*, 8, 219-233.

Tarnopolsky, A., Hand, D.J., Barker, S.M., and Jenkins, L.M. (1980). Aircraft noise, annoyance, and mental health: a psychiatric viewpoint. In J.V. Tobias, G. Jansen and W.D. Ward (eds.), *Noise as a Public Health Problem*. Rockville, MD: ASHA Reports 10, pp. 588-594.

Tarnopolsky, A., Watkins, G., and Hand, D.J. (1980). Aircraft noise and mental health: I. Prevalence of individual symptoms. *Psychological Medicine*, 10, 683-698.

Tatai, K., Osada, Y., Tsunashima, S., Yoshida, K., Ogawa, S., Asano, M., Hirokawa, A., and Haruta, K. (1965). Experimental studies on the influence of noise on physiological functions of the human body. I. Responses of leucocyte counts and of adrenal secretion to noise. *Bulletin of the Institute of Public Health (Tokyo)*, 14, 200-212.

Tatai, K., Osada, Y., Tsunashima, S., Yoshida, K., Ogawa, S., Asano, M., Hirokawa, A., and Haruta, K. (1967). Experimental studies on the influence

of noise on physiological functions of the human body. II. Responses of adrenals, leucocytes, EEG, respirogram and plethysmogram to noise. *Bulletin of the Institute of Public Health (Tokyo)*, 16, 105-111.

Taylor, R. and Lyle, D. (1990). Department of Public Health, Faculty of Medicine, university of Sydney, third runway at Sydney Airport: Possible health effects. *Working paper prepared for Kinhill Engineers Pty. Ltd.*

Taylor, R. and Lyle, D. (1990). *Third Runway Proposal Draft Environmental Impact Statement Sydney (Kingsford Smith) Airport. Possibel Health Effects Part II: An examination of relevant routinely collected mortality and morbidity data.* Department of Public Health, Faculty of Medicine, University of Sydney.

Taylor, S.M. (1982). A comparison of models to predict annoyance reactions to noise from mixed sources. *Journal of Sound and Vibration*, 81, 123-138.

Taylor, S.M. (1984). A path model of aircraft noise annoyance. *Journal of Sound and Vibration*, 96, 243-260.

Taylor, S.M. (1993). Transportation noise annoyance: Studies of the McMaster Research Group. In A. Schick (ed.), *Contributions to Psychological Acoustics*. BIS: Oldenberg, 473-485

Taylor, S.M., Breston, B.E., and Hall, F.L. (1982). The effect of road traffic noise on house prices. *Journal of Sound and Vibration*, 80, 523-541.

Taylor, R., Morrell, S., Carter, N.L., Peploe, P. and Job, R.F.S. (1996). Preliminary results of Inner-Sydney School Blood Pressure Study. *Proceedings (Edited Abstracts) of the International Congress on Stress and Health (Sydney, Australia, October, 1996)*. D. Kenny (Ed.). Sydney, NSW: University of Sydney, 90-91.

Tempest, W. (1976). Infrasound in transportation. In W. Tempest (ed.), *Infrasound and Low Frequency Vibration*. London: Academic Press, ch. 2, pp. 19-36.

Terent'yev, V.G., Sheludyekov, E.E., and Sviridova, E.S. (1969). The reaction of human and nervous cardiovascular systems to the influence of aviation noise. *Voenno-meditsinskii Zhurnal*, 6, 55.

Thackray, R.I. (1972). Sonic boom exposure effects II.3, a startle responses. *Journal of Sound and Vibration*, 20, 519-526.

Theorell, T. (1990). Family history of hypertension—an individual trait interacting with spontaneously occurring job stressors. *Scandinavian Journal of Work and Environment Health*, 16, 74-79.

Theorell, T. Family history of hypertension—an individual trait interacting with spontaneously occurring job stressors. *Scandinavian Journal of Work and Environment Health*, 16:74-79 (1990).

Thiessen, G.J. (1972). *Noise interference with sleep*. Ottawa: National Research Council of Canada.

