
The Influence of Night-time Noise on Sleep and Health

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To the State Secretary for Housing, Spatial Planning and the Environment
PO Box 20951
2500 EZ The Hague

Subject : Report on night-time exposure to noise
Your reference : LMV 2003003076
Our reference : U 1007/WP/718-K
Enclosures : 1
Date : 22 July 2004

Mr State Secretary,

Further to your letter, reference LMV 2003003076, I am pleased to enclose an advisory report on night-time exposure to noise. At my request, the report has been drawn up by a specially formed Health Council Committee. The report has been reviewed by the Standing Committee on Medicine and the Standing Committee on Health and Environment.

The report is based upon the compiling Committee's assessment of the findings of available scientific research into the influence that night-time exposure to noise has on sleep and health. In order to obtain a good overview of the relevant themes, the Committee began its deliberations with a workshop for experts from the Netherlands and other countries. The workshop took place on 2 July 2003 as part of the *8th International Congress on Noise as a Public Health Problem* (ICBEN2003) in Rotterdam. In addition, interested parties were invited—both in direct correspondence from myself and in an advertisement placed in the *Government Gazette* of 22 July 2003—to submit any information that they felt might be helpful to the Committee. The Committee took account of the eleven responses to this invitation that were received when preparing its report, and each respondent received an individual reply from the Committee.

The Committee paid particular attention to the strength of the evidence for a link between exposure to night-time traffic noise and increased risk of hypertension. Almost all the studies that have looked at hypertension and ischemic cardiovascular disease have focused exclusively on associations with noise exposure *during the daytime and evening*. A recent study, to which you also made reference in your letter, has suggested that night-time noise and its effects on and during sleep are much more significant than daytime noise for the development of hypertension. Although the Committee considers it plausible that a causal relationship exists between exposure to *night-*

Gezondheidsraad

Health Council of the Netherlands

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time noise and increased risk of hypertension, the Committee has concluded that the evidence for such a relationship is limited.

The Committee has noted that very little is known about the biological effects on children of exposure to noise when sleeping, or about the impact on children's health and well-being. The findings of the European research project *Road traffic and Aircraft Noise exposure and children's Cognition and Health* (RANCH) are due to be published shortly (probably in the summer of 2004). However, the Dutch participants in this project point out that these results will not entirely eliminate our lack of knowledge regarding the issue of childhood exposure to noise when sleeping.

I am also sending a copy of the enclosed advisory report to the Minister of Health, Welfare and Sport and another to the State Secretary for Transport, Public Works and Water Management.

Yours sincerely,
(signed)
Professor JA Knottnerus

The Influence of Night-time Noise on Sleep and Health

to:

the State Secretary of Housing, Spatial Planning & the Environment

No. 2004/14E, The Hague, 22 July 2004 (corrected version, 27 January 2005)

The Health Council of the Netherlands, established in 1902, is an independent scientific advisory body. Its remit is “to advise the government and Parliament on the current level of knowledge with respect to public health issues...” (Section 21, Health Act).

The Health Council receives most requests for advice from the Ministers of Health, Welfare & Sport, Housing, Spatial Planning & the Environment, Social Affairs & Employment, and Agriculture, Nature & Food Quality. The Council can publish advisory reports on its own initiative. It usually does this in order to ask attention for developments or trends that are thought to be relevant to government policy.

Most Health Council reports are prepared by multidisciplinary committees of Dutch or, sometimes, foreign experts, appointed in a personal capacity. The reports are available to the public.

This report can be downloaded from www.healthcouncil.nl.

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Executive summary

Why this report?

Sleep is very important. It is therefore understandable that unintentional noise-related disturbance of sleep is a serious problem. Since it is not always easy to reduce disturbing noise, which is frequently associated with activities that are of value to the community at large, such as travel and transport, a debate has arisen regarding the health and well-being implications of sleep disturbance by environmental noise.

Like other countries, the Netherlands has regulations designed to limit public exposure to environmental noise, primarily with a view to managing the associated nuisance. Most of the limits relate to exposure over a complete twenty-four-hour period and do not therefore focus specifically on the period during which most people sleep. However, regulations are presently being prepared at EU level that do concentrate on night-time noise exposure. In due course, Dutch law will be brought into line with the new EU legislation.

Against this background, the State Secretary for Housing, Spatial Planning and the Environment wrote to the Health Council on 3 February 2003, asking for its advice regarding the influence of night-time noise on sleep, health and well-being. This report has been compiled by the Council's Noise, Sleep and Health Committee and addresses the questions posed by the State Secretary.

Exposure to night-time noise when sleeping

Environmental noise may originate from a wide variety of sources: air, road or rail traffic; industry and other localised activities; neighbours or one's general neighbourhood.

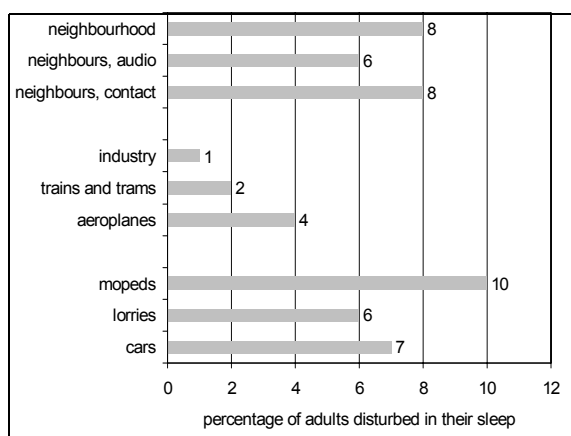
The consequences of exposure to night-time noise when sleeping have mainly been studied in relation to traffic noise. In the vast majority of cases, night-time traffic noise involves individually distinguishable noise events, such as the passage of a train, car or aeroplane.

Little research has been conducted into sleep disturbance from localised noise sources such as factories, firing ranges, shunting yards, wind turbines, climate control systems, building or demolition work. However, the Committee believes that the effects of noise from such sources are unlikely to differ essentially from the effects of traffic noise.

To date there has been no published research into a possible relationship between exposure to the other types of noise in the neighbourhood (recreational activities, children playing) and sleep disturbance. The Committee was therefore unable to assess the influence that such noise has on sleep.

Published research findings indicate that a variety of non-acoustical factors determine whether people are disturbed in their sleep by noises from neighbouring homes (voices, toilet flushing, footsteps, radio, television). The existence and complexity of these factors imply that it is not possible to establish meaningful relationships between night-time noise from neighbouring dwellings and the degree of sleep disturbance one suffers.

Research into the extent to which Dutch people claim to be disturbed by night-time noise during sleep is summarised below:



Effects of night-time noise during sleep

The Committee divided the effects of environmental noise during sleep into two general categories: biological responses and effects on health and well-being.

Biological responses to environmental noise occur because, even when asleep, an organism has to appraise and process stimuli from its environment. Such responses include waking up, having difficulty falling asleep again and increased motility.

It is plausible that, in the event of repeated exposure to night-time noise and under certain circumstances, some biological responses will have long-term implications for health and well-being. The Committee distinguishes five categories of effects:

- reduced sleep quality
- reduced general well-being
- impaired social interaction and reduced concentration during day-time
- specific disease symptoms
- loss of years of life (premature mortality).

Individuals differ from one another both in terms of their biological responses to night-time noise and in terms of the effects on their health and well-being. Thus, one person may take potentially harmful noise exposure levels in his or her stride without any significant adverse effects, while the health and well-being of someone else in a similar situation will deteriorate. In this context, much depends on the extent to which a variety of inherent and acquired personal factors interact with environmental factors.

Evidence

In order to assess the degree of certainty concerning the relationship between exposure to night-time noise and a particular effect, the Committee rates the available evidence as *sufficient*, *limited* or *insufficient*. Evidence is deemed sufficient if an indisputable relationship exists between exposure to night-time noise during the sleeping period and the effect in question, and if it is plausible from a biological model that the effect is attributable, at least in part, to the exposure. Evidence is rated as limited if a relationship between exposure and effect has been observed and a causal relationship is credible and plausible, but where the possibility of bias attributable to other factors cannot be excluded. The Committee also rates the evidence as limited when a relationship is plausible, and it has been observed that night-time noise exposure has an intermediary effect, which is known from other research to lead to the ultimate effect under consideration. Evidence is regarded as insufficient if the underlying research lacks the quality, consis-

tency or weight necessary to support a conclusion regarding the existence of a causal relationship.

Biological responses

There is sufficient evidence that night-time noise events cause direct biological responses, such as increased heart rate, reduced depth of sleep, increased motility and awakening.

Most biological responses begin to manifest themselves at an *SEL* in the bedroom of approximately 40 dB(A) (*L_{Amax}* in the bedroom of at least 32 dB(A))* . Behavioural awakening (established by pressing a button) occurs when the bedroom *SEL* exceeds 55 dB(A).

The Committee also concludes that there is sufficient evidence of a relationship between exposure to night-time noise and a variety of biological responses exhibited before, during and after sleeping. Some of these are consequences of the direct responses already referred to: increased average heart rate, increased average level of motility, more frequent behavioural awakenings, and longer intervals of wakefulness. It additionally appears that average motility in people exposed to night-time traffic noise is greater at higher noise levels than might be expected on the basis of the direct responses. Higher levels of average motility are closely related to more frequent awakening, lower perceived sleep quality and increased daytime drowsiness.

Furthermore, there is sufficient evidence that people who, while attempting to sleep, are exposed to environmental noise or are concerned about being disturbed by noise in the night, have more difficulty falling asleep. After the sleep period, those who were exposed to night-time noise perceive the quality of their sleep to be impaired, find that their daytime mood is adversely affected and experience greater drowsiness, fatigue and irritability, especially in the morning.

There is limited evidence that under certain circumstances night-time noise can influence stress hormone levels. This effect was observed in women who were annoyed by noise at night and unable to protect themselves adequately to prevent the annoyance.

Implications for health and well-being

The Committee believes there is sufficient evidence that night-time noise has an adverse effect on quality of sleep and general well-being. Limited evidence exists that exposure to night-time noise has a negative impact on social interaction, on the performance of

* In acoustics, the following two values are employed to specify a noise event: *L_{Amax}*, the maximum sound level during a noise event, and *SEL* (sound exposure level), a particular summation of all sound levels during a noise event.

concentration-sensitive tasks during the day, on specific complaints or disease symptoms and on loss of life years due to fatal accidents at work.

Reduced sleep quality is evident from studies on reduced self-reported sleep quality, difficulty falling asleep and remaining asleep, more frequent awakening during the night, shorter sleep periods and increased motility during sleep. A reduction in general well-being due to night-time noise is evident from self-reported sleep disturbance, self-reported health problems, use of sleeping pills and sedatives, and adversely affected daytime mood. Among older people in particular, the use of sleeping pills and sedatives is increased by night-time noise.

The medical conditions that may be linked to exposure to night-time noise are insomnia, high blood pressure and cardiac disease, as well as depression in females. Where insomnia is concerned, the Committee considers the evidence of a causal relationship as sufficient, while there is limited *indirect* evidence for the three latter conditions. There is also limited *indirect* evidence of an increased risk of involvement in a fatal accident at work as a result of sleeping problems and insomnia associated with exposure to night-time noise.

The Committee has estimated the extent of the impact of night-time noise on the health and well-being of the Dutch people in the year 2003 in terms of people who report to be highly sleep disturbed and people suffering from insomnia. The results have been based on data regarding cumulative night-time exposure to road, rail and aircraft noise, provided by the Netherlands National Institute for Public Health and the Environment (RIVM).

Effect	Prevalence in 2003
	Number of people affected (thousands)
Self-reported high sleep disturbance	100-1000
Insomnia	10-100

The number of adults in the Netherlands in 2003 who reported to be highly sleep disturbed due to night-time traffic noise is between one hundred thousand and one million. The increase in the number of people with insomnia attributable to exposure to night-time traffic noise is estimated at 2 per cent of the number of people who reported to be highly sleep disturbed.

Using data on the specific exposures to road, rail and air traffic, the Committee estimates the number of adults who reported to be highly sleep disturbed to be more than 100,000 for each noise source (data for the year 2000; data for 2003 are not available as yet). This number for road traffic noise is about two to four times as large as the numbers for rail and aircraft traffic noise. The increased number of individuals with insom-

nia attributable to road and rail traffic noise amounts to between 1000 and 10,000 in each case. For air traffic noise in the region of Amsterdam Schiphol Airport the corresponding figure is between 100 and 1000 individuals.

Recently the collective burden of disease has been quantified in terms of *disability adjusted life years* or DALYs. Using data from an initial study by RIVM into the severity of various health effects, the Committee has calculated that high sleep disturbance resulting from traffic noise results in a burden of disease amounting to several tens of thousands of DALYs. The equivalent figure for insomnia is certainly an order of magnitude less than this. In spite of the uncertainties associated with such estimates, it does appear that, by affecting sleep, night-time traffic noise is one of the most important effects exerted by the physical environment on health.

Groups at higher risk

Direct cardiovascular responses to night-time noise may be more common in people with cardiovascular problems, people who consider themselves sensitive to noise, and in children. Due to lack of research, it is at present impossible to indicate whether children are possibly more sensitive than adults to other direct biological effects of night-time noise.

People with insomnia are at greater risk of biological effects due to night-time noise than good sleepers. Environmental noise exposure increases the time it takes to fall asleep, especially in people who are worried when they go to sleep. In addition, they also perceive their sleep quality as lower.

The Committee also considers it plausible that exposure to night-time noise is more likely to have an adverse effect on the health and well-being of the following groups: older people, pregnant women, women who have given birth within the preceding 12 months or so, people who regularly work at night, people with sleep disorders, physical pain, dementia, depression, hypertension, heart disease and pulmonary disease.

A special metric for night-time noise

In the Netherlands, special rules covering night-time noise are applied only in relation to scheduled overnight aircraft movements. However, from a scientific point of view, there is no reason why night-time noise from road traffic, rail traffic and industrial activities should be regarded as different from aircraft noise with respect to possible effects on health and well-being. In 1997, the Health Council recommended a system with two noise indicators to protect the public from traffic and industrial noise in the living environment. The Committee has taken up this proposal. According to the system put forward in 1997 the metric of exposure to noise over a twenty-four-hour period should be

representative of general annoyance, while the night-time noise metric should be related to sleep disturbance. Such an approach is rational since there is only a limited degree of comparison between the working mechanisms and effects of night-time noise on the one hand and general annoyance on the other hand.

In addition to *Lden*, the indicator of noise over a twenty-four-hour period, the European Union has adopted *Lnight*, an indicator to be used in the regulation of night-time noise. *Lnight* represents the noise exposure at the most exposed façade, calculated for an eight-hour night-time period (11pm to 7am), and averaged over a full year. In the calculations, more weight is given to the louder noise events than to the quieter ones. Since *Lnight* relates to the outdoor situation, the noise exposure in a person's bedroom may in practice be considerably higher than *Lnight* minus the average noise attenuation of a Dutch home. This is partly because homes differ considerably in the attenuation they provide (in the Netherlands, only newly built homes have to meet noise attenuation standards), and partly because most Dutch people choose to sleep with their bedroom windows at least slightly open. Furthermore, requirements on the basis of *Lnight* can never provide complete protection against sleep disturbance, since many Dutch people go to bed before 11pm and still more (roughly half of all adults) sleep beyond 7am.

Nevertheless, the Committee sees no benefit in adopting an alternative to *Lnight*, since it realises that it is impossible to address every conceivable factor by means of a regulatory noise metric. Furthermore, the Committee is of the opinion that regulations based on the use of *Lnight* (as well as *Lden*) could provide a considerable degree of protection against noise during sleep.

Additional metrics

In addition to setting standards based on *Lnight*, exposure limits could also be imposed on noise events, possibly by limiting the maximum permissible sound level or the number of events per night.

At a given *Lnight* value, the most unfavourable situation in terms of a particular direct biological effect of night-time noise is not, as might be supposed, one characterised by a few loud noise events per night. Rather, the worst scenario involves a number of noise events all of which are roughly 5 dB(A) above the threshold for the effect in question. Where motility is concerned, for example, the worst situation is one where all noise events have an *SEL* of roughly 45 dB(A) inside the bedroom. However, limiting the *SEL* inside the bedroom to less than the biological effect threshold levels is not a technically realistic option at the present time. Depending on how *Lnight* is regulated, one option might also be to limit the number of noise events.

An average adult experiences one or two 'spontaneous' behavioural awakenings during a typical night. The more noise events occur each night, the more likely it is that

a sleeper who awakens ‘spontaneously’ during an event will hear the noise, be annoyed by it, and then have trouble getting back to sleep. In extreme cases, a person can hear a noise up to ten times a night without being awoken by it. This would tend to argue in favour of limiting the number of events. Depending on the level to which *Lnight* is limited and the level of protection opted for, it could therefore be possible to limit the number of noise events (e.g. the number of trains, cars or aeroplanes per night). The effectiveness of applying such limits can only be estimated very roughly.

Adjustment of *Lnight* to take account of special noises

The Committee has considered the following ‘special’ environmental noises: low frequency noise (humming), noise containing low frequency components, tonal noise, impulse noise (noise that rapidly rises), industrial noise and sporadic but very loud noise events. Although little information is available concerning the influence on sleep of exposure to noise with these special characteristics, the Committee believes that there are reasons to assume that in some cases the effects are more pronounced than the effects of exposure to ‘ordinary’ traffic noise. In cases involving noise that contains low frequency components, tonal noise and impulse noise, the Committee suggests using the same adjustment factors for *Lnight* as proposed in the Health Council’s 1997 report *Assessing Noise Exposure For Public Health Purposes*. Like its predecessor, the Committee is unable to propose an adjustment factor for low-frequency noise that consists entirely of humming, such as that associated with transformers and wind turbines. In cases involving noise from industrial activities, the Committee takes the view that research conducted since 1997 has shown that adjustments to match the effect of such noise to road traffic noise are not necessary.

It is not known whether sporadic but very loud noise events have any special consequences for sleep. The Committee is therefore unable to produce any scientifically based conclusion regarding these events.

Protective measures

In response to the State Secretary’s question regarding ways in which the public may be protected against night-time noise, the Committee adopts the generally accepted environmental management and occupational health and safety strategies. Hence, the first step should be to reduce the noise at the source (and to reduce the number of sources), followed by measures designed to address the transfer of noise from the source to the ‘receiver’, and finally ‘receiver-oriented’ measures might be considered.

Many of the noise-reducing measures already in place are concerned primarily with limiting the impact of exposure to noise over a twenty-four-hour period. Additional

noise attenuation of the façade of bedrooms is one of the few measures that are taken to deal with night-time noise.

Little scientific research has been conducted into the effectiveness or efficiency of measures intended to protect against the consequences that either general noise exposure or night-time noise exposure has for health and well-being. Consequently, there is no sound scientific basis for making any statement regarding the effectiveness of any protective regime. Furthermore, increasing mobility is liable to offset the benefit that might be gained from many traffic noise reduction measures.

Furthermore, the Committee would like to emphasise the importance of instruction and communication as the final elements among the measures needed to keep the adverse effects of night-time noise within acceptable limits.

Often, there is no choice but to take both source-oriented and transfer-oriented measures, sometimes complemented by recipient-oriented measures. This is because – even disregarding the issues of effectiveness and efficiency – none of the possible forms of intervention is easy to implement. The Committee does not consider the introduction of personal hearing protectors an appropriate collective response to environmental noise, although such protectors may offer relief in specific cases.

Recommendations for future research

The Committee recommends that studies be carried out into various topics, in order to fill what it considers to be the most important gaps in our knowledge regarding exposure to night-time noise. These topics are the long-term effects of night-time noise on health and well-being, the effects of night-time noise on children, the effectiveness and efficiency of noise attenuation measures for façades and between dwellings, and the effects of noise produced by neighbours or by one's general neighbourhood. The Committee advocates that such studies be linked to international programmes, as the Health Council has indeed already proposed in its advisory report entitled *Gezondheid en milieu: Kennis voor beleid (Environmental Health: Research for Policy)*.

Glossary of terms used in this report

Table 1 provides brief definitions of the terms used in this report. Several groups of terms are distinguished: terms relating to sleep and the measurement of sleep parameters, terms relating to the acute effects of exposure to night-time noise when sleeping, terms relating to health and well-being, and terms relating to the indexes of noise exposure used in this report.

Table 1 Glossary of general (sleep-related) terms, biological phenomena, terms relating to health and well-being, and indexes of noise exposure.

Term	Definition
General sleep-related terms	
Sleep inception time	The point in time when a person falls asleep.
Awakening time	The point in time when a person wakes up, as a precursor to arising and becoming active.
Sleep latency/inception period	The length of time taken to fall asleep, i.e. the interval between the point at which a person begins trying to go to sleep or allowing him/herself to go to sleep and sleep inception time.
Sleep period/sleeping time, sometimes referred to as 'sleep'	Period between sleep inception time and awakening time, including any interim intervals of wakefulness.
Time in bed	The sum of a sleep period and the associated sleep latency period.
Polysomnography	The measurement during a subject's time in bed of his or her brain activity by means of EEG, EOG and EMG. In this report, the term EEG measurement or scanning is used. The technique involves the use of electrodes to record electrical potentials in the brain. On the basis of international standards, the data collected can be used to identify phenomena such as the stages of sleep.