Thiessen, G.J. (1978). Disturbance of sleep by noise. *Journal of the Acoustical Society of America*, 64, 216-222.

Thiessen, G.J. (1983). Effect of intermittent and continuous traffic noise on various sleep characteristics and their adaptation. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano, Italy: Centro Recerche e Studi Amplifon, Vol. 2, pp. 995-1005.

Thiessen, G.J., and Lapointe, A.C. (1983). Effect of continuous traffic noise on percentage of deep sleep, waking and sleep latency. *Journal of the Acoustical Society of America*, 73, 225-229.

Thomas, J.R. and Jones, D.M. (1982). Individual differences in noise annoyance and the uncomfortable loudness level. *Journal of Sound and Vibration*, 82, 289-304.

Toth, L. and Krueger, J.M. (1988). Alteration of sleep in rabbits by staphylococcus aureus infection. *Infection and Immunity*, 56, 1785-1791

Toth, L. and Krueger, J.M. (1988b) xxx from Norm

TRACOR. (1971). Community reaction to airport noise, Austin, Texas: Tracor Incorporated, NASA Contractor Report CR-1761, Vol. 1, 89.

US Air Force. (1989). *Aerospace Medicine. Hazardous Noise Exposure*. Washington DC: Department of the Air Force, Air Force Regulation AFR 161-35.

US EPA.(1974). *Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety*. Washington DC, US Environmental Protection Agency, Report EPA 550/9-74.004.

US NCHS. (1987). *Current estimates from the national health interview survey: United States, 1987. Vital and health statistics. Series 10*. Public Health Service. Washington DC: US National Center for Health Statistics [Government Printing Office].

Vallet, M. (1979). *La perturbation du sommeil par le bruit. Evaluation des effets Psychologiques et Physiologiques par une Experience in situ*. Lyon, France: Universite de Lyon II, Doctoral Dissertation.

Vallet, M. (1996). Annoyance after changes in airport noise environment. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2329-2334.

Vallet, M. Sleep disturbance. In P.M. Nelson (eds.)(1987). *Transportation Noise Reference Book*. London Butterworth, pp. 6/1-6/18.

Vallet, M., and Vernet, I. (1991). Night aircraft noise index and sleep research results. In A. Lawrence (ed.), *Inter-Noise 91. The Cost of Noise*. Poughkeepsie, NY: Noise Control Foundation, Vol. 1, pp. 207-210.

Vallet, M., Carrere, C., and Lacoste, P. (1983). La gêne due au bruit des liaisons interurbaines en rase campagne. In *Proceedings of 11th ICA, Paris*, 407-410.

Vallet, M., Gagneux, J.-M., and Simonnet, F. (1980). Effects of aircraft noise on sleep: An in situ experience. In J.V. Tobias, G. Jansen and W.D. Ward (eds.), *Noise as a Public Health Problem*. Rockville, Maryland: ASHA Reports 10, pp. 391-396.

Vallet, M., Gagneux, J.-M., Blanchet, V., Favre, B., and Labiale, G. (1983a). Long term sleep disturbance due to traffic noise. *Journal of Sound and Vibration*, 90, 173-191.

Vallet, M., Gagneux, J.-M., Clairet, J.M., Laurens, J.F., and Letisserand, D. (1983b). Heart rate reactivity to aircraft noise after a long-term exposure. In G. Rossi (ed.), *Noise as a Public Health Problem*. Milano: Centro Ricerche e Studi Amplifon, Vol. 2, pp. 965-971.

Vallet, M., Maurin, M., Page, M.A., Fauvre, B., and Pasiadi, G. (1978). Annoyance from and habituation to road traffic noise from urban roadways. *Journal of Sound and Vibration*, 60, 423-440.

Vallet, M., Pachiaudi, G., Depitre, A., Tanguy, Y., and Francois, J. (1988). Community reactions to aircraft and residual noise. In B. Berglund, U. Berglund, J. Karlsson and T. Lindvall (eds.), *Noise as a Public Health Problem. Vol. 3: Performance, Behaviour, animal, Combined Agents and Community Responses*. Stockholm: Swedish Council for Building Research, D17, 1988, pp. 289-294.