Sleep EEG	Graph created using data from EEG scanning during a subject's time in bed, showing the various stages of sleep as a function of time. From such a graph, it is possible to draw conclusions regarding the structure of the subject's sleep.
Actimetry	The measurement of accelerations associated with the movement of an actimeter. In scientific research, an actimeter is a device resembling a wristwatch, which measures how much the wearer moves (by recording accelerations above a given threshold) over a predetermined time interval, typically between one second and one minute. The curve representing the amount of movement as a function of time is known as an actigram.
Measurement of stress hormones	Measurement of the quantity of (stress) hormones – typically cortisol, adrenaline (epinephrine) and noradrenaline (norepinephrine) – in the blood, urine or saliva.
Registration of wakefulness	The indication by a subject (for the benefit of an investigator) that he or she is awake, typically after waking up in the course of or at the end of his or her sleep period, by pressing a button or performing some other conscious act.
Acute phenomena	
Heart rate acceleration	A temporary rise in heart rate relative to the average heart rate assessed shortly before a noise event.
Change in the quantity of a stress hormone	The difference in the quantity of a stress hormone in blood, urine or saliva samples collected at two successive points in time.
Sleep stage change (from deeper to less deep sleep)	Change from a deeper stage of sleep to a less deep stage, as determined by a sleep EEG.
EEG awakening	Transition from a state of sleep to a state of consciousness, as determined by a sleep EEG.
Motility	The presence of movement in a short time interval, as recorded on an actigram.
Motility onset	The presence of movement in a short time interval, following an interval without movement.
Subject-registered awakening (behavioural awakening)	Awakening that is registered by the subject by means of a conscious action.
Phenomena relating to one or more sleep periods or sleep latency periods	
Average sleep latency period	The average length of the sleep latency period on a number of occasions.
Average heart rate	The average speed at which the heart beats when asleep.
(Stress) hormone concentration	The concentration of (stress) hormone in blood, urine or saliva collected during and/or after a sleep period.
Duration of a sleep stage	The number of minutes that a sleeping person is in a particular stage of sleep.
Sleep fragmentation	Within a sleep period, the frequency and duration of intervals of wakefulness recorded on a sleep EEG or intervals of motility recorded on an actigram.
Average motility/motor unrest	Within a sleep period, the recorded number of intervals involving motility divided by the total number of intervals making up the sleep period.
Average motility onset frequency	Within a sleep period, the recorded number of intervals in which motility begins, divided by the total number of intervals making up the sleep period.
Perceived quality of sleep	The quality of sleep, as perceived by a subject and described in a questionnaire response or journal entry.
Sleeping problems: difficulty falling or staying asleep	Difficulty falling or staying asleep, as perceived by a subject and described in a questionnaire response or journal entry.

Sleep disturbance	Disturbance of sleep by night-time noise, as perceived by a subject and described in a questionnaire response or journal entry.
Health problems	Problems with health, as perceived by a subject and described in a questionnaire response or journal entry
Insomnia	Sleeping disorder consistent with an internationally accepted definition, which takes account of difficulty falling or staying asleep, the daytime implications and the duration of the problems.
Raised blood pressure/hypertension	A condition characterised by systolic blood pressure higher than 160 mmHg and/or diastolic blood pressure higher than 100 mmHg (internationally recognised definition).
Noise exposure indexes	
Sound pressure level at a given point in time	The intensity of a noise at a given point in time, expressed in dB(A) (A-curve decibels).
<i>L_{Amax}</i>	Maximum outdoor sound pressure level associated with an individual noise event.
<i>L_{Amax_i}</i>	Maximum indoor sound pressure level associated with an individual noise event.
Equivalent sound pressure level over a given time interval <i>T</i> : <i>L_{Aeq,T}</i>	Exposure to noise for the duration of a given time interval <i>T</i> (a twenty-four hour period, a night, a day, an evening) is expressed as an equivalent sound pressure level (measured in dB(A)) over the interval in question. The equivalent sound pressure level is an ‘exponential average’ of the sound pressure levels occurring during the interval in question, i.e. an ‘average’ calculated by a method that attributes greater weight to higher sound pressure levels.
<i>SEL</i> (sound exposure level)	Equivalent outdoor sound pressure level associated with an individual noise event, with the equivalent level standardised at one second.
<i>SEL_i^a</i>	Equivalent indoor sound pressure level associated with an individual noise event, with the equivalent level standardised at one second.
<i>L_{night}</i>	Equivalent outdoor sound pressure level associated with a particular type of noise source between 11pm and 7am, calculated over a period of a year.
<i>L_{night_i}</i>	Equivalent indoor sound pressure level associated with a particular type of noise source between 11pm and 7am, calculated over a period of a year. <i>L_{night_i}</i> equals <i>L_{night}</i> minus a sound attenuation value specific to the fabric of the individual building and the particular type of noise source.
<i>L_{den}</i> (d: day, e: evening, n: night)	Equivalent outdoor sound pressure level attributable to a particular type of noise source, over a twenty-four-hour period, adjusted using evening and night factors, calculated on an annual basis.
<i>L_i</i>	Equivalent sound pressure level representative of exposure to a particular type of noise source, occurring in an individual’s bedroom while he or she is asleep.
<i>I_{tu}</i> and <i>I_{tu,k}</i>	Indexes of the attenuation of airborne noise by a screening surface (wall, floor, ceiling) between dwellings; <i>I_{tu,k}</i> is based upon a reception room of standardised dimensions.
<i>I_{co}</i>	Index of the attenuation of contact noise by a screening surface (wall, floor, ceiling) between dwellings.

^a If a noise event lasts for one second, the *SEL_i* for the event is the equivalent noise level during that second (*L_{Aeq,1s}*). If a noise event lasts for a hundred seconds, the *SEL_i* for the event is the equivalent noise level during those hundred seconds: (*L_{Aeq,100s}*) plus $10 \cdot \lg 100 = L_{Aeq,100s} + 20$. A constant-level noise event that lasts for a hundred seconds therefore has an *SEL_i* that is 20 dB(A) higher than the *SEL_i* of a noise event of the same constant level that lasts for one second.

Noise, sleep and health

1.1 Background

People cannot function without sleep. It is therefore understandable that any disturbance of sleep by environmental factors, in particular noise, should be a cause for concern. Since it is not always easy to reduce sleep-disturbing noise, which is frequently associated with activities that are of value to the community at large, such as travel and transport, a debate has arisen regarding the health implications of sleep disturbance by environmental noise. It is undeniably the case that noise tends to disturb sleep^{1,2}. However, the precise significance of such disturbance for perceived health and the development of illness is less clear¹.

Like other countries, the Netherlands has legal controls designed to limit public exposure to environmental noise, primarily with a view to managing the associated annoyance. Most of the limits that exist are concerned with exposure over a complete twenty-four-hour period and do not therefore focus specifically on the period during which most people sleep. In the Netherlands, special rules covering night-time noise are applied only in relation to scheduled overnight aircraft movements. However, legislation is presently being prepared at the EU level that does seek ultimately to reduce night-time exposure. In due course, Dutch law will be brought into line with the new EU legislation.

1.2 Ministerial commission and establishment of the Committee

Against this background, the State Secretary for Housing, Spatial Planning and the Environment wrote to the Health Council on 3 February 2003, asking that an advisory report should be prepared on the effects of night-time noise on sleep and health (see Annex A). Specifically, the State Secretary asked the Council to address the following questions:

- a What are the effects (expressed in quantitative terms as far as possible) of exposure to noise when sleeping?
- b How do such effects compare with other effects on health, in terms of seriousness and magnitude?
- c Is it necessary to take special account of any population groups that are at particular risk?
- d In view of the effects referred to, would it be advisable to introduce special rules, similar to those contained in Directive 2002/49 and the Aviation Act, for night-time noise from sources other than air traffic?
- e If so, is it sufficient for such rules to be based on *L_{night}*, or are additional indexes of exposure required, with a view to regulating impulse-like noises and situations involving relatively infrequent but high-intensity noise events?
- f Could the public be protected by the use of a. performance-related or design requirements for residential buildings, b. personal protective gear, c. rules regarding sound pressure levels outside buildings, d. rules relating to vehicles and machinery, or e. a combination of these measures?

In response, the President of Health Council established the Committee on Sleep, Health and Noise, referred to below simply as the Committee. The members of the Committee are listed in Annex B.

1.3 Methodology

Over the last few decades, the Health Council has produced several advisory reports relating, at least in part, to the influence on sleep of exposure to noise^{1,2,6-8}. The present report builds upon these earlier publications and updates their findings where justified by the subsequent emergence of further scientific information.

To support the Committee's deliberations, the secretary produced a summary of available information concerning the interrelationships between noise, sleep and health. This involved carrying out a number of literature searches. The file of relevant literature was complemented by pertinent data supplied by members of the Committee.

In addition, interested parties were invited – both in direct correspondence and in an advertisement placed in the *Government Gazette* of 22 July 2003 – to submit any information that they felt might be helpful to the Committee. The bodies and individuals that responded to this invitation are listed in Annex C.

On 2 July 2003, the Committee organised an international workshop, which was attended by experts from the Netherlands and other countries. The workshop formed part of the *8th International Congress on Noise as a Public Health Problem* (ICBEN2003), which took place between 30 June and 3 July 2003 at *De Doelen* in Rotterdam. The Committee drew upon the information obtained at the workshop when preparing this report.

The Committee finalised the text of this report in the course of six meetings.

1.4 The collation of available scientific data

Relevant publications and reports were collected by several means:

- A search of the document library at TNO Inro's Department of Health and Environment was carried out for material relating to sleep and the influence of noise on sleep. A collection of relevant documentation was compiled in connection with preparation of the 1994 advisory report *Noise and Health*², and efforts have been made to keep the collection up to date over the intervening decade. In addition, reports on international (acoustic) conferences were screened for publications on the effect of noise on sleep.
- The library staff at the Health Council carried out searches of *Medline*, *Biosis*, *Embase* and *PsychInfo* for relevant documents published since 1994. These searches were performed using combinations of the keywords 'noise', 'sleep' and 'effect', with the latter linked to numerous parameters. Some of the effect parameters used were as listed in the first columns of Tables 12, 13 and 14*. Searches were also carried out using the effect variable specifications** referred to. Information about sleep disorders was sought by the Committee secretary using the keywords 'insomnia', 'prevalence' and 'sleep apnoea', 'prevalence' and 'narcolepsy', and 'prevalence' and 'restless legs syndrome'. Searches were also carried out using the names of a number of researchers known to be active in the field of noise-related sleep disturbance.
- Individual members of the Committee supplied literature concerning their specialist fields.

* The direction of the change in a given effect parameter was not specified. So, for example, searches were made on 'sleep stage', not on transition from a deeper stage of sleep to a less deep stage.

** So, for example, in addition to searching on 'stress hormone', searches were carried out using the terms 'adrenaline', 'noradrenaline' and 'cortisol'.

1.5 Structure of the report

The structure of this advisory report is as follows. Chapter 2 outlines the terminology used. Chapter 3 summarises the results of research into the effects of exposure to night-time noise when sleeping. Next, a number of acoustic issues are considered in chapter 4. In chapter 5, the Committee directly addresses the six questions posed by the State Secretary. The main body of the report concludes with a list of references.

Appendices A, B, and C set out, respectively, the content of the State Secretary's letter, the composition of the Committee, and the names of bodies and individuals who responded to the invitation to submit information for consideration by the Committee. Annex D contains a discussion of research into consequences of exposure to night-time noise when sleeping. Annex E describes the situation with regard to sleep disorders and sleeping problems in the population at large, and Annex F summarises the most recent Health Council advisory report on environmental noise (*Assessing Noise Exposure for Public Health Purposes*)⁸. Annex G reproduces the text of an attachment to a letter from the RIVM containing recent information on the noise exposure in the Netherlands.

Central concepts

In this chapter, the Committee begins by presenting a summary of the different types of environmental noise (2.1). Section 2.2 explains the indexes used in this report to characterise exposure to noise, while section 2.3 is devoted to various aspects of sleep. In section 2.4, a model is presented that describes the influence of environmental factors on health and well-being. Finally, an assessment of the evidence for the effects of night-time noise is made in section 2.5.

2.1 Research into the relationship between environmental noise and sleep and health

Environmental noise can be divided into a number of types on the basis of source:

- Traffic sources: aviation, road traffic, rail traffic and shipping
- Stationary environmental sources, such as factories, shooting ranges, shunting yards, wind turbines, climate control systems, (temporary) building and demolition sites
- People and human activities in the neighbourhood not covered by the first two categories (neighbourhood noise)
- People and human activities in adjacent dwellings (noise from neighbours)

Research into exposure to environmental noise may be divided into two broad types:

- Research into the prevalence of the effects of exposure to environmental noise (inventory research)
-

- Research into the relationship between exposure and the extent to which an effect occurs: epidemiological research with population groups and laboratory research with human subjects.

A nationwide Dutch inventory study was undertaken in 1998, in the context of which four thousand people aged sixteen and above completed questionnaires⁹. This study indicated that passenger cars, lorries and mopeds were the types of vehicle most often associated with sleep disturbance in the Netherlands (being mentioned as causes of disturbance by 7, 6, and 10 per cent of respondents, respectively). Sleep disturbance is (much) less frequently associated with noise from aviation or rail traffic, or from factories and other economic activities. Where noise from neighbours is concerned, the most frequently mentioned problems were contact noise (people going up stairs, slamming doors, etc) and noise from audio equipment, being referred to by 8 and 6 per cent of respondents, respectively. Neighbourhood noises also proved to be a significant cause of sleep disturbance, mentioned by 8 per cent of respondents. See Figure 1; further details are presented in Table 21 in Annex D.

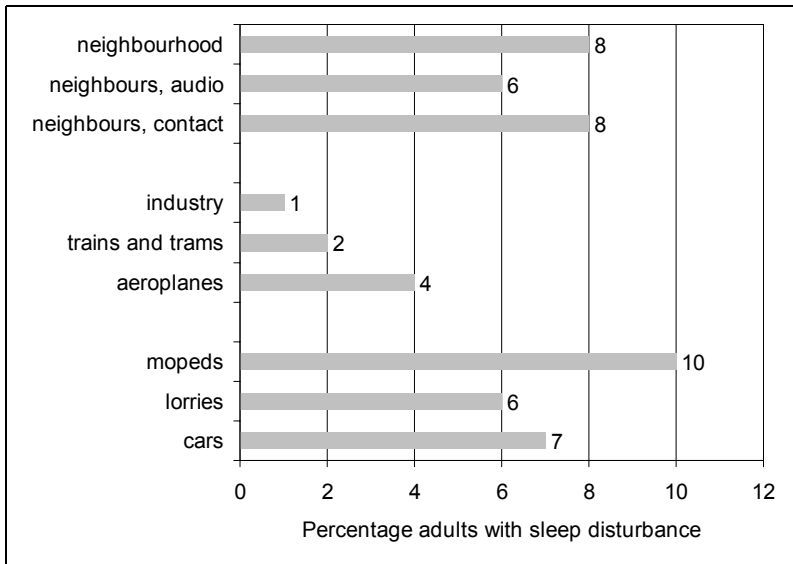


Figure 1 Percentage of adults in the Netherlands experiencing sleep disturbance due to particular noise sources in the residential environment⁹. The national inventory study carried out in 1998 asked respondents to indicate the extent to which their sleep was disturbed by noise from various sources, by giving a number between 0 and 10, where 0 = not disturbed at all and 10 = very highly disturbed. A standardised method was then used to calculate the percentage of respondents reporting sleep disturbance and high sleep disturbance. This involved transforming the 11-point scale into a continuous scale from 0 to 100. Respondents who scored 50 or more on this scale were deemed to suffer from sleep disturbance.

Most of the epidemiological and laboratory research that has been conducted into the relationship between, on the one hand, sleep and health characteristics and, on the other, exposure to night-time noise has focused on *noise from traffic sources* (other than shipping). Epidemiological research into the influence of *stationary environmental sources*, such as industrial premises, has been confined to self-reported noise-related annoyance over a twenty-four-hour period. However, there have also been some isolated laboratory studies that have looked at the effect of specific noise characteristics that can be associated with stationary environmental sources, such as a very rapid rise in intensity at the start of a noise event. The Health Council published a report on this topic in 1997⁸. The way in which the specific characteristics of environmental noise help to determine its effect is briefly explained in Annex F. The Committee returns to this matter in chapter 4, and in its answers to the State Secretary's questions.

Noise from neighbours comes in many different forms. Furthermore, research has shown that the factors which determine whether people are disturbed in their sleep by such noise are both numerous and very varied. As a result, it is not possible to determine the relationship between exposure to noise from such sources and the degree of sleep disturbance. However, in this report, the Committee does comment on the influence of features designed to attenuate noise transmitted between dwellings and on certain matters relating to the disturbance of sleep by noise from neighbours.

So far as the Committee has been able to ascertain, no research has been done into a possible link between exposure to *neighbourhood noise* and sleep disturbance. The Committee has therefore been obliged to disregard this topic.

To sum up, therefore, the nature of the scientific data research available is such that this advisory report necessarily concentrates on the consequences of night-time traffic noise (from sources other than shipping) on sleep and health characteristics.

2.2 Characterisation of exposure to night-time noise

The characteristics of a noise include its intensity and its pitch. The louder a noise is, the greater its intensity. The *intensity* of a noise is expressed in decibels (dB). *Pitch* is an expression of acoustic frequency: a buzzing noise is a low-pitch sound, while a hissing noise is a high-pitch sound. Most environmental noises have both high-pitch and low-pitch components. However, the ear is not equally sensitive to all such components. Consequently, when measuring the intensity of an environmental noise, a filter is normally used to reflect the range of human perception. The most widely used filter is known as the 'A filter', for the determination of a *sound pressure level* in dB(A). The 'A' in 'dB(A)' indicates that the figure is adjusted by an internationally standardised method to reflect the relative sensitivity of the ear to low-frequency and high-frequency

components ('A-weighting'). Another commonly used filter is the C filter; the main difference between the A filter and the C filter is that the latter allows through more low-frequency sound than the former.

The sound produced by most sources of environmental noise does not remain at a constant level over time. The noise from an aeroplane or train, for example, consists of a number of temporally distinct passages (noise events). By contrast, the noise from a motorway, when heard from a distance, is more of a constant drone. Exposure to constant or fluctuating noise for a given time interval (e.g. a twenty-four-hour period, night, day or evening) is expressed as an *equivalent sound pressure level* (in dB(A)) for the interval in question. An equivalent sound pressure level is a sort of average of the sound pressure levels occurring during the relevant time interval. However, it is not a true arithmetical average, since more weight is given to higher sound pressure levels than to lower sound pressure levels. Equivalent sound pressure levels for particular parts of the twenty-four-hour period are used as indexes of exposure both in research and for regulatory purposes.

The indexes used to characterise noise in this advisory report (as previously listed in Table 1) are briefly discussed below.

The *intensity of a noise event, as perceived in the bedroom* is characterised by L_{Amax_i} and SEL_i (i stands for *indoor*). L_{Amax_i} is the maximum sound pressure level during a noise event, while SEL_i is the equivalent sound pressure level of a noise event for a standardised one-second period. The L_{Amax_i} and SEL_i for a given type of noise source are often closely related, as are the L_{Amax} and SEL ; so, for example, the correlation for indoor values of aviation noise was found to be 0.94 and that for outdoor values of lorry noise to be 0.99¹⁰⁻¹³.

The long-term outdoor night-time noise exposure at a particular location associated with a particular noise source is characterised using L_{night} , the annual equivalent sound pressure level between 11pm and 7am attributable to that source. Within the EU, L_{night} is designated as the index of the night-time noise exposure attributable to a given noise source that should be used for certain purposes^{3,4}.

The *long-term night-time noise exposure in dwellings* can be characterised using L_{night_i} . This index of equivalent sound pressure level is calculated by deducting from L_{night} the average attenuation provided by the fabric of the walls. The Building Decree lays down requirements regarding the noise-attenuating properties of the walls of dwellings and other noise-sensitive buildings. The attenuation provided by the wall of a new building has to be at least 20 dB(A)¹⁴.

The *long-term outdoor noise exposure at a particular site, as associated with a given noise source* is characterised with L_{den} , the annual equivalent sound pressure

level over a twenty-four-hour period. In the calculation of this figure, the equivalent sound pressure levels during the evening (7pm to 11pm) and the night (11pm to 7am) are increased by 5 and 10 dB(A), respectively. *Lden* is used in EU directives as an index of noise exposure over a twenty-four-hour period^{3,4}.

Li is an expression of the *personal noise exposure when sleeping associated with a given noise source*. It is an index of the equivalent sound pressure level in an individual's bedroom during the sleep period, as attributable to a given noise source over an extended period of time. It therefore expresses the individual's noise exposure when sleeping, taking account of the length of his or her sleep period, the time he or she goes to sleep and gets up, the outdoor noise exposure and the difference between the individual outdoor and indoor noise exposure. Calculation of the latter difference also takes account of whether the person in question has his or her bedroom window open or closed. Hence, while the *Lnight_i* for a given noise source may be constant throughout a particular part of a residential site, the *Li* values for the individual residents may differ significantly, due to behavioural differences or variations in the properties of the dwellings.

Sound attenuation between dwellings can be quantified using an index for the attenuation of airborne noise, I_{lu} , while $I_{lu,k}$ is a similar index which also takes account of the volume of the reception room and the area of the common screening structure, given its characteristic sound attenuation properties. A screen's ability to attenuate contact noise transmitted between two dwellings is quantified using the index for contact noise, I_{co} ¹⁴.

To give an impression of the environmental noise situation in the Netherlands, Figure 2 shows the distribution of the traffic-related outdoor noise exposure (*Lden*, *Lnight*) on dwellings in the year 2000, broken down by source category (motorway traffic, provincial road traffic, municipal road traffic, rail traffic and air traffic)¹⁵. From the graphs, it will be very clear that municipal road traffic generates the most noise, both at night and over a twenty-four-hour period.

To give another example, 40 dB(A) is a widely used limit for twenty-four-hour noise exposure (equivalent sound pressure level) in Dutch nature reserves and recreational areas. In the Central Veluwe Nature Reserve, the noise exposure (twenty-four-hour equivalent sound pressure level) associated with motorway traffic, provincial road traffic, rail traffic and air traffic accounts for, respectively, 19, 12, 6, and 0 per cent of all environmental noise in areas where this limit is exceeded¹⁶. Across the reserve as a whole, the average equivalent sound pressure level associated with all noise sources together is 53 dB(A); across areas where cycling is possible, the corresponding figure is 57 dB(A) and across areas where walking is possible, it is 52 dB(A).

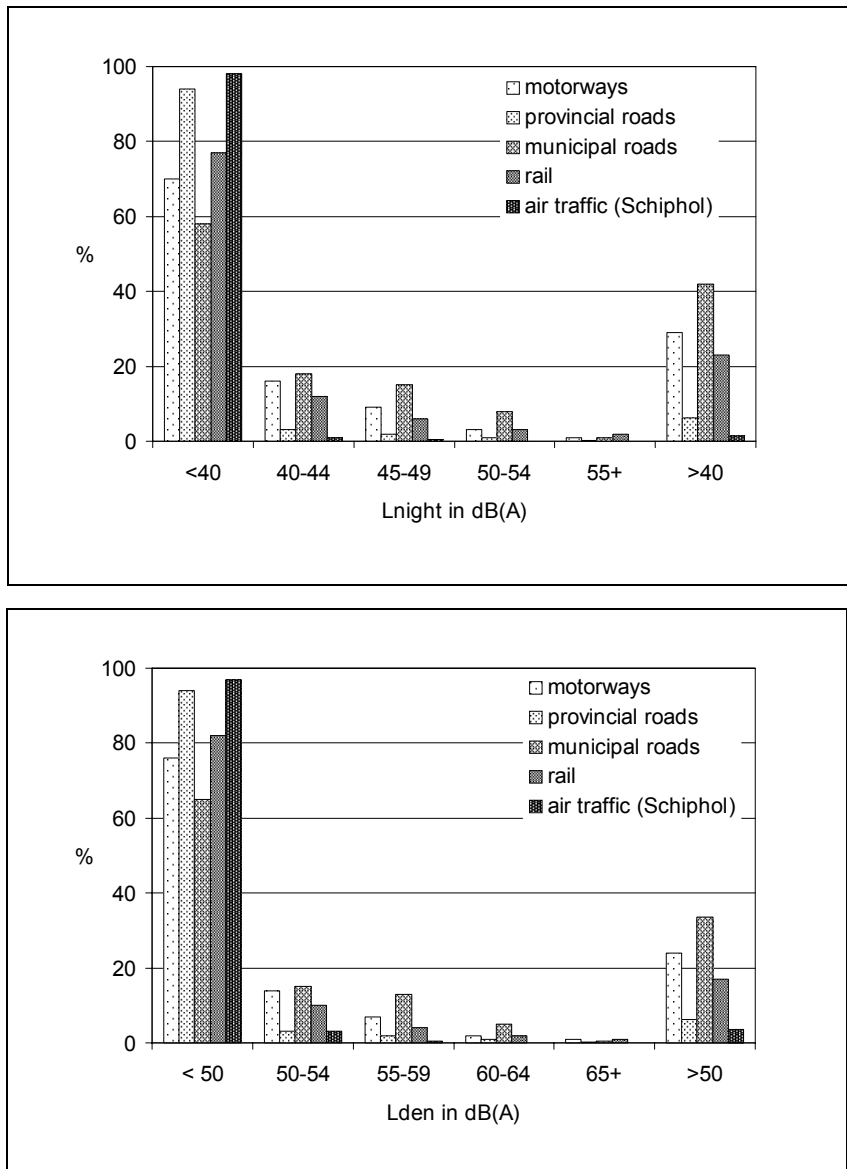


Figure 2 The distribution of traffic-related outdoor noise exposure (L_{night} in the top graph, L_{den} in the bottom graph) on dwellings in the Netherlands in the year 2000, broken down by source category (motorway traffic, provincial road traffic, municipal road traffic, rail traffic and air traffic)¹⁵.

2.3 Sleep

2.3.1 What is sleep*?

In the background study document¹⁷ for the Health Council's 1991 report *Aviation Noise and Sleep*, Hofman – following the textbook *Principles and Practice of Sleep Medicine*¹⁸ – described sleep as a periodically occurring state of apparent inactivity, in which the organism's responses to environmental stimuli are modified to an extent which is not uniform for all stimuli and which differs from one individual to another. Sleep should not be regarded as the mere absence of consciousness, but as a cyclical, active neurophysiological process⁶.

By sleeping, people recover physically and mentally from their efforts. In addition, they process the information that they have absorbed during the day. Finally, sleeping is also enjoyable¹⁹.

Human beings have an internal biological clock with a cycle of roughly twenty-four hours (the circadian rhythm: *circa* = approximately, *dies* = day). Sleep is also a cyclical phenomenon: in adults, it generally consists of roughly five periods of approximately 90 minutes, in each of which there is a spell of so-called 'REM sleep' (or 'dreaming sleep'; REM stands for *rapid eye movement*) and a spell of non-REM sleep. Non-REM sleep is itself divided into four stages, discernible from distinctive electroencephalogram (EEG) patterns. Stages 1 and 2 are referred to more generally as light sleep and stages 3 and 4 as deep or SWS sleep (SWS stands for *slow wave sleep*, a phrase that refers to the extended delta waves that characterise deep sleep on an EEG). When a person is awake, his or her EEG is characterised by so-called alpha and beta waves. Deep sleep tends to occur more towards the start of a period of sleep and REM more towards the end. As one gets older, the amount of deep sleep one needs declines. Waking up from time to time in the course of a period of sleep is part of a normal sleeping pattern¹⁸. Such waking periods may be brief or may last some while. 'EEG awakenings' of short duration, lasting between three and fifteen seconds, are referred to as (*cortical*) *arousals*.

It is generally believed that deep sleep and REM sleep are the most important sleep components, and that stages 1 and 2 are transitional stages. Both deep sleep and REM sleep are necessary for the processing of information taken in during the period prior to sleeping²⁰⁻³¹.

When one is asleep, changes also occur in one's hormone balance.

* See table 1 for explanations of the terms used.

2.3.2 *What is normal sleep?*

The term 'normal sleep' is defined in various ways in the published literature, by reference to both objective and subjective criteria. The objective criteria used include sleep duration, the length of time taken to fall asleep (sleep latency period), sleep efficiency (the time that one spends asleep as a percentage of the time one spends in bed), and the number of EEG awakenings, including cortical arousals. As well as being generally age-related and sometimes gender-related, these sleep characteristics vary substantially from one individual to the next. The subjective criteria used to define normal sleep are based on self-reported sleep characteristics, such as satisfaction with one's sleep, the feeling of being well-rested when one wakes up, and alertness during the day. As long as the values for all three characteristics are within a given range, the subject's sleep may be regarded as 'normal'.

People without sleep disorders who are not while sleeping exposed to loud noises (whether environmental noise, noise from inside their own dwellings or neighbouring dwellings) typically report waking up (subject-registered, behavioural awakening) one and a half to two times during an average sleep period, not counting the occasion that they wake up prior getting up⁵². The number of EEG awakenings, including cortical arousals, averages ten to twelve per night (although there is considerable individual variation)⁵². Such events are therefore approximately six to seven times more frequent than spontaneous subject-registered awakenings. The general figures of one and a half to two subject-registered awakenings per night and ten to twelve EEG awakenings per night can be seen as defining the range of spontaneous awakening frequencies in a population unaffected by sleep disorders or sleep disturbance.

2.3.3 *Sleep and quality of life*

The phrase 'quality of life' is used to mean various things, three of which are taken into account here. First, 'quality of life' can refer to satisfaction with one's health: health-related quality of life. The phrase can sometimes also be an expression of satisfaction with life in general. In the latter sense, 'quality of life' is synonymous with 'happiness'. The third relevant meaning of the phrase is satisfaction with the environment in which one lives. It is in this third sense that 'quality of life' is most often used by researchers concerned with the annoyance caused by night-time noise. Nevertheless, in the Netherlands in particular, more attention has in recent years been given to quality of life in the first sense³²⁻³⁵.

In order to measure any diminution of *health-related quality of life* associated with a given cause, such as night-time noise, one first has to specify the nature of the health

diminution. Where health diminution is detected (or assumed), an assessment of the subject's quality of life ('satisfaction'), in the form of a weighting factor, can be linked to the diminished state of health. In this way, diminution in health-related quality of life can be determined in quantitative terms. One expression of such diminution is Murray's DALY (*Disability Adjusted Life Year*)³⁶.

Diminished satisfaction with the environment in which one lives can be determined relatively easily by obtaining information from the subject using a questionnaire.

As a 'condition', sleep is also seen as a component of health. Thus, if a person is not sleeping well, the direct consequences – fretful waking periods in the night, tiredness the next day and the real or supposed impact of tiredness on daytime activities – lead to a diminution of his or her health-related quality of life. Such diminution can be substantial, as illustrated by the quality-of-life weighting system developed by Stolk *et al*³⁷. Insomnia, as diagnosed by a GP, has a quality-of-life weighting of 0.83, compared with 0.93 for a spastic colon and 0.68 for localised lumbar pain.

The sleep disorders – particularly insomnia – and sleeping problems prevalent in the population at large are reviewed in Annex E. Following the examination of the influence that night-time noise has on sleep, the Committee considers whether there may be correspondences between, on the one hand, certain sleep disorders and sleeping problems in the population at large and, on the other, noise-related sleep disturbance and, if so, whether certain conclusions may reasonably be drawn concerning the influence of noise on sleep.

2.4 Environment and health

In several recent reports, the Health Council has presented its view of the relationship between environmental factors and health^{1,38}. Figure 3 is a schematic illustration of the way that factors in the environment exert an influence and thus can have implications for human health and well-being. The use of the phrase 'health and well-being' in this context is indicative of the fact that, in considering the relationship between environmental factors and health, account is taken of subjective perceptions of health³⁹.

People are not passive under the influence of environmental factors. External influences trigger responses designed to modify their effects and, insofar as the influences are harmful, to counter them or compensate for them. Environmental factors will therefore always have an effect on a person, which is demonstrable in many cases. However, such effects do not necessarily have negative long-term implications for health and well-being.

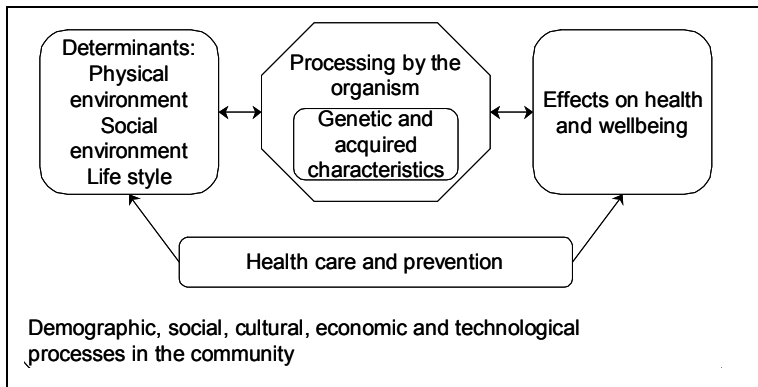


Figure 3 Model of the interrelationships between an individual's environment and his or her health and well-being (from earlier Health Council reports^{1,38}).

The way an individual responds to external factors depends on a combination of inherent and acquired characteristics. Consequently, the effects of such factors and their implications for the health and well-being of the individual differ from person to person. A given potentially harmful influence may be tolerated by one person, but may adversely affect the health and well-being of another. Furthermore, the effect that an environmental factor has can be influenced by the extent to which other factors are simultaneously at work.

2.4.1 Cause-effect chain

The study of links between environmental factors and health generally involves following cause-effect chains⁴⁰ (see Figure 4).

At the point of progression from each block to the next, two questions have to be addressed:

- Is there a causal relationship: is the next event a consequence of the last?
- What influence do other factors have?

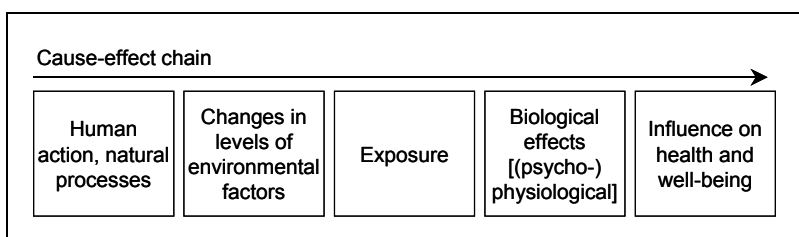


Figure 4 Cause-effect chain.

The ‘exposure’ block plays a special role. It may be regarded as a ‘filter’, which under certain circumstances connects the first two blocks to the last two. In line with the model shown in Figure 4, exposure leads to what are described in the diagram as ‘biological’ effects: physiological and psycho-physiological responses by the individual. These responses are sometimes predictors of brief or prolonged declines in the individual’s health and well-being.

2.5 Assessment of the effects of night-time noise

For an assessment of the relationship between exposure to night-time noise when sleeping and effects on an individual’s health and well-being, the Committee considers the following to be of particular importance:

- The distinction between biological effects and health effect (see Figure 4)
- The ‘significance’ of a health effect
- The exposure-effect process
- The strength of the evidence for each relationship.

These four topics are considered in more detail below.

2.5.1 *The distinction between biological effects and health effects*

In the model illustrated in Figure 3, environmental noise triggers biological responses from the individual because, even when sleeping, he or she still needs to assess and process ‘stimuli’ from the environment. The biological responses that are liable to occur include waking up, difficulties getting off to sleep and increased motor unrest while sleeping. To some extent, these responses involve acute changes during exposure to a noise, and to some extent they involve changes that manifest themselves over a night (before, while and after sleeping). In research, such effects are often used as markers of change in an individual’s state of health and well-being. However, this makes it necessary to consider whether a given biological effect is in fact a predictor of long-term decline in health and well-being, which may or may not depend upon the nature and duration of the exposure. To this end, the Committee distinguishes between biological effects and effects on an individual’s health and well-being. The former manifest themselves at the time of exposure and in the course of a sleep period, while the latter become apparent only in the longer term.

2.5.2 *The significance of a health effect*

The ‘significance’ of a health effect is a concept that includes the seriousness of the effect. The Committee has grouped the relevant effect parameters under five headings: quality of sleep; general well-being; social contacts and concentration; medical conditions; reduction in life expectancy.

2.5.3 *The exposure-effect process*

Not all levels of night-time noise have an effect. It is therefore desirable to be familiar with the exposure process that is liable to induce an effect. The Health Council’s 1994² report on the consequences of exposure to noise introduced the term ‘observation threshold’ for use in this context. This term is defined as follows:

The lowest level of exposure at which epidemiological research has shown noise typically has an effect on health. Where an exposure-effect function has been calculated for a given effect (...) the observation threshold will be obtained from that function.

In the current report, the term ‘observation threshold’ is also applied to effects that are not *necessarily* health effects. In most cases, epidemiological research with human subjects has found that effects occur only when exposure exceeds a certain level. It is possible that effects also occur – in some people, at least – at lower levels, but this possibility is usually not easy to investigate in practice.

2.5.4 *Strength of the evidence*

In order to define the degree of certainty concerning the relationship between exposure to night-time noise and a particular effect, it is normally necessary for a researcher to describe his/her findings in detail, since this is the only way to give a proper account of what is and is not known. However, when preparing a report for policy support purposes, it is desirable to indicate the degree of (un)certainly using a simple scale. The Committee has accordingly introduced a simple uncertainty scale, based on those developed by IARC⁴¹ and a research team in Jülich, Germany⁴².

Since this advisory report draws mainly on *epidemiological* research into the influence that night-time noise has on people’s sleep, supplemented by a small number of laboratory studies, assessment of the strength of the evidence concerning a given relationship here involves determining the extent to which there is a statistically significant correlation between exposure and effect, so that a conclusion may be drawn concerning

causation by applying the so-called ‘Hill criteria’⁴³ (about which more will be said later) and taking account of any other relevant considerations.

In line with the position taken by the IARC and the findings of the 1994 advisory report *Noise and health*, the following definitions have been adopted for the three categories of evidence.

Table 2 The strength of evidence concerning a relationship: definitions of the three levels.

Sufficient	A causal relationship has been demonstrated between exposure to night-time noise during the sleep period and a given effect. A relationship has been observed between exposure and effect in research which may reasonably be deemed to exclude the possibility of coincidence, bias and distortion, and it is plausible that the effect is attributable, at least in part, to the exposure.
Limited	A relationship between exposure and effect has been observed, and a causal relationship is credible, but the possibility of coincidence, bias or distortion cannot confidently be excluded. The presence of a relationship is generally plausible. No direct link has been established between exposure and effect, but there is good quality indirect empirical evidence for such a link, and the presence of a link is plausible. Indirect evidence may be said to exist if it has been observed that exposure has an intermediary effect, which is known from other research to lead to the ultimate effect under consideration.
Insufficient	The underlying research lacks the quality, consistency or weight necessary to support a conclusion regarding the existence of a causal relationship between exposure and effect. A link is not particularly plausible or is implausible.

The definitions given in Table 2 incorporate those developed by the IARC, but additionally make reference to the plausibility of a relationship. Hence, for the evidence of a relationship to be classed as ‘sufficient’, it is necessary for the causal link to be plausible. Otherwise, the evidence is classed as ‘insufficient’. Furthermore, a subcategory of limited evidence not recognised by the IARC has been added: there is deemed to be limited evidence of a relationship where there is indirect empirical evidence that exposure has an intermediate effect, which is known from other research to lead to the ultimate effect under consideration. Inclusion of a relationship within this category depends on examination of its plausibility, with particular emphasis on the differences and similarities in nature and seriousness of the intermediate effect in each case (see Figure 5).

Hill criteria for assessing degree of certainty

When assessing epidemiological research findings to determine whether there is evidence of a causal relationship between exposure and effect, use is often made of the so-called Hill criteria⁴³. In a speech to the *Section on Occupational Medicine* of the Royal

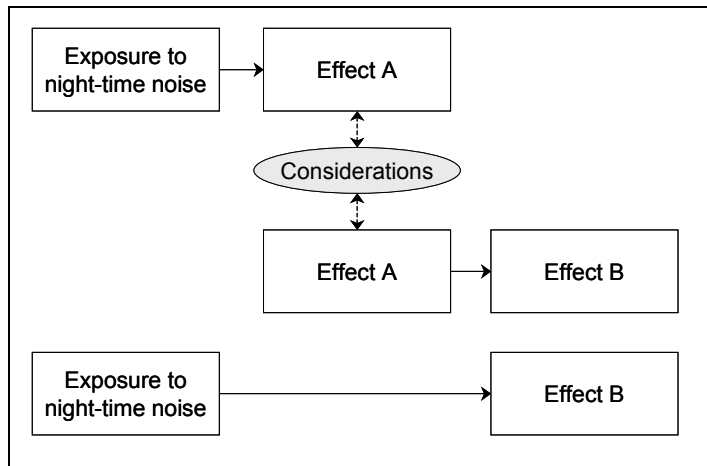


Figure 5 Indirect evidence. Indirect evidence that exposure to night-time noise has an effect (effect B). There is sufficient evidence for a link between exposure to night-time noise and effect A, and there is sufficient evidence that effect A leads to effect B in the general population. Furthermore, it is plausible that noise-induced effect A is consistent with effect A in the general population. Hence, there is limited evidence of a link between exposure to night-time noise and effect B.

Society for Medicine, the section chairman, Professor Austin Bradford Hill, put forward the following criteria for establishing an argument of causation:

- Strength of the relationship
- Consistency
- Specificity
- Temporal sequence
- Biological gradient
- Biological rationale
- Coherence
- Experimental evidence
- Analogous evidence.

Hill pointed out that it was not possible to provide absolute rules for the application of his criteria. What was required was careful assessment of the data, using the criteria for guidance. In practice, decisive criteria tend to be ‘consistency’, ‘biological rationale’, ‘strength of the relationship’ and ‘biological gradient’⁴⁴.

Hill also said that statistical significance was of secondary importance, except insofar as a significance test served to remind the assessor that a study’s observations might have been the product of mere chance. In recent years, meta-analytical methods have been developed to enable conclusions to be drawn by examining a number of studies

collectively. However, whether the application of such methods can ever substitute for careful, well-informed analysis is open to question⁴⁵.

Irrespective of the merits of meta-analysis for the extraction of evidence, the Committee does not believe that the available research data lends itself to quantitative meta-analysis with a view to reaching conclusions regarding the relationship between exposure to noise during the sleep period and (ultimate) effects on health and well-being. What is necessary is to reach consensus regarding the significance of the research findings, in which context the Hill criteria can, as indicated above, play a useful role.

Effects of exposure to noise when sleeping

In sections 3.1 to 3.4, the Committee presents a survey of the effects of exposure to noise when sleeping, and draws a number of conclusions regarding the correlations between, on the one hand, certain sleep disorders and sleeping problems in the population at large and, on the other, the consequences of noise-related sleep disturbance. In Section 3.5, an estimate is made of the prevalence of some of the consequences of exposure to night-time noise for health and well-being and the associated disease burden in the Dutch population.

3.1 Laboratory and field research

In the following discussion of the available research data on the effects of exposure to noise when sleeping, the Committee concentrates on the findings of field research. The reason being that laboratory research does not always take proper account of the habituation to noise that tends to take place in practice. (Although it was, in fact, laboratory research that first demonstrated this effect twenty-five years ago (see Figure 6)⁴⁶.)

Figure 6 shows that, in the course of an experiment, the probability of EEG awakening decreases substantially, although there is barely any alteration in the probability of change from a deeper stage of sleep to a lighter stage. It may therefore be concluded that habituation does not influence all the effects of exposure to noise when sleeping to a similar extent. It should be pointed out that laboratory research has also shown that the probability of exposure to noise having a given effect can *increase* in the later nights of a study⁴⁷.

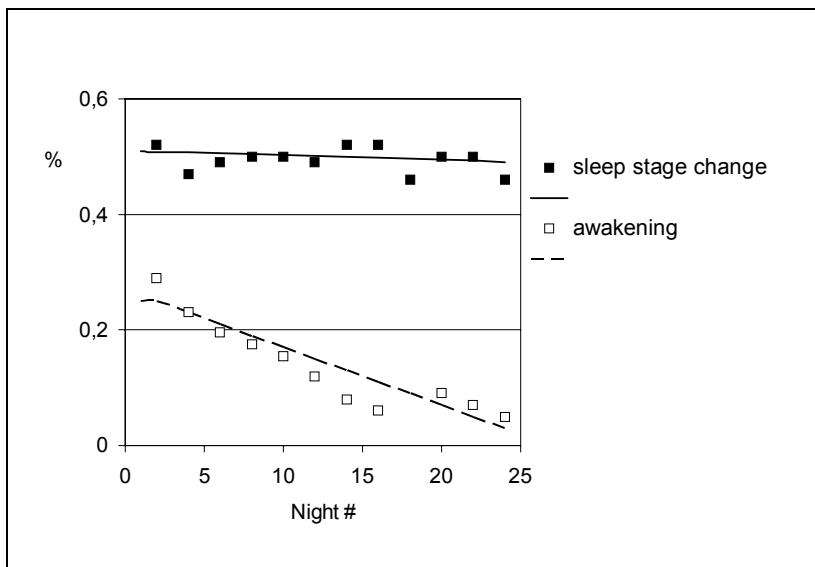


Figure 6 Average probability of the noise of a lorry with an L_{Amax_i} of 65 dB(A) resulting in a change from a deeper stage of sleep to a less deep stage, or in EEG awakening, as a function of the night of exposure⁴⁶.