Van Dijk, F., Souman, A., and De Vries, F. (1983). Industrial noise, annoyance, and blood pressure. *Proceedings of the Fifth International Congress on Noise as a Public Health Problem, Milan*, 615-627.

Van Kamp, I. (1990). *Coping with noise and its health consequences*. Dissertation. Groningen: Styx and PP Publications.

van Dijk, F.J.H., Souman, A.J., and de Fries, F.F. (1987). Non-auditory effect of noise in industry. VI. A final field study in industry. *International Archive of Occupational and Environment Health*, 59, 133-145.

Velazquez, J., Escobar, R., and Almaraz, A. (1969). Audiologic impairment due to n-butyl alcohol exposition. In H. Kita (ed.), *Proc. XVI International Congress of Occupational Health*. Tokyo: Japan Industrial Safety Association, pp. 231-234.

Vera, M.N., Vila, J., and Godoy, J.F. (1995). The role of negative statements on the subjective effects of traffic noise. *Journal of Sound and Vibration*, 188, 347-361.

Vercammen, M.L.S. (1992). Low-frequency noise limits. *Journal of Low Frequency Noise and Vibration*, 11, 7-13.

Vernet, M. (1983). Comparison between train noise and road noise annoyance during sleep. *Journal of Sound and Vibration*, 87, 331-335.



Vernon, J., Brown, J.J., Meikle, M., and Brummett, R.E.(1978). The potentiation of noise-induced hearing loss by neomycin. *Otolaryngology*, 86, 123-124.

Villchur E. (1974). Simulation of the effect of recruitment on loudness relationship in speech. *Journal of the Acoustical Society of America*, 56, 1601-1611.

Vinsintainer, M.A., Volpicelli, J.R., and Seligman, M.E.P. (1982). Tumor rejection in rats after inescapable or escapable shock. *Science*, 216, 437-439.

Vipac

von Békésy, G. (1960). *Experiments in Hearing*. [Tran. and ed.by F.G. Wever] New York, McGraw-Hill.

von Brennecke, W., and Remmers, H. (1983). Physikalische Parameter bei der Bewertung der Lästigkeit von Industriegerauschen. *Acustica*, 52, 279-289.

von Eiff, A.W., Friedrich, G., Langewitz, W., Neus, H., Ruddel, H., Schirmer, G., and Schulte, W. (1981). Traffic noise and hypertension risk. A hypothalamic theory of essential hypertension. Second Communication. *Munchener Medizinische Wochenschrift*, 123, 420-424.

von Gierke, H.E., and Nixon, C.W. (1976). Effects of intense infrasound on man. In W. Tempest (ed.), *Infrasound and Low Frequency Noise Vibration*. London: Academic Press, ch. 6, pp. 115-150.

von Gierke, H.E., Davis, H., Eldredge, D.H., and Harry, J.D. (1953). Aural pain produced by sound. In H.W. Adeset al., (ed.), *Benox Report, An Exploratory Study of the Biological Effects of Noise*. Chicago, IL: University of Chicago, ONR Project NR 144079, pp. 29-36.

von Klingholz, F., Siegert, C., Schleier, E., and Thamm, R. (1978). Lärmbedingte Stimmstörung bei Angehörigen unterschiedlicher Berufsgruppen [Noise-induced vocal diseases in persons of different occupations]. *HNO-Praxis*, 313, 193-201.

Vos, J. (1990). On the level-dependent penalty for impulse sound. *Journal of the Acoustical Society of America*, 88, 883-893.

Vos, J. 91996). Annoyance caused by impulse sounds produced by small, medium, and large firearms. *Proceedings of Inter-noise '96, Liverpool, U.K.*, 2231-2236.

Vos, J., and Geurtsen, F.W.M. (1987). Leq as a measure of annoyance caused by gunfire consisting of impulses with various proportions of higher and lower sound levels. *Journal of the Acoustical Society of America*, 82, 1201-1206.

Vos, J. (1992). Annoyance caused by simultaneous impulse, road-traffic, and aircraft sounds: A quantitative model. *Journal of the Acoustical Society of America*. 91, 3330-3345.

Wachs, T.D., and Gruen, E.G. (1982). *Early Experience and Human Development*. New York: Plenum.

Walker, J.G. and Chan, M.F.K. (1996). Human response to structurally radiated noise due to underground railway operations. *Journal of Sound and Vibration*, 193, 49-63.

Walsh-Healey Public Contracts Act (1969). Federal Register 34, No. 96.

Ward, W.D. (1960). Latent and residual effects in temporary threshold shift. *Journal of the Acoustical Society of America*, 32, 135-137.

Ward, W.D. (1962). Studies on the aural reflex. II. Reduction of temporary threshold shift from intermittent noise by reflex activity: Implications for damage-risk criteria. *Journal of the Acoustical Society of America*, 34, 234-241.

Ward, W.D. (1970). Temporary threshold shift and damage-risk criteria for intermittent noise exposures. *Journal of the Acoustical Society of America*, 48, 561-574.

Ward, W.D. (1973). Noise-induced hearing damage. In M.M. Paparella and D.A. Shumrick (eds.), *Otolaryngology*. Philadelphia, PA: Saunders, vol 2. pp. 377-390.

Ward, W.D. (1991). Noise-induced hearing damage. In M.M. Paparella, D.A. Shumrick, J.L. Gluckman and W.L. Meyerhoff (eds.), *Otolaryngology. Vol II: Otology and Neuro-Otology*. Philadelphia, PA: Saunders, Ch. 45, pp. 1639-1652.

Ward, W.D., and Nelson, D.A. (1971). On the equal-energy hypothesis relative to damage-risk criteria in the chinchilla. In D.W. Robinson (ed.), *Occupational Hearing Loss*. New York: Academic Press, pp. 225-231.

Ward, W.D., Glorig, A., and Sklar, D.L. (1958). Dependence of temporary threshold shift at 4 Kc on intensity and time. *Journal of the Acoustical Society of America*, 30, 944-954.

Ward, W.D., Glorig, A., and Sklar, D.L. (1959). Temporary threshold shift produced by intermittent exposure to noise. *Journal of the Acoustical Society of America*, 31: 791-794.

Ward, W.D., Selters, W., and Glorig, A. (1961). Exploratory studies on temporary threshold shift from impulses. *Journal of the Acoustical Society of America*, 33, 781-793.

Warren, R.M. (1970). Perceptual restoration of missing speech sounds. *Science*, 167, 392-393.

Watkins, G., Tarnopolsky, A., and Jenkins, L.M. (1981). Aircraft noise and mental health: II. Use of medicines and health care services. *Psychological Medicine*, 11, 155-168.