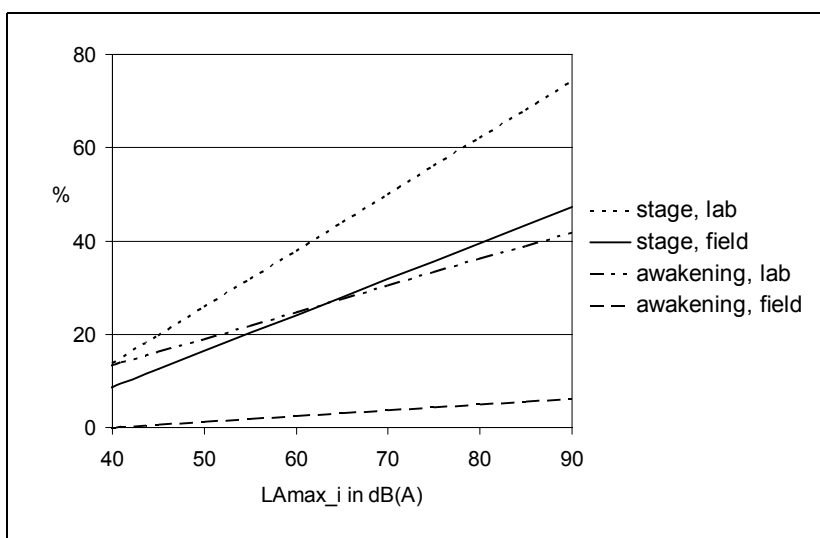


Figure 7 Average probability of sleep stage change and of EEG awakening as functions of L_{Amax_i} for laboratory research subjects and for field research subjects exposed at home⁴⁸.

The fact that laboratory research sometimes sheds little light on the habituation effect is illustrated by the exposure-effect relationships reported by Pearsons *et al*⁴⁸. The effects studied by this team were the probability of EEG awakening and the probability of change from a deeper stage of sleep to a less deep stage. Their findings, as obtained from field and laboratory research, are illustrated in Figure 7. From the figure, it will be clear that, for a given L_{Amax_i} , the probability of EEG awakening or sleep stage change is much greater among laboratory subjects than among people accustomed to experiencing night-time noise at home.

Therefore, to obtain insight into the effects of noise on sleep and health, it is particularly important to carry out field research involving people who are exposed to a given noise source over a longer period of time. Mechanisms can be studied in the laboratory, but the strength of an effect observed in the laboratory is not representative of the 'real' world.

The Committee has divided the effects of exposure to night-time noise on sleep into two groups: biological effects (acute responses to noise and effects over a night (before, while and after sleeping)) and effects on health and well-being resulting from chronic exposure to noise when sleeping (for details, see Tables 12 to 14 in Annex D).

3.2 Acute biological effects

The position as described in an earlier Health Council report

In 1991, the Health Council published an advisory report on aviation noise and sleep⁶. In the associated background study document, Hofman summarised the results of laboratory and field research published up to 1991⁶. Her findings are presented in Table 3. She grouped the results of the reviewed studies into five categories: significant change in the anticipated direction (significance level: 2.5 per cent), trend in the anticipated direction, no change, trend not in the anticipated direction, significant effect not in the anticipated direction. In the table, the latter four categories are unified under the heading 'no statistically significant change in the anticipated direction'. The results relate mainly to noise from road and air traffic, although one or two of the reviewed studies were concerned with the effects of noise from rail traffic or industrial activities.

Table 3 The results of research published up to 1991 relating to acute changes induced by exposure to night-time noise events¹⁷.

Detection method	Effect	Number of studies in which significant change was observed	Number of studies in which no significant change was observed
EEG	Prolongation of sleep latency period	17	15
	EEG awakening	38	9
	Change from a deeper stage of sleep to a less deep stage	35	20
	Transition from REM sleep to another sleep stage and change in sleep structure	27	11
ECG	Increased heart rate	16	7

3.2.1 Comparison of five acute effects of exposure to aviation noise

A great deal of laboratory research has been carried out into acute responses to noise. The precise temporal correlation between noise and response observed in these studies leaves no doubt that the responses in question were brought about and strengthened *by noise*.

Figure 8 illustrates the relationship between each of several acute responses to a noise event (the passage of an aeroplane) and exposure to the event in question. The relationships were determined by the Committee using data from field research into the consequences of (almost exclusive) exposure to aviation noise. The graph shows the probability of a noise-induced response in a time window of five minutes spanning the occurrence of a noise event (from approximately one minute before to four minutes after the *L_{Amax_i}* of the noise event). Notably, most responses occurred in the interval from one minute before to one minute after the moment of maximum noise exposure (*L_{Amax_i}*). As indicated by the graph, noise increases the probability of the following:

- Change from a deeper stage of sleep to a less deep stage, as detected by EEG (stage_EEG)
- Motility (motor unrest) in one of the ten thirty-second intervals making up the five-minute observation window (motility)
- Motility onset (onset of motor unrest) in one of the ten thirty-second intervals making up the five-minute observation window (motility_onset)
- EEG awakening (awake_EEG)

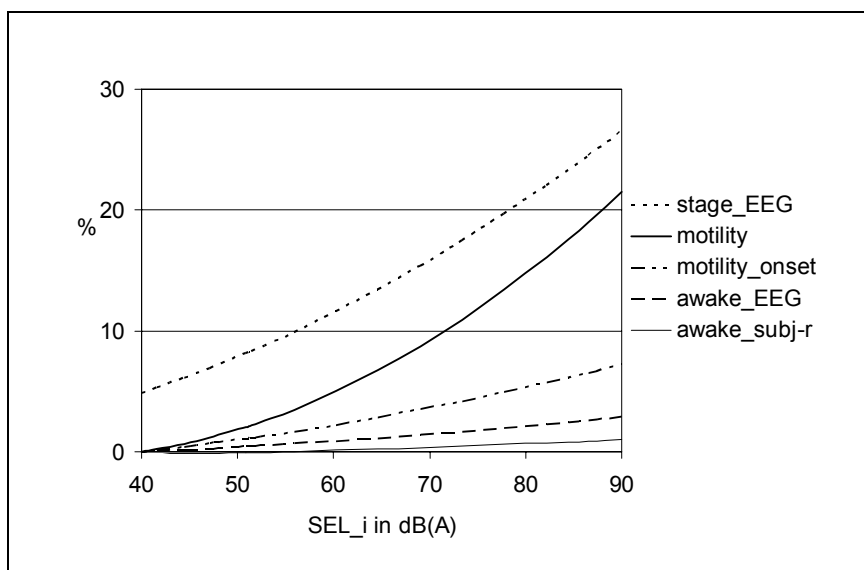


Figure 8 Comparison of the probability of various acute responses exhibited by a subject exposed to noise events while sleeping. The responses concerned are those occurring within a five-minute time interval, from one minute before to four minutes after the L_{Amax_i} of the noise event. For an explanation of the response curve labels, see the main text. The relationships have been determined almost exclusively from research into aviation noise. Because of the assumptions upon which they are based, the curves for EEG awakening (awake_EEG) and sleep stage change (stage_EEG) should be regarded as, respectively, tentative and very tentative⁴⁸⁻⁵³.

- Subject-registered (or behavioural) awakening (awake_subj-r). Subject-registered awakening is generally awakening that the subject registers by pressing a button. In other words, it is an event that entails the subject not only waking up, but also being aware of his/her circumstances to the extent necessary to recall that his/her wakefulness should be registered by performing the prescribed action. Subject-registered awakening therefore implies a higher level of consciousness than EEG awakening.

The relationships shown in Figure 8 are given for the range of SEL_i values from 40 to 90 dB(A). At night, an aeroplane passage with an SEL_i of 40 dB(A) is normally readily discernible indoors. An SEL_i of 90 dB(A) equates to a very loud noise event.

Not all the relationships illustrated in Figure 8 are equally reliable. The Committee believes that the relationships between exposure and subject-registered awakening, motility and motility onset have been defined on the basis of sound evidence. However, definition of the relationships based on EEG data (EEG awakening and sleep stage change) required an assumption, namely that the probability of noise-induced EEG awakening is 40 per cent of the probability of motility being triggered by noise^{**}. However, it is not certain that this assumption is valid in the particular context of exposure to

aviation noise. Furthermore, in order to estimate the probability of a sleep stage change, the Committee has drawn upon the relationships between exposure and the probability of EEG awakening and the probability of sleep stage change illustrated in Figure 7. The Committee therefore regards the curve for EEG awakening as tentative and the curve for sleep stage change as very tentative.

From Figure 8, it is apparent that the observation threshold for the acute effects ‘motility’, ‘motility onset’, and ‘EEG awakening’ is an SEL_i of 40 dB(A) (L_{Amax_i} of 32 dB(A)), while the observation threshold for subject-registered awakening is an SEL_i of 54 dB(A). On the basis of the tentatively plotted curves, the observation threshold for sleep stage change appears to be lower than an SEL_i of 40 dB(A).

3.2.2 *Extrapolation from aviation noise to road and rail traffic noise*

Figure 8 is based almost entirely on the results of research into aviation noise. Road and rail traffic noise also increase the probability of motility onset and of EEG-registered changes (EEG awakening and sleep stage change), and the observation thresholds for these noise sources are similar to those for aviation noise (see Annex D). It should be pointed out that this observation is based primarily on outdoor sound pressure level data; the use of accurate indoor data might yield a different result. In consideration of these matters, while there is insufficient evidence that road and rail traffic noise can cause subject-registered awakening, the Committee anticipates that road and rail traffic noise events are indeed capable of triggering such a response, although the threshold might not be an SEL_i of 54 dB(A).

3.2.3 *Motility and motility onset*

Over the last ten years, three large-scale field studies on aircraft noise have been carried out. Using data from these studies, it is possible to define the relationship between L_{Amax_i} or SEL_i and the probability of acute motility being induced by the noise of a passing aeroplane^{12,49,51}. The probability of acute motility increases as L_{Amax_i} or SEL_i increases. From the Dutch research, it also appears that, at a given L_{Amax_i} or SEL_i , the probability depends to a considerable degree on the indoor equivalent sound pressure level from the plane (L_i): people who are ordinarily exposed to high levels of aviation noise while sleeping respond less to an individual aeroplane passage than people who only experience such exposure from time to time. The study findings also indicated that the type of aircraft manoeuvre (landing or taking off) did not affect the

* The figure of 40 per cent was calculated by Ollerhead by comparing all thirty-second intervals during which EEG arousals were observed in his subjects and all thirty-second intervals during which motility onset was observed⁵¹.

probability of aviation noise-induced motility. The researchers also asked subjects about their attitude to air traffic and to the expansion of Schiphol Airport. Attitude was found to have no influence on the probability of acute motility induced by aviation noise.

The Dutch research findings are consistent with the findings of the study carried out in the USA⁴⁹. However, the relationship between motility onset and the *L_{Amax}* of an aeroplane passage defined on the basis of the British data is quite different from the relationship between motility and *L_{Amax_i}* deduced from the Dutch research. The British researchers came to the conclusion that the threshold for motility onset by the noise of an aeroplane passage was an *L_{Amax}* of 82 dB(A)⁵¹. If this outdoor value is reduced by 25 dB(A) (the figure given by the researchers⁵⁴ as the difference between outdoor and indoor sound pressure levels), one arrives at a threshold *L_{Amax_i}* value of 57 dB(A). This is 25 dB(A) higher than the observation threshold determined by the Dutch researchers for motility and motility onset. In view of the pioneering nature of the British research and the significance that has long been attached to its results, the Committee considers the difference between the British and Dutch studies at more length in Annex D. Its conclusion is that the British research had certain shortcomings that the more recent Dutch research did not share.

3.2.4 *Subject-registered awakening and EEG awakening*

The relationship between the probability of subject-registered awakening and *SEL_i* illustrated in Figure 8 has been defined on the basis of a secondary analysis by Passchier-Vermeer⁵². According to this analysis, the observation threshold for aviation noise-induced subject-registered awakening is an *SEL_i* of 54 dB(A), corresponding to an *L_{Amax_i}* of 42 dB(A).

The Committee puts the typical frequency of ‘spontaneous’ EEG awakenings, including short duration arousals, at ten to twelve occurrences per night and the typical frequency of ‘spontaneous’ subject-registered awakenings at 1.5 to two occurrences per night (in periods without noise events). If someone has woken up ‘spontaneously’, they will be able to hear a car, aeroplane or train that passes while they are awake. The *more frequent* and *longer in duration* the passages are, the greater the chance of hearing one after waking up spontaneously. In an extreme case, therefore, it is theoretically possible that someone could hear a passing car, plane or train ten times in the night without the associated noise being the cause of the person waking up.

The Committee found three reports on the effects of night-time noise on children’s EEGs. These related to laboratory studies involving twenty-four, eight and six children, respectively⁵⁵⁻⁵⁷ and one study of five children in their home environments⁵⁶. Busby⁵⁵ found that children in the final third of their sleep (which mainly involves REM sleep) exhibited EEG awakening in response to noise in nearly 60 per cent of cases – albeit

involving noises of up to 95 dB(A). However, partly because of the lack of additional information regarding the cortical responses of children to night-time noise, the Committee is not able to make any definitive statement about the possibility of children being more sensitive to night-time noise than adults.

3.2.5 *Heart rate acceleration and stress hormone concentrations in the blood*

From the field research data published by Hofman *et al*⁵⁸, the Committee has calculated that peaks in the noise from a motorway (e.g. when a lorry passes) have approximately a 60 per cent chance of inducing heart rate acceleration, irrespective of the *L_{Amax_i}*. The *L_{Amax_i}* values recorded by the Hofman team were mostly between 30 and 70 dB(A). The average increase in heart rate worked out at four beats per minute, irrespective of the subject's sleep stage. The Committee regards heart rate acceleration as one form of acute cardiovascular change. Other acute changes directly associable with heart rate acceleration, such as acute changes in systolic blood pressure and vasoconstriction, follow the same pattern⁵⁹⁻⁶³ (see Annex D). On the basis of laboratory research findings, it seems likely that the noise of a passing lorry or aeroplane with a similar *SEL_i* would have a broadly similar effect on heart rate⁶⁴⁻⁶⁷ (see Annex D). Laboratory research has also indicated that, if one uses *SEL_i* as one's index of noise, noise events that quickly become louder at the start (such as the noise of a low-flying military jet or gunshot noise) have a greater effect on heart rate than noise events characterised by a more gradual increase in level (such as the noise of a lorry or a civil aircraft)^{64,65,67}. However, it is not possible to quantify the extent of the effect.

The Committee is not aware of any field studies that have looked at acute noise-induced changes in the (stress) hormone balance. It is not surprising that no such research has apparently been carried out, since it would necessarily be highly invasive and therefore inappropriate for large-scale studies of subjects in a domestic setting.

Only one study was traced that focused on the impact that exposure to night-time noise has on children's physiological functions. In 1967, Semczuk investigated the effects of exposure to noise when sleeping, by using thoraxgraphy to monitor breathing in a study group of fifty children (five to seven years old) and a hundred adults⁶⁸. The trigger level for respiratory changes associated with an aural stimulus (sound of a particular pitch) was 10 to 15 dB(A) lower in children than in adults. The researcher accordingly concluded that a child's autonomous nervous system is more readily activated by noise when sleeping than an adult's, and that children are therefore physiologically more sensitive to night-time noise than adults. The Committee supports this conclusion.

3.2.6 *Acute annoyance*

None of the studies reviewed by the Committee entailed the recording of acute noise-related annoyance during the sleep period, but some did involve subjects subsequently being asked questions on the topic. It is likely that making journal entries during the night would have a distorting effect by interfering with the sleep process. The Committee assumes that people do feel inconvenienced by noise during the night, even though such feelings have not actually been recorded. The subsequent logging of inconvenience by subjects serves as an indirect indicator of the existence of acute annoyance.

3.2.7 *Ranking of acute responses*

In Figure 9, the acute responses to noise are ranked in order of decreasing probability of induction by noise. Although no research into acute annoyance has been reported, the Committee considers it reasonable to suppose that inconvenience can only be experienced by a person who actually is awake.

3.2.8 *Groups with heightened sensitivity to acute effects*

The Committee has also sought to identify any evidence in the available research data that might indicate whether certain personal characteristics might be associated with heightened sensitivity to acute noise-induced effects on sleep. Although the strength of the evidence found by the Committee is limited, it does appear that people with cardio-

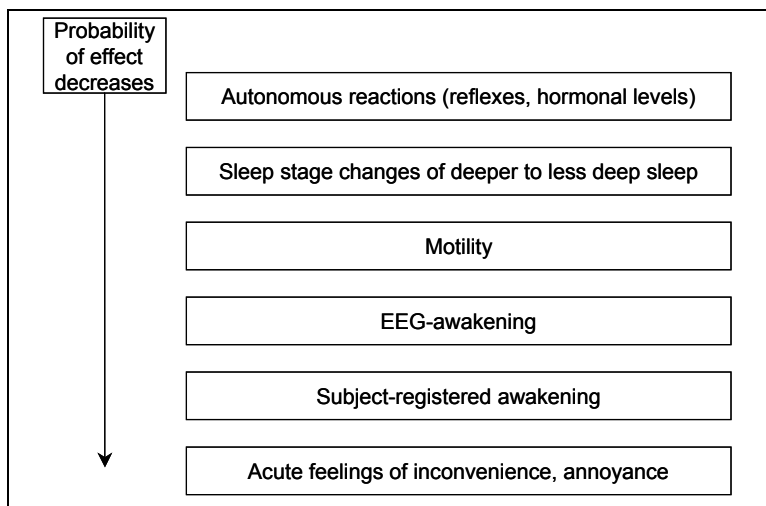


Figure 9 Acute effects of exposure to noise when sleeping.

vascular problems, people who regard themselves as particularly sensitive to noise, and children may all be particularly sensitive to acute cardiovascular effects. Because of the shortage of research data on children, it is not possible to say with confidence whether children are more sensitive than adults to other acute biological responses.

3.2.9 Conclusions

On the basis of the considerations set out above, the Committee draws the following conclusions:

- Road, rail and air traffic noises can induce acute responses in people who are sleeping. Response induction begins at a fairly low threshold level and becomes more likely as the intensity of the noise increases. The observation threshold for EEG awakening, motility, and motility onset associated with traffic noise is an *SEL_i* of approximately 40 dB(A); the corresponding figure for heart beat acceleration is less than 40 dB(A), and that for subject-registered awakening (due to aviation noise) is approximately 54 dB(A). The observation threshold for EEG-detected sleep stage change is probably lower than 40 dB(A) (the relationship cannot be defined with confidence. Although there is insufficient data to provide direct evidence that road and rail traffic noise can induce subject-registered awakening, the Committee believes that peaks in road and rail traffic noise probably have the same effect as aircraft noise, although the associated observation threshold may not be an *SEL_i* of 54 dB(A). The induction of acute changes by industrial noise has not been the subject of scientific study. Nevertheless, the Committee expects that exposure to industrial noise is capable of inducing similar responses. It seems quite possible that the observation thresholds for industrial noise may be broadly similar to those for traffic noise, but the Committee draws no conclusions on this point.
- Almost no research data is available regarding the acute effects of night-time noise on children. The results of the one study that looked at children's respiratory response to noise exposure indicate that the threshold for response induction in children is 10 to 15 dB(A) lower than in adults. Because of the shortage of data, the Committee cannot exclude the possibility that children are also more sensitive than adults to acute cortical effects when sleeping; however, if so, this may only be the case during REM sleep, rather than during deep sleep.
- Laboratory research indicates that, if *SEL_i* is used as the index of noise, noise events involving a very rapid rise in intensity to their peak level have a greater effect on heart rate than events characterised by a more gradual early rise in intensity. However, the Committee is not able to quantify the effects concerned. Although what is known about the relationship between noise from military jets and subject-registered awakening is based purely on data collected from people living in the

vicinity of one airbase, and therefore needs to be verified by other pertinent scientific data, it would appear that, at high noise exposures, subject-registered awakening is much more likely to be induced by military jets than by civil aircraft. The Committee suspects that the increased probability of subject-registered awakening in response to louder military jet passages is linked to the great speed with which the noise from the approaching jet increases in intensity, thus inducing feelings of anxiety.

- The *more* noise events a person is exposed to per night, the greater the chance is that he or she will happen to hear one of the noises after waking up ‘spontaneously’. The Committee believes it is reasonable to assume that, broadly speaking, between 1,5 to two times and ten to twelve times per night, a person is sufficiently conscious to coincidentally hear a noise event that has not actually awoken him or her. This may help to explain the extent of night-time noise-related annoyance. At a given *Lnight* value, the probability of coincidentally hearing a noise event after waking up will often be considerably greater with road traffic than with air and rail traffic, since road traffic noise involves frequent lower-level noise events, in addition to the peaks.
- Although the strength of the evidence is limited, it may well be the case that (as indicated above) people with cardiovascular problems, people who regard themselves as particularly sensitive to noise, and children are particularly sensitive to the acute cardiovascular effects of noise.

The results of the research into the acute effects of exposure to night-time noise when sleeping are summarised in Figure 10. The upper element of the diagram illustrates the general principle: night-time noise influences sleep in a way that can be measured by

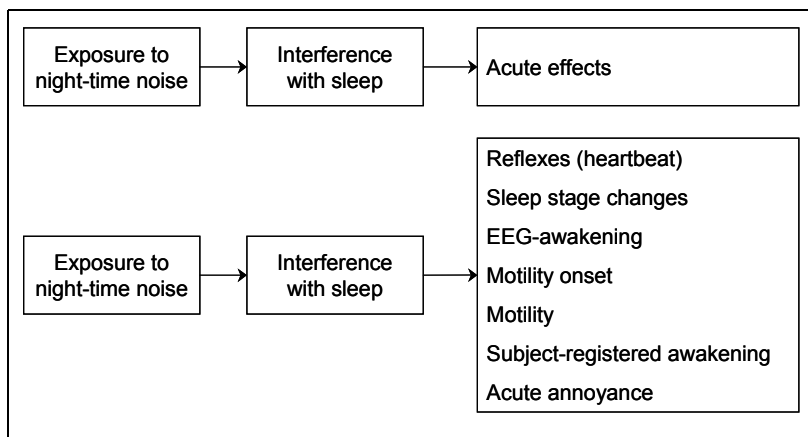


Figure 10 Results of research into the acute effects of exposure to night-time noise when sleeping.

reference to acute effect parameters. The lower element of the diagram indicates which parameters appear to be affected by noise during the sleep period. All acute responses to noise are regarded as biological effects by the Committee.

3.2.10 *Strength of the evidence*

Exposure to noise during the sleep period induces immediate physical responses. Table 4 lists the effects concerning which there is sufficiently strong evidence to conclude that they occur as a direct result of noise events during the night-time sleep period.

Table 4 Acute biological effects.

Cardiovascular changes^a

Sleep stage change, from deeper to less deep sleep

EEG awakening

Motility onset

Motility

Subject-registered awakening

^a The advisory report focuses mainly on heart beat acceleration, but there is also sufficient evidence of the induction of vasoconstriction and acute blood pressure rises.

There is no evidence that an acute change in (stress) hormone levels can be induced by exposure to night-time noise when sleeping, but one may assume that this is the case. It is not, however, possible to investigate the possibility in a field study, since such research would involve the use of invasive monitoring techniques. Also, there is only limited indirect evidence that noise events can induce acute annoyance.

3.3 **Biological effects before, while and after sleeping**

The scientific situation as described in an earlier Health Council report

To support preparation of the previously mentioned Health Council report on aviation noise and sleep, Hofman¹⁷ also summarised the results of research published up to 1991 that had looked into the effects that exposure to night-time noise has during the course of a night or a day and over a longer timescale. Hofman's findings are presented in Table 5. As was the case with research into acute effects, the research referred to in the table related mainly to noise from road and air traffic, but one or two of the reviewed studies were concerned with the effects of noise from rail traffic or industrial activities.

Table 5 The results of research published up to 1991 relating to the effects of exposure to night-time noise events, as reviewed by Hofman¹⁷.

Effect registration method	Effect	Number of studies in which significant change was observed	Number of studies in which no significant change was observed
Journal/cognitive testing	Over a night or day		
	- Diminished sleep quality	15	10
	- Daytime irritability and impaired cognitive performance	8	6
Questionnaire	- Sleep disturbance	25	2
	Over the longer term		
	- Night-time noise-related annoyance	42	2
	- Seeking healthcare	6	5
	- Increase in self-reported health problems	10	8
	- Increase in the use of somnifacient drugs and sedatives	8	5

As indicated in the table, almost all studies found that increasing night-time noise exposure was associated with statistically significant rises, particularly in long-term annoyance and sleep disturbance (difficulty getting to sleep, waking up in the night, waking up too early in the morning and not being able to get off to sleep again). In line with Hofman's review¹⁷, the table provides no information about exposure levels or study quality.

Only a small number of field studies looked specifically at the relationship between noise exposure and its effect on sleep latency time, sleeping time, or the post-sleep period. Furthermore, research data on acute noise-induced changes (see section 3.3) has not in most cases been aggregated to provide full-night data. Most of the information presented below relates to research into the effects of road traffic and aviation noise. In most of the reviewed studies, several effect parameters were studied at once, which has made it difficult for the Committee to present a summary structured along the lines of the previous section (on acute effects). This section begins with a discussion of the results of research into the influence of road traffic noise, which is followed by a subsection on the effects of aviation noise. Consideration is then given to the findings of field research into the effects of night-time noise on motility and on stress hormone concentrations. Finally, the Committee addresses the possibility that immune functions might be influenced by exposure to night-time noise, which has been investigated only in the context of laboratory research.

3.3.1 Road traffic noise: various effect parameters

In 2003, the RIVM published a review of field research concerned specifically with the effects of night-time *road traffic* noise on sleep⁶⁹. In the eleven reviewed studies that involved the use of sleep EEGs, ECGs or actimetric measurements and sometimes of journals, noise was also measured (in the bedroom) during the study nights.

Five of the eleven studies were deemed unsuitable for inclusion in the detailed analysis for various reasons (too small, no usable findings). Useful data was produced by four intervention studies carried out on behalf of the European Commission between 1980 and 1983. By increasing the acoustic insulating properties of bedroom windows, using personal hearing protection gear and sleeping on the quiet side of the house, the road traffic-related noise exposure was reduced by approximately 10 dB(A) on half of the subject-nights^{58,59,70-73}. The studies in question involved a total of seventy people and 922 subject-nights. Jurriëns drew the following conclusions regarding the effects observed in relatively noisy situations (compared with quieter situations after intervention)⁷⁰:

- The average duration of REM sleep is 6.5 minutes shorter (in adults, REM sleep normally lasts for approximately two hours).
- In reaction time tests, the average reaction time is twelve milliseconds (12 ms) longer than the overall average reaction time of 350 ms, and more mistakes are made (8 per cent)
- Self-reported quality of sleep is less (7 per cent)
- The W (waking) time recorded by EEG is 7 minutes longer (determined in two of the four studies)
- The average heart rate when sleeping is higher. In the Dutch research, the rate was 3.2 beats per minute higher (71.5 bpm, compared with 68.3 bpm)⁵⁸.

A study by Öhrström⁷⁴, which involved the use of journals only, was also included in the RIVM review. In this study, it was found that in situations characterised by higher levels of road traffic noise at night, people had more difficulty getting to sleep, were more likely to be woken up in the night by traffic noise, had poorer sleep quality and were more likely to be tired and irritable in the morning. The same research team recently completed a small longitudinal intervention study with adults and a cross-sectional study with children and adults, neither of which found that exposure to night-time road traffic noise had any statistically significant effect on the studied effect parameters^{75,76}.

The RIVM review additionally took in a German study of road and rail traffic noise^{77,78}. This study's findings regarding average motility are discussed in more detail later.

3.3.2 *Aviation noise: various effect parameters*

A report by Passchier-Vermeer¹² defines the relationship between *aviation noise* and each of several effects on sleep over one sleep period (see Figure 23 in Annex D). The effect variables were: high motility for the subject's age; recalled aviation noise-induced awakening; subject-registered awakening three or more times per night; use of somnifacient drugs. The use of somnifacient drugs and sedatives rose markedly with increasing night-time noise exposure mainly among older subjects. Night-time aviation noise did not appear to have any effect on subjects' performance in reaction time tests taken at the end of the evening. The degree of subject-reported morning drowsiness (as indicated at 10am) did, however, appear to be related to night-time noise exposure: the greater the overnight exposure, the sleepier subjects felt in the morning.

The Passchier-Vermeer study also indicated that increased aviation noise exposure (equivalent sound pressure level) during the sleep latency period was associated with prolonged sleep latency and greater difficulty getting to sleep. People who when they went to bed were concerned about the possibility of being disturbed by aviation noise took an average of a quarter of an hour longer to go to sleep than the people that were not concerned.

3.3.3 *Road, rail and air traffic noise and motility*

In the above-mentioned German research into *road and rail traffic noise*^{77,78} 188 subjects were exposed mainly to road traffic noise and a similar number mainly to noise from passing trains. The number of subject-nights with results on motility was 1710 in the road traffic group and 1581 in the rail traffic group. A recent analysis⁷⁹ of the data indicated that, among people exposed to *rail traffic noise*, average motility for a single sleep period was unrelated to the equivalent indoor or outdoor traffic sound pressure level during the period in question, whereas an increase in such levels was associated with a statistically significant rise in motility among people exposed to *road traffic noise*. The Dutch sleep disturbance study also found that average motility rose with increasing *aviation noise* exposure during the sleep period¹². With road traffic noise, the increase in average motility per dB(A) rise in noise exposure was approximately 30 per cent greater than with aviation noise.

The Bristol-based team of Smith *et al*⁸⁰ made a phased investigation of the interrelationships between aviation noise, sleep disturbance and health. In the final phase, the motility of ninety people (forty-five couples) was monitored using actimeters for three nights, during which sound pressure levels were measured in the subjects' bedrooms. The sources of the noises audible in the subjects' bedrooms were not objectively deter-

mined, nor were any outdoor sound pressure levels measured. The study revealed no relationship between noise exposure and average actimetric level over the course of a night. The researchers took the view that this was mainly because the noise exposures experienced by the subjects were low.

3.3.4 *Road traffic and aviation noise: stress hormone concentrations*

Babisch⁸¹ produced a survey of research into the effects of *road traffic and aviation noise* on hormone concentrations (adrenaline, noradrenaline, cortisol) determined from urine samples collected over the course of a night and in one study from saliva samples taken after awakening (for the measurement of cortisol only). In all, the survey took in eight field studies (see Tables 16 and 17 in Annex D).

In seven of the studies, the subjects were children, who in five studies were exposed to aviation noise and in two studies to road traffic noise. No link was found between exposure to aviation noise and cortisol concentrations, but higher road traffic noise exposures were associated with statistically significant rises in levels of this hormone. Adrenaline and noradrenaline concentrations exhibited statistically significant rises at higher aviation noise exposures in two of the four studies, but could not be linked to road traffic sound pressure levels in one study (not all of the studies involved monitoring concentrations of all three of the hormones referred to). Whether the increased hormone concentrations were brought about by exposure to night-time road traffic noise is unclear; they could also have been an after-effect of daytime noise exposure.

The only field study involving adult subjects focused on the effect of road traffic noise on the quantity of adrenaline and noradrenaline in the night-time urine of 234 women ages thirty to forty-five⁸². Among the women whose bedrooms were on the street side of their homes, increasing traffic volume (and therefore increasing equivalent sound pressure level) was associated with a statistically significant increase in noradrenaline concentration, but no link was established between traffic volume and adrenaline concentration. Among women whose homes had the living room on the street side, traffic volumes had no apparent influence on either adrenaline or noradrenaline concentrations. The fact that it was mainly noradrenaline concentrations that were raised is consistent with Ising's model, which predicts that noradrenaline concentration is particularly likely to increase in response to noise to which a person has in part habituated⁸³. The effect of road traffic noise on noradrenaline concentration was particularly pronounced in women who indicated that they slept with the bedroom window closed to prevent their sleep being disturbed by road traffic noise. Among women who experienced no noise-related annoyance when their windows were closed, no statistically significant increase in noradrenaline concentrations was observed.

The modest amount of data available on this subject prevents the Committee drawing any firm conclusions. It does nevertheless appear that, under certain circumstances, exposure to noise can lead to raised stress hormone levels in sleeping adults; the possibility that noise can have a similar effect on children cannot be excluded. More definite conclusions must await the availability of further research data.

3.3.5 *Various noises in laboratory research: immune function*

Between 1968 and 1974, Osada *et al*⁸⁴⁻⁸⁷ investigated immunological parameter changes associated with exposure to noise. However, the major changes observed in the four laboratory experiments with twenty-one subjects were almost certainly attributable to shortcomings in the study design*. The Committee is not aware of any other research into the influence of night-time noise exposure on immune functions.

In their survey article *The Neuroendocrine Recovery Function of Sleep*, Born and Fehm devoted a section to the possibility that night-time exposure to noise might affect the immune system⁸⁸. On the basis of two experiments in which subjects were either deprived of sleep or allowed to sleep 'normally', the two authors postulate that night-time noise exposure may have a negative influence on the immune system. They add, however, that a great deal more research would be necessary to confirm such a hypothesis.

3.3.6 *Conclusions*

On the basis of the considerations set out above, the Committee draws the following conclusions regarding biological effects over the course of a night (before, while and after sleeping):

- There is sufficient evidence that, above a given threshold noise exposure, exposure to road and air traffic noise while sleeping is associated with the following:
 - Increased difficulty getting to sleep
 - Increased sleep latency period
 - Use of somnifacient drugs and sedatives, particularly among older people
 - Reduced REM sleep and increased time in a conscious state, as determined by EEG
 - Raised average heart rate
 - Raised average level of motility
 - More frequent subject-registered awakening
 - More frequent recalled noise-induced awakening

* Marth, personal communication.

- Reduced self-reported quality of sleep
- Increased drowsiness, tiredness and irritability
- There is limited evidence that exposure to road and air traffic noise while sleeping is associated with the following:
 - Increased daytime irritability
 - Impaired daytime cognitive performance
- Exposure to rail traffic noise has been investigated on an incidental basis only: no statistically significant rise in average motility during a sleep period was detected in response to exposure. No research has been carried out into the consequences of exposure to industrial noise.
- Little is known about the influence of exposure to night-time noise on immune functions.
- There is limited direct evidence that, under certain circumstances, exposure to night-time noise can influence (stress) hormone levels when sleeping; this effect was observed in women who were troubled by noise during the night and were unable to relieve the problem. The Committee suspects that noise has no consistent effect on stress hormone levels, and that any effects depend partly on personal and situational factors. More definite conclusions must await the availability of further research data.

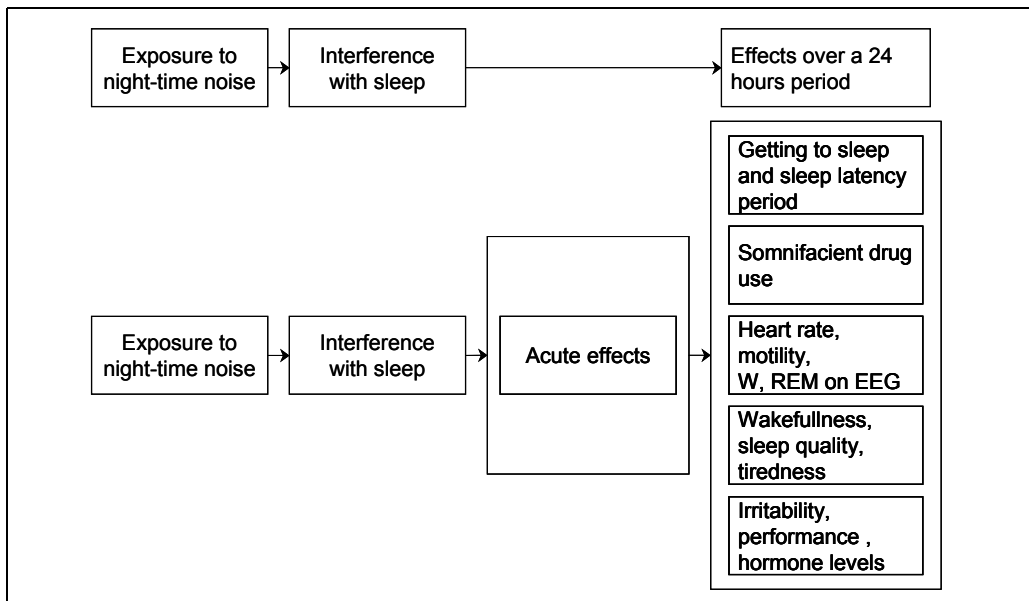


Figure 11 Results of research into the effects of night-time road and aviation noise on biological parameters over the course of a night (before, while and after sleeping). There is sufficient evidence of a causal relationship between exposure and the parameters in the upper four effect boxes, but only limited evidence of such a relationship with the parameters in the bottom effect box.

Figure 11 indicates which parameters appear to be affected by road and aviation noise during the sleep period. There is sufficient evidence of a causal relationship between exposure and the parameters in the upper four effect boxes, but only limited evidence of such a relationship with the parameters in the bottom effect box.

3.3.7 *Biological effects as predictors of impact on health and well-being*

In some cases, there is empirical data indicating that a biological effect of night-time noise can, after repeated exposure and under certain circumstances, ultimately have consequences for a person's health and well-being. Where certain other biological effects are concerned, although no such data is available, it is plausible that chronic exposure to night-time noise when sleeping may lead to physical responses indicative of a negative influence on health and well-being. The Committee's assessment regarding each of the effects concerned is given in Table 6.

Table 6 Biological (physiological and psycho-physiological) effects for which there is either sufficient or limited evidence of a causal relationship with night-time noise and which could plausibly have a negative influence on health and well-being in the event of chronic exposure^a.

Variable	Probability of negative implications for health and well-being
Difficulty getting to sleep, difficulty staying asleep	Empirical data
Change in cardiovascular activity	Plausible
Increased motility	Plausible
Changes in duration of various stages of sleep and in sleep structure, fragmentation of sleep	Empirical data
Changes in (stress) hormone concentrations	Plausible
Waking during the sleep period and/or prematurely in the morning	Empirical data
Drowsiness/Tiredness during the day and evening	Plausible
Impaired cognitive performance	Plausible
Increased irritability	Plausible

^a The effects in question can occur after a single night's exposure. However, there is no empirical evidence that the occurrence of any of the effects in the context of a single night's exposure can influence health or well-being, nor is it plausible that this might be the case. The effects after a single night's exposure all come under the heading 'no empirical evidence of implications for health and well-being and no plausible causal association'.

3.4 The effects of long-term exposure

In field research with subjects who are exposed to noise on a nightly basis, it is not easy to distinguish the effects of a single disturbed night from the effects of long-term exposure. In many cases, the way relationships are defined depends on what is known about the noise exposure. Where the available data concerns sound pressure levels on particular nights, observed effects are typically related to such data. However, if the only available data consists of estimates of longer-term noise exposure, observed effect parameters are considered representative of the consequences of prolonged exposure. Making a distinction is therefore important mainly in the context of research data structuring. The consequences of noise-related sleep disturbance described in section 3.3 can therefore also be seen as the effects of long-term exposure, since our knowledge of them comes from data concerning people who have experienced chronic exposure to environmental noise. Hence, the Committee also considers the effects listed in Figure 11 to be the effects of long-term exposure.

3.4.1 *Insomnia*

A group of Japanese researchers carried out a questionnaire-based survey of 3600 adult Japanese women (aged between twenty and eighty) to gather information about the factors that contribute to insomnia⁸⁹. Some 11 per cent of subjects were found to be affected by insomnia (as defined on the basis of the WHO's ICD10 classification system⁹⁰). Analysis of the survey data took account of various distorting variables, such as age, number of (small) children in the family, social status, receipt of medical treatment, regularity of bedtimes, apnoea-like problems and serious unpleasant experiences in the six months prior to completing the questionnaire. When the percentage of insomniacs in each of the three areas with the highest exposures was compared with the percentage in the low-exposure areas, the ratios worked out at, respectively, 1.4 (2100 vehicles per hour, *Lnight* of around 65 dB(A)), 2.1 (2400 vehicles per hour, *Lnight* of around 67 dB(A)) and 2.8 (6000 vehicles per hour, *Lnight* of around 70 dB(A)). The most frequently reported problem was difficulty getting to sleep.

The seriousness of the problems caused by insomnia is illustrated by the quality-of-life weighting system developed by Stolk and Van Busschbach^{91,92}, under which insomnia has a quality-of-life weighting of 0.83. This means that a year affected by insomnia results in the loss of 0.17 DALYs.

Research into the effects of exposure to air and road traffic noise has shown that increases in night-time noise exposure or in noise exposure during the sleep latency

period have a statistically significant adverse impact on subjects' ability to get off to sleep and on sleep inception periods^{12,13,93,94}.

3.4.2 Hypertension

In the context of a longitudinal study (Spandauer Gesundheits Survey)⁹⁵, the health of adults in Berlin's Spandau district has been surveyed every two years since 1982. The ninth survey round involved 2015 subjects. In addition to going through the usual tests and questionnaires, 1718 (85 per cent) of these subjects were asked about noise-related annoyance from road, rail and air traffic, as well as from industrial sources (see Annex D). Hence, the noise research element of the study took the form of a cross-sectional study. The noise exposure was estimated using noise calculation models. The estimates made for aviation noise are not regarded as reliable by the Committee, but those for road traffic noise do not suffer from the same shortcomings. Furthermore, the road traffic noise exposure was measured on an incidental basis both during the day and at night. Details of the subjects' medical treatment histories over the two years since the previous survey and over the entire research period were gathered in interviews with the subjects. The findings showed that, after taking account of other factors that could explain any association between medical condition and noise exposure, the prevalence of hypertension was higher (by a statistically significant margin) among people for whom the *road traffic-related L_{night}* was more than 55 dB(A) than among people for whom the road traffic-related *L_{night}* was less than 50 dB(A) (odds-ratio 1.9). Prevalence among people for whom the road traffic-related *L_{night}* was between 50 and 55 dB(A) was at an intermediate level. However, no statistically significant association was found between the prevalence of hypertension and road traffic noise *during the day*. The researchers suggest that hypertension is associated with night-time exposure but not with daytime exposure partly because people are often elsewhere during the day and partly because people are more sensitive to noise at night than during the day.

The Committee considers the following points to be relevant to the assessment of the research findings outlined above:

- The investigated outcomes: use of personal statements as the only means of determining whether subjects were receiving medical treatment for conditions such as hypertension. This may have led to considerable distortion of the research results. Although the report speaks at length about tests such as blood pressure measurement and the registration of medicine use, the resulting data is not used in the analyses. The Committee takes the view that if the measured data had been used for the analyses or – even better – if the analyses had been based entirely on measured data, the findings would have carried more weight.

- The researchers point out that the study population was made up largely of people who were very conscious of their health. In other words, the subjects were self-selected and this may also have led to distortion. The point being that, if night-time noise does have an effect on health and well-being, making people feel uneasy about their health, they may well be inclined to report all sorts of other problems that they don't really have. This could have resulted in the prevalence of hypertension among the most heavily exposed group being overestimated.
- The researchers do not report the raw data, i.e. the data in its original form, uncorrected for other factors capable of distorting the relationship between night-time noise exposure and the probability of developing a condition (confounding). It is therefore difficult to estimate how important these factors were and how plausible their supposed influence on the relationship between probability of hypertension and night-time noise exposure was.

On the basis of the considerations outlined above, the Committee has concluded that, although a link between night-time noise and increased risk of hypertension is plausible, the Spandau survey does not provide sufficient evidence of a causal association.

In this context, the Committee would point out that, in the 1994 report *Noise and Health*², an international Health Council Committee concluded on the basis of data from various, mostly German, studies that a causal relationship did probably exist between daytime noise exposure and hypertension risk. It was suggested that the observation threshold was an equivalent sound pressure level of 70 dB(A) over the course of a day. Consideration was not given to the possibility that night-time noise exposure might be at least partly responsible for the increased probability of hypertension associated with what it should be said are very high noise exposures. The Committee would like to see the possibility explored of re-analysing the data in a way that takes night-time noise exposures into account.