- Watts, G. (1991). Assessing vehicle noisiness. In A Lawrence (ed.), *Inter-Noise 91: The Cost of Noise*. Poughkeepsie, NY: Noise Control Foundation, Vol. 1, pp. 41-44.
- Weber, R., and Mellert, V. (1978). Vergleichende Beurteilung von Verkehrsgeräuschen - Korrelation mit Lautstärkeparametern. In: *DAGA '78*. Berlin, Germany: Verein Deutsche Ingenieure, pp. 271-274.
- Webster, J.C. (1969). Effects of noise on speech intelligibility. In: *Noise as a Public Health Hazard*, Washington, DC, American Speech and Hearing Association, ASHA Reports No. 4.
- Webster, J.C. (1974). The effects of noise on hearing speech. In: US Environmental Protection Agency (eds.), *Noise as a Public Health Problem*. Washington DC: US EPA, pp. 25-43.
- Weinstein, B.E. Presbycusis. In J. Katz (ed.)(1994). *Handbook of Clinical Audiology*. Baltimore: Williams and Wilkins, pp. 568-584.
- Weinstein, N.D. (1980). Individual differences in critical tendencies and noise annoyance. *Journal of Sound and Vibration*, 68, 241-248.
- Weinstein, N.D. (1982). Community noise problems: evidence against adaptation. *Journal of Environmental Psychology*, 2, 87-97.
- Welch, B.L., and Welch, A.S. (eds.)(1970). *Physiological Effects of Noise on Man*. New York, NY: Plenum.
- Widmann, U. (1996). Scaling annoyance of street traffic noise as a function of loudness and speech intelligibility. *Proceedings of Internoise '96, Liverpool, U.K.*, 2215-2220.
- Wilkinson, R.T. and Campbell, K.B. (1984). Effects of traffic noise on quality of sleep: Assessment by EEG, subjective report and performance the next day. *Journal of the Acoustical Society of America*, 75, 468-475.
- Wilkinson, R.T. (1963). Interaction of noise with knowledge of results and sleep deprivation. *Journal of Experimental Psychology*, 66, 332-337.
- Wilkinson, R.T. (1984). Disturbance of sleep by noise: Individual differences. *Journal of Sound and Vibration*, 95, 55-63.
- Williams, H.L., et. al. xxx full refs from Norm(1964). Responses to auditory stimulation, sleep loss and the EEG stages of sleep. *Electroencephalography and Clinical Neurophysiology*, 16, 269-279.
- Wilson, W.P., and Zung, W.W.K. (1966). Attention, discrimination, and arousal during sleep. *Archives of General Psychiatry*, 15, 523-528.
- Winneke, G., Neuf, M., and Steinheider, B. (1996). Separating the impact of exposure and personality in annoyance response to environmental stressors, particularly odors. *Environment International*, 22, 73-81.

Wolsink, M. and Sprengers, M. (1993). Windturbine noise: A new environmental threat? *Proceedings of Noise as a Public Health Problem*, Vallet, M., ed., Arcueil Cedex, France.

World Health Organisation (1994) *Basic Documents*, 40th Ed., Geneva.

Yamada, I. and Kaku, J. (1996). Changes in people's attitudes toward airport resulting from decrease in number of flights. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2079-2084.

Yamamoto, T., Shoji, H., and Takagi, K. (1968). Prediction of temporary threshold shift following exposure to noise having arbitrary spectrum and temporal characteristics. In: *The Sixth International Congress on Acoustics*, Tokyo, August 21-28, 1968, pp. A-9 to A-12.

Yano, T., Yamashita, T., and Izumi, K. (1996a). Social survey on community response to railway noise; Comparison of responses obtained with different annoyance scales. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2299-2302.

Yano, T., Yamashita, T., and Izumi, K. (1996b). Effects of a belt of trees on road traffic noise annoyance. In *Proceedings of Internoise '96, Liverpool*. St Albans, U.K.: Institute of Acoustics, 2307-2310.

Young, J.S., Upchurch, M.B., Kaufman, M.J., and Fechter, L.D. (1987). Carbon monoxide exposure potentiates high-frequency auditory threshold shifts induced by noise. *Hearing Research*, 26, 37-43.

Young, R.W., and Peterson, A. (1969). On estimating noisiness of aircraft sounds. *Journal of Acoustical Society of America*, 45, 834-838.

Zakrisson, J.E. (1975). The role of the stapedius reflex in post stimulatory auditory fatigue. *Acta Otolaryngol*, 79, 1-10.

Zhao, Y., Zhang, S., Selin, S., and Spear, R.C. (1991). A dose response relation for noise induced hypertension. *British Journal of Industrial Medicine*, 48, 179-184.

Zwicker, E. (1987). Procedure for calculating partially masked loudness based on ISO 532B. In Li Peizi (ed.), *Intronoise 87*. Beijing, China: Acoustical Society of China, Vol. II, pp. 1021-1024.

Zwicker, E., and Fastl, H. (1990). *Psychoacoustics. Facts and Models*. Berlin: Springer-Verlag.