3.4.3 *Motility*

British research into the effect of aviation noise on sleep has revealed that the average probability of motility (motor unrest) during the course of a sleep period rises with increasing exposure to air traffic noise⁹⁶. Horne reported that there was a strong relationship between average motility and perceived quality of sleep. Dutch field research into the effect of aviation noise on sleep and German research regarding the effect of road traffic noise has also found that average motility (motor unrest) increased with noise exposure when sleeping^{12,13,79}. However, no association has been detected between motor unrest and rail traffic noise. Furthermore, the increase in motility with the *Li* of air and road traffic noise proved to be much greater than might be expected on the basis of

accumulated acute noise-related motility. The Committee believes that this phenomenon can be explained if one assumes that chronic exposure increases the physiological arousal level when sleeping, not only in the periods of the night when vehicles or aeroplanes are passing, but also when there is no traffic. In the Dutch field research into the effects of aviation noise on sleep, it was observed that overnight average motility was strongly associated with the number of occasions that a subject recalled waking during his or her sleeping time, with the number of subject-registered awakenings during this time, and with a series of variables determined from the questionnaire completed by the subject at the beginning of the study. The variables in question were: whether the subject used somnifacient drugs; quality of sleep; number of sleeping problems; number of times awoken by aviation noise; number of times per week aviation noise had a negative effect on sleep; health problems included on the abbreviated Health Perceptions Questionnaire ('VOEG-lijst').

The observed relationship between average motility and various negative consequences of exposure to night-time noise is regarded by the Committee as a strong indication that increase in average motility should also be seen as a negative consequence of exposure to noise when sleeping.

3.4.4 *Self-reported sleep disturbance*

On the basis of TNO's Disturbance Knowledge Base, exposure-response relationships have been defined for self-reported sleep disturbance by road, rail and air traffic^{97,98}. The associated TNO reports contain various assessments of factors that influence sleep quality (problems caused by waking up in the night, waking up too early in the morning, night-time noise-related annoyance). Just as 'annoyance' is covered by an international definition, so high sleep disturbance is defined as a score of 72 or more on a scale of 0 (no sleep disturbance at all) to 100 (extreme sleep disturbance). The relationships between the various kinds of traffic noise and self-reported high sleep disturbance are illustrated in Figure 12.

From Figure 12, it will be apparent that, at a given *Lnight* value, aviation noise is linked to slightly more self-reported high sleep disturbance than road traffic noise, while rail traffic noise is associated with less disturbance than either of the other sources. The illustrated relationships are closely consistent with the provisional curves presented in 1997 in the Health Council's advisory report *Assessing Noise Exposure for Public Health Purposes*⁸.

However, when one looks at the relationships between *Lnight* and the percentages of people experiencing 'at least sleep disturbance' and 'at least slight sleep disturbance', one finds that the relative positions of road traffic noise and aviation noise are reversed. It is worth noting that less certainty exists regarding the relationships between distur-

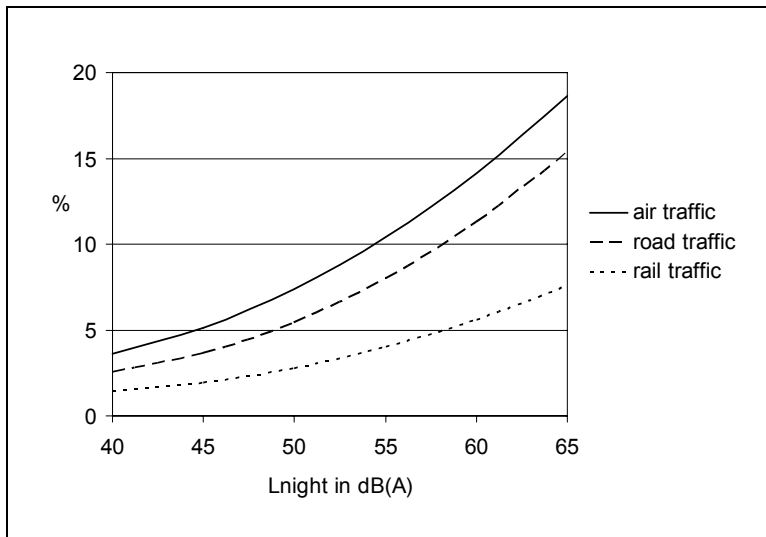


Figure 12 The percentages of people experiencing high noise-related sleep disturbance attributable to air, road and rail traffic, as a function of L_{night} ^{97,98}.

bance and aviation noise than regarding the relationships involving road and rail traffic noise.

The RIVM report⁶⁹ mentioned in 3.3.1 considers the question of whether a quantitative meta-analysis could be made of the results of questionnaire-based research into the influence of road traffic noise on perceived quality of sleep and on awakening. Although the RIVM describes several studies as being good quality, the researchers decided that it was not possible to perform a meta-analysis because of discrepancies in the studies' nomenclature, methods, exposure determination techniques and approaches to adjustment for distorting variables. Their ultimate conclusion was therefore that there were indications that road traffic was associated with reduced perceived quality of sleep and more frequent (or more prolonged) night-time awakening.

Leidelmeier and Marsman⁹⁹ carried out an interview-based study of 1242 households in the Netherlands, in which subjects were asked about daytime and night-time noise from neighbours and any associated annoyance. Distinction was made on the basis of the part of the house in which the noises were audible and any associated annoyance was experienced. Subjects proved least tolerant of noise from their neighbours that was audible in the master bedroom. The researchers distinguished five types of noise, which are listed below, along with the percentage of subjects who indicated hearing the relevant type of noise from a neighbouring dwelling at night in the master bedroom:

- Contact noise 22 per cent
- Noise from sanitary fittings, central heating, etc 19 per cent
- Noise from radio, TV and hi-fi 12 per cent
- Do-it-yourself (DIY) noises 8 per cent
- Pets 6 per cent

Where each of the five investigated types of noise were concerned, roughly 10 to 15 per cent of subjects indicated that they felt it was unacceptable for the noise to be audible during the day. Overall, nearly 30 per cent of subjects said that sanitary fittings should not be audible at night, while approximately 50 per cent felt each of the other four types of noise were unacceptable by night.

In 1993, Kranendonk *et al* produced a synthesis of the research conducted up to that point in time into the annoyance associated with noise from neighbours¹⁰⁰. Subsequently, in 1998, Van Dongen *et al*¹⁰¹ published a report on the relationship between noise from neighbouring dwellings and the airborne and contact noise attenuating indices I_{lu} , $I_{lu,k}$, and I_{co} , drawing on data from a questionnaire-based survey of the residents of six hundred dwellings, whose acoustic quality was determined in 202 cases. The results of the two studies are reasonably consistent (see Annex D). Both found that the chief causes of annoyance were loud radios, hi-fis and TVs, audible and sometimes intelligible voices, the slamming of doors and footsteps on floors and staircases. In both cases, it proved that, when I_{lu} had a value of 0 (the minimum requirement for new homes), 10 per cent of subjects reported high annoyance and 15 per cent reported annoyance caused by noise from neighbouring dwellings. These figures are not specific to night-time noise, but apply to annoyance over a twenty-four-hour period.

On the basis of the findings outlined above, the Committee concludes that the standard of inter-dwelling sound attenuation presently required does not provide sufficient protection to prevent annoyance caused by noise from neighbours. Since people are less tolerant of the noise their neighbours make at night-time than of their neighbours' evening or daytime noise, it may be assumed that much of the annoyance associated with noise from neighbours relates to the influence of such noise on sleep. The Committee returns to this point when addressing the State Secretary's questions.

3.4.5 Health problems

The Dutch field research into the effects of aviation noise on sleep established a relationship between personal noise exposure when sleeping (Li) and the frequency of health problems included on the abbreviated Health Perceptions Questionnaire^{12,13}. Compiled on the basis of stress research, the Health Perceptions Questionnaire identifies

thirteen health-related problems, such as headache, stomachache, tiredness and digestive problems. It will be apparent that these are not life-threatening conditions. A rise in aviation noise-related L_i from 0 to 35 dB(A) is associated with a two-fold increase in the frequency of problems. Various factors that might be expected to influence the relationship between noise and problem frequency, such as what time a person wakes up and whether they sleep with their bedroom window open, prove not to be influential in practice. The Committee interprets these findings as a strong indication that exposure to night-time aviation noise causes a rise in the incidence of health problems.

3.4.6 *Complaints about night-time noise*

The Committee believes that the submission of a complaint about noise is symptomatic of reduced well-being. Numerous factors influence a person's inclination in a given situation to make an 'official' complaint about a noise-related problem. It is not therefore possible to draw any general conclusions on the basis of what happens in a given situation. In the Netherlands, people can make complaints about, for example, the annoyance caused by noise from aircraft using Schiphol Airport, by noise road, rail and air traffic in the Rijnmond area, by events, and by industrial sources. Analysis of these complaints shows that, relatively speaking, night-time noise generates more complaints than day-time noise (see Annex D).

3.4.7 *Conclusions*

The Committee draws the following conclusions:

- Above a certain observation threshold, exposure to road and air traffic noise while sleeping has the following chronic consequences (where the strength of the evidence for a causal relationship is indicated between brackets):
 - Insomnia (sufficient evidence)
 - Increase in average motility (sufficient evidence)
 - Self-reported sleep disturbance (sufficient evidence)
 - Increase in self-reported health problems (sufficient evidence)
 - Submission of complaints (sufficient evidence)
 - Reduced sleep quality (sufficient evidence)
 - Increased use of somnifacient drugs and sedatives and increased reference to healthcare professionals (sufficient evidence)
 - Increased daytime irritability (limited evidence)
 - Impaired cognitive performance (limited evidence)
 - Impaired social contacts (limited evidence)

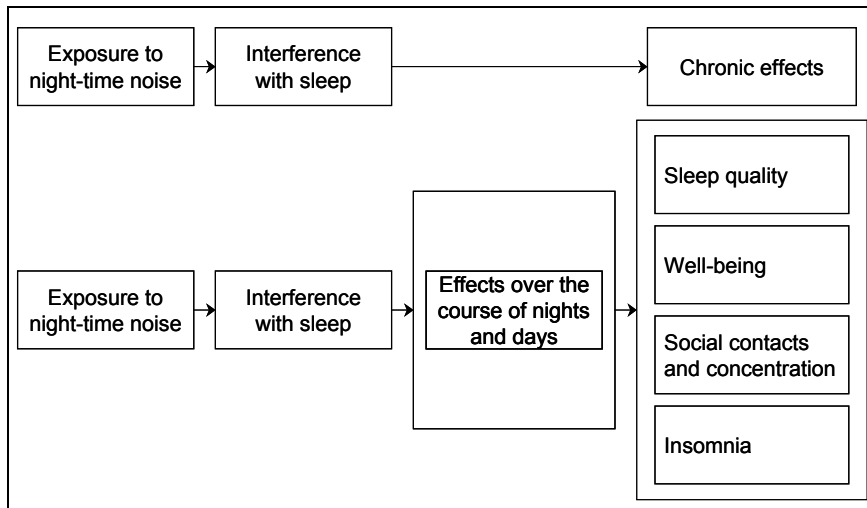


Figure 13 Results of research into the influence of exposure to night-time road and aviation noise on long-term health and well-being parameters.

- The effects of exposure to rail traffic noise have been studied only on an incidental basis. Average motility when sleeping was not found to be discernibly increased by such exposure. At a given *Lnight* value, the percentages of people experiencing self-reported slight sleep disturbance, sleep disturbance and high sleep disturbance due to rail traffic noise were slightly lower than the percentages experiencing such problems in connection with road traffic noise and aviation noise
- No information is available about the consequences of chronic exposure to industrial noise.

The findings outlined above are summarised in Figure 13. The effects referred to in the figure should be interpreted as follows:

- Social contacts and concentration: impaired social contacts and impaired performance of cognitive tasks
- Well-being: self-reported sleep disturbance, self-reported health problems, use of somnifacient drugs and sedatives, increased daytime irritability
- Sleep quality: reduced perceived sleep quality, difficulty getting to sleep and staying asleep, awakening, reduced sleeping time, increased average motility when sleeping.

3.4.8 *The influence of noise on sleep: correlations with sleep disorders and sleeping problems*

Thus far, consideration has been given to studies into the relationship between night-time noise exposure and the characteristics of sleep, health and well-being. Such charac-

teristics may be objectively measured (sleep latency period; EEG parameters; average motility; physiological and endocrine functions; reduced cognitive performance) or self-reported (difficulty getting to sleep; difficulty staying asleep; reduced sleep quality; waking up in the night; tiredness/drowsiness during the day; night-time noise-related annoyance; health problems; insomnia). A number of these characteristics are closely related to the characteristics of sleeping problems and insomnia generally observed in the population at large (see Annex E). Clearly, the disturbance of sleep by night-time noise is a matter of influence by an external factor, whereas the occurrence of insomnia and other sleeping problems in the population at large is probably attributable largely to personal characteristics; nevertheless, the Committee believes it is reasonable to assume that the same physical and mental processes are involved. Hence, it is plausible that sleep disturbance by environmental noise might contribute to the development or occurrence of female depression, hypertension, cardiovascular disease and occupational accidents, since all these phenomena are known to be associated with sleeping problems and insomnia. The size of any such contribution cannot be estimated. The evidence for such a link is indirect and limited in its strength.

It is plausible that people who suffer from insomnia or other sleep disorders that cause them to wake up frequently at night are more likely to be troubled by night-time noise. Insomnia is particularly prevalent among people with physical pain, dementia, depression, hypertension, heart and respiratory illness, and among older people and women who are pregnant or have been pregnant in the last twelve months. Age is not in itself a determining factor in the occurrence of insomnia or sleeping problems, which are attributable more to the accumulation of various age-related phenomena, such as lack of physical activity, changed eating and drinking patterns, dissatisfaction with one's social environment, illness and other medical conditions (see also Annex E).

People who work night shifts have to sleep by day, at least some of the time. Since in the daytime it is generally much noisier both indoors and outdoors than at night, people with variable working hours often have to sleep under less favourable circumstances than most of the population. Furthermore, such people tend to suffer some degree of disturbance to their sleeping-waking rhythm, as a result of which they frequently experience reduced-quality sleep even on the nights when they can go to bed at a 'normal' time. Consequently, night-shift workers are particularly sensitive to effects of night-time noise.

The Committee believes that certain groups of people are more likely to suffer adverse effects if exposed to night-time noise, and that this should be taken into account. The groups in question are as follows: older people; women who are pregnant or have been pregnant in the last twelve months; people who work night shifts; and people who

suffer from sleep disorders, physical pain, dementia, depression, hypertension, cardiovascular disease or respiratory illness.

3.4.9 *Strength of the evidence*

The Committee's conclusions regarding the associations between exposure to night-time noise when sleeping and changes in health and well-being are summarised in Table 7. The effect parameters which the Committee has grouped under the five categories are specified individually and in each case an indication is given of the strength of the evidence for a causal relationship between the effect parameter in question and night-time exposure to noise when sleeping. With regard to the long-term health and well-being implications of exposure to night-time noise during the sleep period, the Committee's overall conclusion is that there is sufficient evidence that such exposure leads to reduced sleep quality and reduced general well-being, and limited evidence that it leads to impaired social contacts and concentration, increased probability of developing medical conditions and reduced life expectancy.

Table 7 Effects on health and well-being of prolonged exposure to noise during the sleep period.

	Effect parameter	Evidence
Sleep quality	Reduced perceived sleep quality	Sufficient evidence
	Difficulty getting to sleep, difficulty staying asleep	Sufficient evidence
	Sleep fragmentation, reduced sleeping time	Sufficient evidence
	Increased average motility when sleeping	Sufficient evidence
Well-being	Sleep disturbance	Sufficient evidence
	Health problems	Sufficient evidence
	Use of somnifacient drugs and sedatives	Sufficient evidence
	Increased daytime irritability	Limited evidence, plausible
Social contacts and concentration	Impaired social contacts	Limited evidence, plausible
	Impaired cognitive performance	Limited evidence, plausible
Medical conditions	Insomnia	Sufficient evidence
	Hypertension	Limited, indirect evidence, plausible
	Depression (in women)	Limited, indirect evidence, plausible
	Cardiovascular disease	Limited, indirect evidence, plausible
Reduction in life expectancy (premature mortality)	Occupational accidents	Limited, indirect evidence, plausible

3.5 Prevalence and disease burden

3.5.1 Quantification

The prevalence of an effect that is attributable to night-time noise in an exposed population is the difference between the number (or percentage) of people in the exposed population who experience the effect in question and the corresponding number (or percentage) of people in an unexposed population with otherwise similar personal and demographic characteristics.

By taking account of the extent and seriousness of an effect, the associated disease burden on a population can be calculated. The disease burden of an effect is an index of the reduction that the effect in question causes within a population in the number of healthy years of life, expressed in units such as DALYs (*Disability Adjusted Life Years*)^{33,102}.

In order to make a very rough estimate of the prevalence of the effects of night-time traffic noise on sleep, and thus on health and well-being, one first requires data on the distribution of exposure to night-time noise in the Dutch population. Such data is available, albeit in the form of rough estimates, within the RIVM; see Annex G. By linking this data to the exposure-effect relationships described in this advisory report, it is then possible to estimate the prevalence of an effect in the Dutch population.

In order to determine the disease burden of an effect, it is necessary to know the weighting factor for the calculation of the associated DALYs^{91,92}. However, scientific consensus is as yet lacking with regard to the weighting factors for certain effects³².

3.5.2 Biological effects

The Committee has divided biological effects into two groups: acute effects and effects over the course of a night (before, while and after sleeping).

In order to estimate the prevalence of acute effects, such as being woken by night-time noise, it is necessary to have nationwide data on the distributions of traffic noise *SEL* or *L_{Amax}* values. Because sleeping times should preferably be included in the calculations, but are subject to considerable inter-personal variation, one ought to additionally know how *SEL* or *L_{Amax}* values are distributed in various periods e.g. in each hour covering the overall spread of sleeping times, rather than simply between 11pm and 7am. To arrive at a reasonably reliable estimate, one should also have national data on distribution in the acoustic insulating properties of dwelling walls, taking bedroom window status (open/closed) into account. However, using a simplified model, one could generate point estimates of the prevalence of an effect using average sleeping time and

attenuation values, plus point estimates of the prevalence at above-average and below-average sleeping time and attenuation values, thus providing some insight into the spread of results associated with variations in these factors. Although such an exercise is in principle viable, the Committee is not in a position to perform the calculations itself.

3.5.3 *Health and well-being*

The Committee has concluded that there is sufficient evidence that exposure to night-time noise during the sleep period reduces sleep quality and general well-being. Furthermore, there is limited evidence of a causal association between exposure and impaired social contacts and concentration, increased risk of developing certain medical conditions, and premature mortality due to fatal occupational accidents. This conclusion is based upon assessment of research data regarding various effect parameters. The parameters in question are interrelated; for example, difficulty getting to sleep and staying asleep is closely related to diminished perceived sleep quality (all three effect parameters for sleep quality). Consequently, if one calculated the prevalence of each effect parameter separately (supposing that were possible), and aggregated the figures, one would arrive at an overestimate of the consequences of exposure to night-time noise. The Committee has therefore chosen to base its estimates of the prevalence of diminished sleep quality and general well-being on self-reported high sleep disturbance data. Where this parameter is concerned, exposure-effect relationships have been established for noise from road, rail and air traffic. Since there is only limited evidence that night-time noise can lead to impaired social contacts and concentration, hypertension and premature mortality due to fatal occupational accidents, and little is known about the possible exposure-effect relationships, no estimate can be made of the prevalence of these effects. The Committee has, however, worked out a figure for the prevalence of insomnia, but would emphasise that this figure, like that for self-reported high sleep disturbance, is merely an indicative estimate. For this reason, the estimate is couched in very general terms.

The estimates have been made using *L_{night}* values for the year 2003 provided by the RIVM; see Annex G. The data used reflects the annual burdens on dwellings, as associated with road, rail and air traffic collectively (cumulative noise exposure). By combining this information with what is known about the exposure-effect relationships for self-reported high sleep disturbance by road traffic noise^{97,98} (see Figure 12)* and insomnia¹⁰³, the Committee has been able to estimate the increase in the prevalence

* The estimates are based on road traffic, as in the Netherlands night-time noise exposure to road traffic noise is much higher than that to air and rail traffic noise. Furthermore, using the separate noise sources would lead to overestimating the total self-reported high sleep disturbance.

within the Dutch population of the two effects that was attributable to night-time traffic noise in 2003. The results are presented in Table 8.

Table 8 Rough estimate of the prevalence within the adult Dutch population (12.5 million people) of high sleep disturbance and insomnia attributable to night-time traffic noise in 2003.

Effect	Prevalence band ^a
Self-reported high sleep disturbance	6
Insomnia	5
Ratio between insomnia and self-reported high sleep disturbance	2%

^a Prevalence bands: band 0: 0-1 person, band 1: 1-10 people, band 2: 10-100 people, band 3: 100-1000 people, band 4: 1000-10 000 people, band 5: 10 000-100 000 people, band 6: 100 000- 1 000 000 people.

As indicated in Table 8, the prevalence of noise-related self-reported high sleep disturbance among adults in the Netherlands falls in band 6 (100,000 to a million adults). The prevalence of noise-related insomnia is estimated to be significantly lower.

For the year 2000, the RIVM estimated separate *L_{night}* values for the noise exposures associated with road, rail and air traffic noise in the Netherlands¹⁵. On the basis of these figures, it has been estimated that, in 2000, the prevalence of noise-related self-reported high sleep disturbance among adults in the Netherlands, as attributable to each of these three sources, fell in band 6 (more than 100,000 adults). The number of adults with high sleep disturbance by road traffic noise will have been between two and four times higher than the numbers able to report such disturbance by rail or air traffic noise. The prevalence of insomnia attributable to either road or rail traffic noise was in each case estimated to have been in band 4 (between one thousand and ten thousand people), while that attributable to aviation noise (calculated on the basis of data on the noise exposure in the general vicinity of Schiphol) was estimated to have been in band 3 (between a hundred and a thousand people).

3.5.4 *Disease burden*

In recent years, there has been considerable focus on quantifying the collective disease burden attributable to environmental factors. One initiative in this area has been the introduction of the *disability adjusted life year* (DALY)^{32,34} as a unit of measurement; see also subsection 2.3.3. In response to questions posed by the State Secretary for Housing Spatial Planning and the Environment, the Health Council is to prepare a separate advisory report on the issues associated with the use of DALYs³⁸.

In order to quantify a disease burden, it is necessary to know how many people experience a given effect and for how long, as well as how serious the effect is. In its prevalence calculations described above, the Committee concentrated on self-reported high sleep disturbance and insomnia, in relation to which estimates were made of the numbers of people affected and for how long. To calculate the associated disease burdens, the Committee has adopted the weighting score of 0.17 ascribed to insomnia by Stolk *et al*³⁷, even though this figure was defined for a different purpose. In the context of seeking to put a figure on the disease burden associated with sleep disturbance³², De Hollander suggested weighting factors of between 0.01 and 0.1, but indicated that further study was desirable.

On the basis of the available data, the Committee has concluded that the best estimate of the disease burden associated with high sleep disturbance by night-time traffic noise in the Netherlands is several tens of thousands of DALYs. The corresponding figure for insomnia is certainly considerably lower. These estimates suggest that, through its influence on sleep, night-time traffic noise accounts for an important part of the overall effect that the physical environment has on public health^{32,104}.

By means of disease burden calculations of this kind, the effects of night-time traffic noise on health and well-being can be compared with the effects of other factors. However, the Committee wishes to emphasise that a cautious approach should be taken, since there is considerable uncertainty about many of the estimates.

Acoustic considerations

Night-time noise in the domestic environment almost always consists of a combination of separate noise events, with the exception of certain forms of industrial noise. In section 4.1, the Committee considers how such noise events combine to create an overall noise exposure over the course of a night.

Noises come in many different forms, from a low rumble to a soprano's top C, from a steady whisper to a sudden bang, from a murmur to a squeak or a grating sound. It seems reasonable to assume that the nature of a noise influences its effect. The question is, is it possible to define an exposure-effect relationship in a way that takes account of the influential characteristics of a noise, for example by applying adjustment factors to the exposure or noise data. In the 1997 advisory report *Assessing Noise Exposure for Public Health Purposes*, a Health Council Committee looked at this issue in detail (see Annex F for a summary)⁸. In section 4.2, the Committee considers the content of that report.

In the chapter's final section (4.3), the efficiency and effectiveness of domestic insulation as a means of reducing the influence of noise on sleep are examined.

4.1 The combination of noise events and acute effects

4.1.1 *The combination of noise events*

Where night-time environmental noise involving individually distinguishable noise events is concerned, *Lnight* is a so-called ‘exponential summation of the *SEL* values of the constituent events’*.

A given *Lnight* value is a unique specification of the number of noise events with a certain *SEL value*. Since, where a particular type of noise (such as a train or aeroplane passage) is concerned, there is a very high correlation between the *SEL* and the maximum level of a noise event (*LAmx*), a given *Lnight* value also specifies the number of noise events with a certain *LAmx* value. For example, an *Lnight* of 35 dB(A) is the result of *one noise event per year* with an *SEL* of approximately 105 dB(A), *one noise event per night* (every night) with an *SEL* of approximately 80 dB(A) or *hundred noise events per night* (every night) with an *SEL* of approximately 60 dB(A).

4.1.2 *Lnight and effects*

It follows that, at least where the above-mentioned acute effects of exposure to night-time noise are concerned, the consequences associated with a given *Lnight* value may vary. Generally speaking, the sum of all acute effects (over a year, since *Lnight* is an annual average) in a situation characterised by a small number of high-intensity events is less than in a situation characterised by numerous events whose intensity is above the effect threshold but nevertheless comparatively low. The least favourable situation (that involving the most acute effects per year) would be a series of events with *SEL* values 4 to 5 dB(A) above the observation threshold for the effect in question^{97,105,106}. For subject-registered awakening by aircraft noise, for example, the worst-case scenario involves all aircraft passages having an *indoor SEL (SEL_i)* of approximately 60 dB(A), whereas the worst situation for increased probability of acute motility would involve all passages having an *SEL_i* of approximately 45 dB(A). In other words, at a given *Lnight_i*, the characteristics of the least favourable situation depend on which acute effect one is concerned with.

In Table 6, the Committee indicated that long-term exposure to night-time noise when sleeping leads to an accumulation of acute effects indicative of a negative influence on health and well-being. Where the overall effect of exposure to night-time noise

* The points made in this section relate to both outdoor and indoor noise levels (although the latter are expressed in units that have the suffix ‘*i*’). For definitions of the acoustic variables, see table 1.

is not the sum of the acute effects, such as frequently being awoken by noise, sleep disturbance and self-reported sleep quality, the Committee considers it plausible that a series consisting of numerous relatively low-intensity noise events has a greater effect than a series with the same overall *Lnight* value, consisting of a smaller number of higher-intensity noise events.

4.1.3 *Consequences for regulation*

The 1997 Health Council report *Assessing Noise Exposure for Public Health Purposes* proposes the use of *Lnight* for the regulation of exposure to night-time environmental noise. Of course, the extent to which controls based on *Lnight* can protect against the effects of exposure to night-time noise when sleeping depends on the level at which the limit is set. However, it follows from the considerations set out above that various situations might arise in which, although the prescribed *Lnight* value was not exceeded, the exposure levels were undesirable from a health and well-being perspective, due to the occurrence of relatively frequent low-intensity noise events.

If one concludes that exposure should be limited further, but that that cannot be achieved by applying stricter *Lnight* exposure limits, the best way forward would be to place a limit on the number of noise events. The reason being that setting *SEL* or *LAm_{ax}* exposure limits for noise events would allow for less favourable situations, unless the exposure limits were set at impracticably low levels. Hence limitation of the number of events is preferable.

There is another reason for specifying a maximum permissible number of noise events. The *greater the nightly number* of noise events (above the observation threshold), the greater the chance is that one will coincidentally hear such a noise after ‘spontaneously’ waking up in the night, possibly leading to annoyance and problems going back to sleep. As indicated in section 3.2, if all intervals of ‘spontaneous’ wakefulness were to coincide with a noise event audible in the bedroom, a person might under extreme circumstances hear a noise that had not woken him or her up approximately ten times in the course of a night.

4.1.4 *Conclusion*

At a given *Lnight*, (or *Lnight_i*) an acute effect of exposure to night-time noise is most influential if the *LAm_{ax_i}* or *SEL_i* values of the separate noise events are approximately 5 dB(A) above the observation threshold for the effect in question. In order to prevent the occurrence of the worst-case scenario associable with a given *Lnight* value, consideration should be given to regulating not only *Lnight*, but also the number of noise events. One consequence of setting a ceiling on the number of noise events would be

that one was less likely to hear a noise event after ‘spontaneously’ waking in the night, and therefore less likely to suffer sleep disturbance.

Whether it is necessary or desirable to set an exposure limit on the number of noise events, in addition to limiting *L_{night}* values, depends on the level of the *L_{night}* limit and the level of protection one wishes to provide. The relationships between acute effects and *SEL_i* values defined in this report, make this method of regulation a viable option.

4.2 Noise characteristics

The Committee has identified a number of forms of noise that may have a particularly pronounced effect on people exposed to them:

- Noise characterised by low-pitch components (buzzing)
- Noise consisting entirely of one or more low buzzing sounds (low-frequency noise)
- Tonal noise
- Noise events characterised by a rapid increase in intensity at the beginning (impulse noise)
- Industrial noise
- Noise characterised by sporadic high *L_{Amax}* or *SEL* values.

4.2.1 Noise characterised by low-pitch components

As indicated in chapter 2, noise exposure is generally measured using a so-called A-weighting, which takes account of the frequency sensitivity of the human ear. However, there is evidence to suggest that this method may place insufficient emphasis on low-frequency noise components in particular. This possible drawback does not apply if use is made of the so-called C-weighting, which affords nearly as much weight to low-pitch components as to high-pitch components.

In the Netherlands, a study is in progress aimed at determining the differences between outdoor A-weighted and C-weighted equivalent sound pressure levels measured in situations that frequently arise in practice¹⁰⁷. The measured average differences so far determined for aircraft, lorries, freight trains, shipping and industrial activities are, respectively, 9, 7, 5, 14, and 13 dB and the ranges of the measured differences are, respectively, 2-13, 2-15, 1-15, 9-21, and 6-24 dB. From these figures, it is apparent that noise from shipping and from industrial activities contains more low-frequency components than noise from road, rail or air traffic. The researchers believe that the differences are much greater indoors than out, because the fabric of residential buildings attenuates some frequencies more than others.

The extent to which the presence of lower-frequency components increases noise-related annoyance or sleep disturbance is still under investigation. The Committee antic-

ipates that the results of the research currently in progress will enhance understanding of the contribution that lower-frequency noise components make to annoyance and sleep disturbance, but does not expect that it will be necessary to revise the exposure-response relationships that have so far been defined, since these definitions already take account of any extra influence of lower-frequency components. However, the tendency to use higher powered equipment may mean that in the future the noise from certain sources will contain much more low-frequency noise components, possibly necessitating modification of the exposure-effect relationships as presently defined.

4.2.2 *Low-frequency noise*

After considerable deliberation, the authors of the 1997 Health Council report decided that low-frequency noise should not be incorporated into the assessment framework, since there was no reliable means of defining the necessary low-frequency noise adjustment factor. The present Committee sees no reason to revise this view, as no relevant new data has become available since. However, it does follow that the conclusions set out in this advisory report do not necessarily apply to low-frequency night-time noise. It should nevertheless be pointed out that low-frequency noise is relatively unusual in the domestic environment; at least, the Committee is unaware of any commonplace sources of such noise. Where sources of low-frequency noise are present, however, annoyance is most likely to occur at night, when such noise is not masked by higher-frequency noises in the domestic environment.

4.2.3 *Tonal noise*

Nor has any new data relating to tonal noise become available since 1997. The Committee accordingly endorses the recommendation contained in the earlier Health Council report, namely that the equivalent sound pressure level should be increased by between 0 and 5 dB(A) in cases that involve exposure to tonal noise when sleeping (see Annex F). It is worth noting that, like low-frequency noise, tonal noise is rare in the domestic environment.

4.2.4 *Impulse noise*

An impulse noise is a noise that increases very quickly, so that, as far as the listener is concerned, it seems to reach its maximum intensity almost immediately. Examples include gunshots and low-flying military jets. The international standard ISO1996/01¹⁰⁸, published in 2002, sets out a method for the assessment of impulse noises that is consistent with the thinking of the Health Council's 1997 report. This system indicates that

adjustment factors of 5 and 12 dB(A), respectively, should be used for certain specified impulse noises (low-flying military jets, car doors slamming, church bells chiming) and certain specified very impulse-like noises (gunshots, metal beating, pneumatic hammering, shunting of rail rolling stock). ISO 1996/01¹⁰⁸ lists the impulse noises and very impulse-like noises in respect of which adjustment factors should be applied, because, according to the working group that developed the standard, ISO 1996/01 there was too little readily interpretable research data available to enable quantification of the adjustment factors in audiological, physical or acoustic terms. The ISO standard did not adopt the assessment method prescribed in the 1996 US standard ANSI S12.9¹⁰⁹, which was based on the speed with which the sound pressure level rose at the beginning of an impulse noise. In the Netherlands, however, a provisional assessment method was introduced for railway yards, which followed the US method in working on the basis of the speed with which the sound pressure level rises at the beginning of a noise event¹¹⁰. The maximal adjustment factor that can be used is the 12 dB(A) applicable in relation to very impulse-like noise.

The adjustment factors of 5 and 12 dB(A) are derived from research into noise-related annoyance. People probably find impulse noises more annoying because of the startle responses they tend to induce¹⁰⁵. Research by Griefahn⁶⁵ (into the effects of gunshot noise in the laboratory), Vos¹¹¹ (into the effects of gunshot noise in the field, see Figure 24 in Annex D) and Fidell⁴⁹ (the effects of noise from military jets in the field, as analysed by Passchier-Vermeer⁵², see Figure 22 in Annex D) have all shown that noise events characterised by a rapid initial rise in sound pressure level also cause considerably more sleep disturbance than 'ordinary' environmental noises.

4.2.5 Industrial noise

While attaching certain caveats, the 1997 Health Council report suggests that, in situations characterised by lower noise exposures, the equivalent sound pressure levels associated with industrial noise should be corrected by between 0 and 10 dB(A). This proposal was based on considerations regarding noise-related annoyance relative to noise exposure over the full twenty-four-hour period. Recent research has since shown that there is no scientific basis for making such an adjustment¹¹².

Figure 14 illustrates the relationships between industrial noise and annoyance, as defined using data from recent research by Miedema *et al*¹¹², and the relationships between road traffic noise and annoyance¹¹³. The figure shows the percentages of people experiencing high annoyance attributable to road traffic noise and industrial noise, the percentages of people experiencing at least moderate annoyance, and the percentages of people experiencing at least slight annoyance, as functions of *Lden*. It will be seen that the curves for industrial and road traffic noise are almost identical, and certainly do no

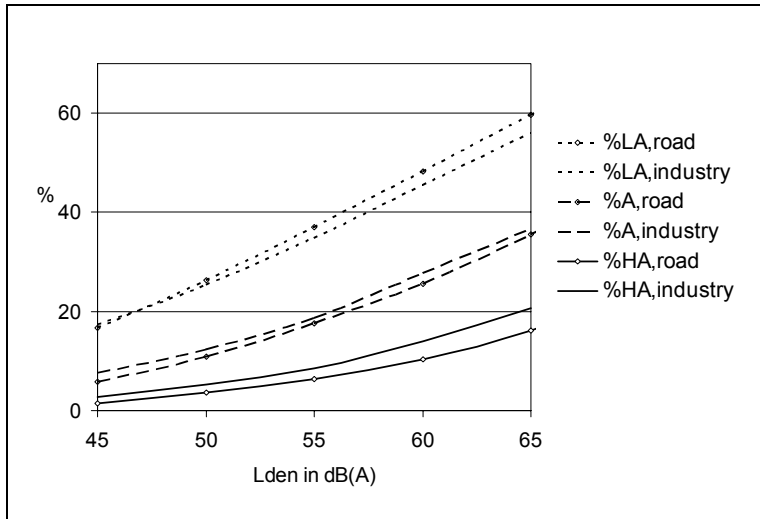


Figure 14 Annoyance caused by road traffic noise and industrial noise as a function of L_{den} ^{112,113}. %HA is the percentage of people experiencing high annoyance, %A is the percentage of people experiencing at least moderate annoyance, and %LA is the percentage of people experiencing at least slight annoyance.

justify the conclusion that, at L_{den} values of between 40 and 60 dB(A), industrial noise causes more annoyance than road traffic noise. The Committee consequently believes that there is no longer any justification for correcting the equivalent sound pressure levels associated with *night-time* industrial noise either.

4.2.6 Sporadic high L_{Amax} or SEL values

The exposure-response relationships described above have been defined on the basis of data from situations where night-time noise events occurred regularly. It is therefore pertinent to ask whether these relationships remain valid in situations characterised by sporadic noise events with comparatively high SEL and L_{Amax} values. The Committee anticipates that, in such a situation, the probability of an *acute* effect (of whatever kind) will be greater than the defined relationships suggest, since the hearer will necessarily be unused to noise events of the kind involved, and anxiety is very likely to play a role. Anxiety is particularly likely to play a role where the hearer associates a noise with a previously experienced threat to him/herself or others. A single event of this kind can also have consequences for the hearer's quality of sleep for the rest of the night and on subsequent nights. However, the Committee does not have sufficient research data at its disposal to develop these assumptions more fully.

In questionnaire-based studies of self-reported long-term effects (such as diminished sleep quality and night-time noise-related annoyance), a one-year assessment period is typically used. The Committee is not aware of any research that has looked at the specific effects that noise events with relatively very high *SEL* or *L_{Amax}* values have on such self-reported parameters. The Committee cannot therefore make any scientifically justified statement about such effects.

4.2.7 Conclusion

Although little is known about how sleep is affected by exposure to noises with unusual characteristics, the Committee believes that it is reasonable to assume that the effects of exposure to some ‘special’ types of noise are greater than the effects of exposure to ‘ordinary’ traffic noise. The Committee is of the opinion that the conclusions of the 1997 Health Council report *Assessing Noise Exposure for Public Health Purposes* remain valid in relation to noise with low-frequency components, low-frequency noise, tonal noise and impulse noise. The adjustment factors that need to be applied to the exposure indexes are given in Annex F. However, where noise from industrial activities is concerned, data published since 1997 indicates that the application of an adjustment factor is no longer justified. The Committee is unable to make any definitive statement regarding the possibility that occasional, very loud noise events may have more far-reaching consequences.

4.3 Efficiency and effectiveness of the acoustic insulation of homes

4.3.1 Data

In the Netherlands, there have only been a number of isolated studies into the efficiency and effectiveness of acoustic insulation in the reduction of perceived road and aviation noise levels, or into people’s views regarding such insulation¹¹⁴⁻¹¹⁹.

Bitter *et al* looked at the effects of fitting additional acoustic insulation to flats beside busy motorways in Dordrecht¹¹⁴ and Amsterdam¹¹⁵. A survey of residents 2.5 years after the modifications were made revealed that half the people living in the flats were no longer annoyed by night-time road traffic noise.

Van Dongen *et al*¹¹⁶ carried out an exploratory study into sleep quality in homes fitted with additional acoustic insulation in the vicinity of Amsterdam’s Schiphol Airport. Comparative analysis revealed that self-reported sleep disturbance and self-reported high sleep disturbance were slightly lower in the better-insulated dwellings than in ‘ordinary’ dwellings. However, the design of the study precluded the drawing of definitive conclusions.

Three reports were published between 1994 and 1999¹¹⁷⁻¹¹⁹ regarding people's general views concerning modifications made to homes near Schiphol with a view to reducing aircraft noise-related problems. Some 85 per cent of subjects reported that the insulation had reduced noise-related annoyance indoors. Nevertheless, people in more than 55 per cent of the homes continued to experience at least slight noise-related annoyance, and people in 15 per cent of the homes reported experiencing high annoyance since the modifications were made. The distribution patterns of both overall and night-time levels of aircraft noise-related annoyance were clearly seasonal: on (cold) winter nights, 10 per cent of subjects often or always experienced annoyance during the sleep period, compared with 40 per cent on (warm) summer nights. The differences were closely related to the use of windows: only 25 per cent of respondents said they slept with the bedroom window at least slightly ajar in the winter, whereas 70 per cent did so in the summer.

Almost no research into the efficiency of domestic acoustic insulation has been done in other countries either, the exceptions being studies by Fidell and Silvati¹²⁰, Utley¹²¹ and Minoura¹²².

Fidell and Silvati¹²⁰ investigated what effect the fitting of insulation to attenuate aviation noise had on levels of annoyance. However, they did not look specifically at annoyance during the sleep period.

In the UK, an extensive study was done to establish how effective extra acoustic insulation was in reducing exposure to road traffic noise¹²¹. In the specially insulated homes, approximately a quarter of subjects whose bedrooms faced the street reported being very highly or highly annoyed by night-time road traffic noise; a similar number had difficulty getting to sleep because of the noise, and more than a quarter of respondents said they were woken up at night by road traffic noise. The results proved to be influenced to a considerable extent by whether the subject felt that, without the window open, his or her bedroom was too hot in the summer: 37 per cent of those who felt unable to sleep with the window closed in warm weather were very highly or highly annoyed by night-time road traffic noise, whereas only 15 per cent of those who didn't mind having the window closed experienced similar problems.

Minouri investigated the situation in the vicinity of a US air base on a Japanese island, with a view to determining how effective additional acoustic insulation was in an area with a very high aircraft noise exposure. Because the circumstances on the island are quite unlike any in the Netherlands, the findings – which indicated that the insulation was disappointingly ineffective – are not transferable to the Dutch situation.

In an interview-based study of 1242 households in the Netherlands, Leidelmeijer and Marsman⁹⁹ investigated the audibility of and annoyance associated with noise from neighbours during the day and at night. The researchers distinguished between five types of noise: noise from sanitary fittings, contact noise, noise from audio equipment,

do-it-yourself (DIY) noise and noise from pets. Further distinctions were made according to the part of the house where the noise was audible or caused annoyance, and the time of the day or night. Subjects proved least tolerant of noise from their neighbours that was audible in the master bedroom. Where each of the five investigated types of noise were concerned, roughly 10 to 15 per cent of subjects indicated that they felt it was unacceptable for the noise to be audible during the day. In each case, a higher percentage said the noise should not be audible in the evening, and a still higher percentage did not want to hear the noise at night (between 11pm and 7am). Overall, nearly 30 per cent of subjects said that sanitary fittings should not be audible at night, while approximately 50 per cent felt each of the other four types of noise were unacceptable by night.

Subjects were also asked whether they could hear voices from neighbouring homes. While the percentage of affirmative answers varied according to the type of dwelling, ordinary speech was to some extent audible in an average of 35 per cent of dwellings, and partially or readily comprehensible in approximately 8 per cent of dwellings. Raised voices could be heard, at least some to extent, in approximately 65 per cent of dwellings; they were at least partially comprehensible in 27 per cent of homes and readily comprehensible in approximately 10 per cent.

In 1993, Kranendonk *et al* produced a synthesis of the research conducted up to that point in time into the annoyance associated with noise from neighbours¹⁰⁰. TNO later produced a report¹⁰¹ on neighbour-noise and acoustic insulation based on the findings of a questionnaire-based survey of the residents of six hundred homes. They established that nearly half of the respondents heard at least some noise from neighbouring dwellings every day. Approximately 10 per cent of subjects found their neighbours' noise highly annoying. The chief causes of annoyance were loud radios, hi-fis and TVs, the slamming of doors and footsteps on floors and staircases.

The authors of both studies concluded that, given the minimum level of acoustic insulation required in new dwellings under the Building Decree¹⁴ (an *Ilu,k* value of 0 dB(A)), noise from neighbours caused high annoyance for 10 per cent of subjects and at least moderate annoyance for 25 per cent.

4.3.2 Conclusion

From the little data available, the Committee concludes that fitting additional acoustic insulation to homes can reduce the annoyance associated with night-time traffic noise to some extent. It is not presently possible to quantify the benefit, however. One thing that is clear, is that if steps are not also taken to enable householders to keep their bedrooms cool in hot weather, the benefit of additional acoustic insulation is liable to be offset in the summer by people opening their windows.

In addition, the Committee considers the following points to be important for assessment of the effectiveness and efficiency of domestic acoustic insulation and therefore important in the context of research in this field:

- There is a danger that fitting high-grade acoustic insulation to exterior walls in an effort to deal with a form of noise that is much louder than other noises in the environment will have the effect of cutting out all noises except the one that is causing problems.
- High-grade acoustic insulation against noises from external sources has implications for inter-dwelling acoustic insulation. If the latter is only of a moderate standard, as is frequently the case in the Netherlands, noises from neighbouring dwellings (sanitary facilities, TV, radio, kitchen noises, people going up and down stairs, parties, rows, voices) becomes much more apparent, potentially leading to social tensions.
- Many people like to sleep with their windows at least partially open, which negates the effect of acoustic insulation on the exterior walls to some extent. Although there are technical solutions for this problem, such as variable ventilation systems, that adjust the ventilation opening in line with rising or approaching noises from outside, they are not in widespread use.
- Very high levels of insulation can cause ‘acoustic isolation’: cutting the householder off from ‘pleasant’ outside noises, such as birdsong and children at play. However, the Committee anticipates that acoustic isolation is less likely to be a problem at night than during the day.

The Committee believes that the standard of inter-dwelling acoustic insulation presently required is not sufficient to provide protection against annoyance attributable to noise from neighbours. Since people are a lot less tolerant of the noise their neighbours make at night-time than of their neighbours’ evening or daytime noise, it may be assumed that much of the annoyance associated with noise from neighbours relates to the influence of such noise on sleep.

Answers to the State Secretary's questions

In this chapter, the Committee presents its answers to the specific questions posed by the State Secretary and summarises its conclusions. The answers to the State Secretary's questions are based upon the information provided in chapters 3 and 4. First, however, the Committee explains how the answers fit into the environment and health context described in section 2.4.

5.1 General principles

5.1.1 *Effects of exposure to noise when sleeping*

In its evaluation of the consequences of exposure to noise when sleeping, the Committee has applied the model illustrated in Figure 3. In this model, biological phenomena occur in response to environmental noise because, even when sleeping, an individual still needs to assess and process 'stimuli' from the environment. The biological responses that are liable to occur include waking up, difficulties getting off to sleep and increased average motility while sleeping. To some extent, these responses involve acute changes during exposure to a noise, and to some extent they involve changes that manifest themselves over the course of a night (before, while and after sleeping). Such effects can be predictors of long-term decline in health and well-being, which may or may not depend upon the nature and duration of the exposure. It is not therefore possible to say in advance whether a biological response to night-time noise will lead to a decline in health or well-being.

5.1.2 *Strength of the evidence*

In order to define the degree of certainty concerning the relationship between exposure to night-time noise and a particular effect, the Committee has defined three categories of evidence: sufficient, limited and insufficient evidence; see Table 2. The category ‘limited evidence’ is subdivided into two forms:

- A causal relationship is plausible, and has been observed to a limited extent in epidemiological research.
- No direct link has been epidemiologically established between exposure and effect, but there is good quality indirect empirical evidence for such a link, and the presence of a link is plausible. Indirect evidence may be said to exist if it has been observed that exposure has an intermediary effect, which is known from other research to lead to the ultimate effect under consideration.

5.2 **Effects of noise when sleeping**

Question 1: What are the effects (expressed in quantitative terms as far as possible) of exposure to noise when sleeping?

Environmental noise can be divided into noise from traffic (such as air, road and rail traffic), noise from stationary sources (such as factories and shunting yards), neighbourhood noise (noise from, for example, sports stadiums, racing circuit or open air events) and noise from neighbours (contact noise, noise of audio equipment, voices). Research into the relationship between, on the one hand, sleep characteristics and health and, on the other, exposure to night-time noise has tended to focus mainly on road and air traffic noise. In the following subsections, the Committee accordingly first addresses noise from these sources, before moving on to consider noise from rail traffic and stationary environmental sources, the neighbourhood noise and noise from neighbours.

The Committee distinguishes between biological effects and the accumulated effects on health and well-being of exposure resulting from sleeping in an environment affected by night-time noise. The Committee has divided effects of the latter kind into five categories: diminished sleep quality, diminished general well-being, impaired social contacts and concentration, medical conditions and reduction in life expectancy.

5.2.1 *Biological effects of road traffic noise and aviation noise*

Biological effects can be divided into acute (immediate) effects and effects that occur over the course of a night (before, while and after sleeping).

Acute biological effects

Noise during the sleep period induces an immediate response from the body. The effects that have been observed to take place in direct response on noise events that occur while the subject is sleeping are listed in Table 9. There is sufficient evidence for a causal relationship between each of these effects and night-time noise events.

Table 9 Acute biological effects for which there is sufficient evidence of a causal relationship with night-time noise (see Table 1 for terminological definitions).

Effect
Cardiovascular change ^a
Sleep stage change, from deeper to less deep sleep
EEG awakening
Motility
Onset of motility
Subject-registered awakening

^a The advisory report focuses mainly on heart rate acceleration, but there is also sufficient evidence of the induction of vasoconstriction and acute blood pressure rises.

Most of these effects have been sufficiently well studied to enable exposure-effect relationships to be defined. Hence, it appears that effects such as EEG awakening and increased motility first manifest themselves at indoor *SEL* values of approximately 40 dB(A). Noise-related subject-registered awakening is liable to occur at *SEL* values of 55 dB(A) and above. These values are valid for adults; insufficient data is available to enable the definition of relationships for children. It is assumed that night-time noises can induce acute changes in the (stress) hormone concentrations in a sleeping subject's blood, but this has not been proven. Such changes cannot easily be studied in a field situation, because it would involve the use of invasive test techniques.

Effects before, while and after sleeping

Numerous biological effects over a night (before, while and after sleeping) have been observed in epidemiological research. Some of these relate directly to the acute responses: raised average heart rate, increased motility, more frequent subject-registered awakening, and longer waking intervals (as registered on a sleep EEG). The level of average motility observed in people who are exposed to night-time road and air traffic noise appears to be greater than might be expected on the basis of the acute responses alone. Average motility is closely related to waking up more frequently, diminished perceived sleep quality and increased drowsiness during the day. Furthermore, people who

when trying to get to sleep are exposed to road or air traffic noise, or are worried about the possibility of being disturbed by noise in the night ahead, have more difficulty getting to sleep. The effects that manifest themselves after a sleep period are reduced perceived sleep quality, increased irritability and rise of drowsiness and tiredness during the day. There is therefore sufficient evidence of a causal relationship between noise and all these effects.

There is limited direct evidence that under certain circumstances exposure to night-time noise can influence (stress) hormones levels in sleeping subjects: this effect was observed in women who were troubled by noise in the night and unable to take corrective action. However, more definitive conclusions regarding the influence of noise on (stress) hormone levels must await the availability of further research data.

The exposure-related biological effects over the course of a night are listed in Table 10. For each effect, the table indicates the strength of the evidence for the existence of a causal relationship between exposure and effect, and the plausibility of the effect being indicative of a negative influence on health and well-being.

Table 10 Biological (physiological and psycho-physiological) effects observed after chronic exposure over numerous nights, indicating the strength of the evidence for a causal relationship with exposure to road and air traffic noise and the plausibility of the effect being indicative of an influence on health and well-being.

Variable	Strength of the evidence	Plausibility of influence on health and well-being
Change in cardiovascular activity	Sufficient evidence	Plausible
Increased average motility (motility)	Sufficient evidence	Plausible
Changes in duration of various stages of sleep, in sleep structure, fragmentation of sleep	Sufficient evidence	Empirical data
Prolongation of the sleep inception period, difficulty getting to sleep	Sufficient evidence	Plausible
Changes in (stress) hormone levels	Limited evidence, plausible	Plausible
Immune functions	Insufficient evidence	-
Waking up in the night and/or too early in the morning	Sufficient evidence	Empirical data
Drowsiness/Tiredness during the day and evening	Sufficient evidence	Empirical data
Impaired cognitive performance	Limited evidence, plausible	Plausible
Increased irritability	Limited evidence, plausible	Plausible
Annoyance	Limited evidence, plausible	Plausible

5.2.2 *Consequences for health and well-being*

Road and air traffic noise

The Committee's conclusions regarding the relationships between exposure to night-time road and air traffic noise when sleeping and changes in health and well-being are

summarised in Table 11. The effect parameters which the Committee has grouped under the five categories listed in the first column are specified individually and in each case an indication is given of the strength of the evidence for a causal relationship between the effect parameter in question and night-time exposure to noise when sleeping.

Table 11 Effects on health and well-being of prolonged exposure to noise during the sleep period.

	Effect parameter	Evidence
Sleep quality	Reduced perceived sleep quality	Sufficient evidence
	Difficulty getting to sleep, difficulty staying asleep	Sufficient evidence
	Sleep fragmentation, reduced sleeping time	Sufficient evidence
	Increased average motility when sleeping	Sufficient evidence
Well-being	Sleep disturbance	Sufficient evidence
	Health problems	Sufficient evidence
	Use of somnifacient drugs and sedatives	Sufficient evidence
	Increased daytime irritability	Limited evidence, plausible
Social contacts and concentration	Impaired social contacts	Limited evidence, plausible
	Impaired cognitive performance	Limited evidence, plausible
Medical conditions	Insomnia	Sufficient evidence
	Hypertension	Limited, indirect evidence, plausible
	Depression (in women)	Limited, indirect evidence, plausible
	Cardiovascular disease	Limited, indirect evidence, plausible
Reduction in life expectancy (premature mortality) ^a	Occupational accidents	Limited, indirect evidence, plausible

^a Cardiovascular disease also involves the loss of healthy life expectancy. However, no account has been taken here of the lost life-years, since there is only limited evidence for a causal association between cardiovascular disease and exposure to night-time noise.

With regard to the long-term health and well-being implications of exposure to night-time noise during the sleep period, the Committee's overall conclusion is that there is sufficient evidence that such exposure leads to reduced sleep quality and reduced general well-being, and limited evidence that it leads to impaired social contacts and concentration, increased probability of developing medical conditions and reduced life expectancy due to fatal occupational accidents.

Rail traffic and stationary environmental sources

Epidemiological research into the effects of rail traffic noise has been confined to self-reported sleep disturbance, changes in sleep EEG and motility. At a given noise expo-

sure, rail traffic noise is slightly less likely to induce these effects than road traffic noise or aviation noise. Although there is no direct evidence that rail traffic noise has any other effects, the Committee considers it plausible that other effects can occur, although the relationship between noise exposure and observation thresholds may not be the same as where road or air traffic noise are concerned.

No epidemiological research has been carried out into the consequences of exposure to night-time noise from stationary environmental sources. However, laboratory research has indicated that the effects of individual noise events associated with stationary environmental sources are essentially similar to the effects of events associated with road and air traffic noise. Lack of epidemiological research data prevents the Committee from drawing any definitive conclusions regarding the effects of continuous noise from stationary environmental sources.

Neighbourhood noise and noise from neighbours

Inventory research in the Netherlands indicates that sleep disturbance attributable to the most annoying forms of neighbourhood noise and noise from neighbours (contact noise and human noises in the environment) is on a similar scale to disturbance attributable to the most annoying sources of road traffic noise (mopeds and passenger cars). It is reasonable to assume that chronic sleep disturbance is in the long term liable to have consequences for health and well-being. The sound pressure level and other noise characteristics are liable to determine the nature of the influence to some extent, but certain other factors play a more prominent role than is the case with traffic noise. These factors include appreciation of the noise and of the party responsible for the noise, as well as the hearer's personal circumstances. However, scientific understanding of the relative importance of and interaction between acoustic and non-acoustic factors is not sufficient for the Committee to draw any definitive conclusions regarding the relationship between, on the one hand, exposure to night-time neighbourhood noise and noise from neighbours and, on the other, health and well-being.

5.3 Public health perspective

Question 2: How do such effects compare with other effects on health, in terms of seriousness and magnitude?

The Committee assumes that what the State Secretary is interested in is the magnitude of the effects within the Dutch population. The Committee has estimated the consequences of exposure to night-time traffic noise on the health and well-being of the Dutch population in terms of self-reported high sleep disturbance and insomnia. The Committee's

estimates are based on the cumulative noise exposure associated with road, rail and air traffic in 2003 (Annex G). Because the calculations inevitably involve considerable uncertainty, the results should be regarded as merely indicative.

The number of adults in the Netherlands experiencing high sleep disturbance due to traffic noise in 2003 has been estimated at between a hundred thousand and a million. The increase in the number of adults suffering from insomnia attributable to exposure to night-time traffic noise is put at between ten thousand and a hundred thousand. The number of people suffering from insomnia caused by traffic noise is 2 per cent of the people with high sleep disturbance.

For the year 2000, the RIVM has estimated separate *L_{night}* values for the noise exposures attributable to road traffic, rail traffic and air traffic¹⁵. On the basis of this data, the Committee has calculated that the number of adults in the Netherlands experiencing self-reported high sleep disturbance due to noise from each of these three types of traffic in that year was between a hundred thousand and one million. The increase in the number of people suffering insomnia attributable to road traffic noise and rail traffic noise is in each case estimated at between one thousand and ten thousand, while the corresponding figure for aviation noise in the general vicinity of Schiphol Airport is between a hundred and a thousand people.

In recent years, there has been considerable focus on quantifying the collective disease burden attributable to environmental factors. One initiative in this area has been the introduction of the DALY as a unit of measurement. In response to questions posed by the State Secretary for Housing, Spatial Planning and the Environment, the Health Council is to prepare a separate advisory report on the issues associated with the use of DALYs. On the basis of information from a thesis by De Hollander and noise data provided by the RIVM (see Annex G), the Committee concludes that the disease burden associated with high sleep disturbance by night-time traffic noise in the Netherlands is several tens of thousands of DALYs. The corresponding figure for insomnia is certainly considerably lower. Although these estimates involve considerable uncertainty, they would appear to indicate that, through its influence on sleep, night-time traffic noise accounts for an important part of the overall effect that the physical environment has on public health.

By quantifying effects in DALYs, the effects of night-time traffic noise on health and well-being can be compared with the effects of other physical environmental factors. However, the Committee wishes to emphasise that a cautious approach should be taken, since there is considerable uncertainty about many of the estimates.

5.4 Risk groups

Question 3: Is it necessary to take special account of any population groups that are at particular risk?

As indicated in Chapter 3, the consequences of a given level of exposure to night-time noise when sleeping vary from person to person. The question therefore arises, is it possible to identify certain groups that are at increased risk? The Committee believes that there are some population groups whose health and well-being are more likely to be affected than others. This belief is based on extrapolations from what is known about sleep disorders and sleeping problems as they generally occur in the population at large, since very little of the research that has been done into the effects of night-time noise exposure has shed light on the risk factors affecting particular groups.

Although the strength of the evidence found by the Committee is limited, it does appear that people with cardiovascular problems, people who regard themselves as particularly sensitive to noise, and children may all be particularly sensitive to the acute cardiovascular effects of exposure to night-time noise. Because of the shortage of research data on children, it is not possible to say with confidence whether children are more sensitive than adults to other acute biological effects.

Where effects over the course of a night are concerned, people who suffer from insomnia constitute a risk group. People who during the sleep latency period worry about environmental noise need longer to get to sleep and perceive the quality of their sleep to be diminished.

Although there is no direct evidence, the Committee believes that adults who suffer from insomnia or another sleep disorder or who have another sleeping problem that causes them to wake up frequently in the night are more likely than 'sound sleepers' to suffer annoyance due to night-time noise reaching their bedrooms. The Committee also considers it plausible that there is an increased risk that the health and well-being of the following groups of adults will be adversely affected by exposure to night-time noise: older people; pregnant women and women who were pregnant within roughly the last year; people who work night shifts; people affected by physical pain, dementia, depression, hypertension, cardiovascular disease or respiratory illness. No research has been carried out into the relative risk of exposure to night-time noise having adverse consequences for the health and well-being of children.

5.5 Protection against night-time noise

Question 4: In view of the effects referred to, would it be advisable to introduce special rules, similar to those contained in Directive 2002/49 and the Aviation Act, for night-time noise from sources other than air traffic?

The Committee has been able, in its answers questions 1 to 3 (concerning the influence of noise on health), to comment regarding the influence of road and air traffic noise, and to a very limited extent regarding the influence of rail traffic noise and industrial noise, but has not been able to comment regarding the influence of noise from stationary sources, neighbourhood noise or noise from neighbours. Nothing can be said regarding noise from the latter group of sources in answer to question 4 either.

5.5.1 Two noise indexes

There is no decisive medical reason why road traffic, rail traffic or industrial activities should be treated differently to air traffic in the context of night-time noise regulation. In its 1997 advisory report *Assessing Noise Exposure for Public Health Purposes*, the Health Council put forward a system of two noise indexes for use in protection of the general public against traffic noise and industrial noise in the domestic environment⁸. The Committee sees no reason to depart from its predecessor's recommendations. As indicated in the 1997 report, an index of exposure to noise over a twenty-four-hour period needs to reflect general noise-related annoyance, while an index of exposure to night-time noise should be related to sleep disturbance. The desirability of a two-index system is emphasised by the summary given in Chapter 3: the effect mechanisms of and consequences of exposure to night-time noise differ at least in part from those associated with general noise-related annoyance.

The approach currently recommended by the European Union involves the application of the noise indexes *Lden* and *Lnight* (see section 2.2). In essence, this approach closely matches that put forward by the Health Council's 1997 report⁸. Again, one might ask whether it would not be sufficient to work with a single index, *Lden*, for all sources of noise. After all, *Lden* does make allowance for night-time noise, even attaching an additional weighting factor to nocturnal values. Furthermore, the regulation of sound pressure levels on the basis of *Lden* would imply limiting *Lnight* to a value 5 dB(A) or

more lower than L_{den}^* . However, by using a two-index system, one can apply separate criteria to general noise-related annoyance and sleep disturbance, each tailored to the effects in question. This makes for more transparent regulation and, particularly in situations where high values of L_{den} are permitted, to more effective protection**.

5.5.2 Shortcomings of the index for night-time noise

Although, as indicated above, the Committee favours L_{night} as the index for night-time noise, this expression does have certain shortcomings.

If exposure to noise is the decisive factor influencing sleep, then the noise exposure in a person's bedroom is the variable that is most closely related to the effects of exposure. A number of examples are given in Chapter 3 to illustrate this point. Although the Building Decree¹⁴ makes certain requirements regarding the noise-attenuating properties of the walls of new dwellings, and thus makes indirect requirements regarding the indoor noise exposure, the rules do not apply to existing homes. Consequently, at a given outdoor noise exposure, there is considerable variation in the noise exposures that people actually experience in their bedrooms. The picture is further complicated by differences in people's attitude to bedroom ventilation. Hence, the actual noise exposure and the magnitude and seriousness of the associated effects can vary substantially at a given L_{night} value.

It is also important to recognise that the nation's sleeping times vary sharply, and that most people – especially younger people – have a different sleeping pattern at the weekend from the one they follow during the week. It is estimated that approximately 15 per cent of adults in the Netherlands go to sleep before 11pm, and 50 per cent sleep beyond 7am. Therefore, because L_{night} relates to the period from 11pm to 7am, it by no means covers the sleeping times of the entire population. Hence, no requirement based on L_{night} can ever provide full protection against sleep disturbance.

Despite the shortcomings highlighted here, the Committee does not advocate the use of an alternative index, because it is unrealistic to suppose that any regulatory method could address every conceivable factor. Furthermore, it is the Committee's view that a regulatory system based on the use of L_{night} (in addition to L_{den}) can provide considerable protection against exposure to noise when sleeping. Just how effective such a regulatory system actually is will obviously depend on the L_{night} -based standards and limits that are defined.

* In the most extreme case, where all noise occurs between 11pm and 7am, L_{den} would be 5 dB(A) higher than L_{night} . ($L_{night} = x$, $L_{den} = 10 \cdot \lg[8/24 \cdot 10^{0.1x}] = x + 5$ (dB(A)). Under all other circumstances, L_{night} would be more than 5 dB(A) lower than L_{den} .

** Such as additional acoustic insulation for bedrooms.

5.6 Indexes for night-time noise

Question 5: If so, is it sufficient for such rules to be based on *L_{night}*, or are additional indexes of exposure required, with a view to regulating impulse-like noises and situations involving relatively infrequent but high-intensity noise events?

This question may be divided into the following two elements:

- Is *L_{night}* an adequate sole exposure index for noise with no special characteristics?
- Should any additional indexes be used for the regulation of noise with special characteristics or in special situations?

The Committee's answers are based upon the deliberations set out in, respectively, section 4.1 and section 4.2.

5.6.1 *L_{night} as an index of exposure*

The question is, would protection be enhanced by regulating not only *L_{night}* values, but also individual noise events? One might, for example, impose a *maximum sound pressure level* for a noise event or limit the *number of* noise events per night. As indicated in section 4.1, the Committee considers it inappropriate to impose a maximum sound pressure level. The reason being that, for a given *L_{night}* value, situations characterised by numerous events with relatively low *SEL* or *L_{Amax}* values are generally more likely to be problematic than situations involving smaller numbers of events with higher *SEL* or *L_{Amax}* values.

The *more* noise events a person is exposed to per night, the greater the chance is that he or she will happen to hear one of the noises after waking up 'spontaneously', and then have trouble getting back to sleep. This may help to explain the prevalence of sleep disturbance, and could justify limiting the number of noise events per night. As indicated in subsection 3.2.4, in an extreme case it is theoretically possible that someone could hear a passing car, plane or train car ten times in the night without the associated noise being the cause of the person waking up. The Committee believes that calculations could theoretically be made regarding these matters, but does not believe that there is presently enough detailed data available for anything better than rough estimates.

5.6.2 *Adjustment of L_{night} for special noises*

As indicated in section 4.2, the Committee considers the following 'special' noises to be of particular relevance for the night-time domestic environment:

- Noise with lower-frequency components (such as engine noises with deep components)
- Low-frequency noise (such as noise from transformers)
- Tonal noise (such as sirens)
- Impulse noise (such as the noise from low-flying military jets or gunshot noises)
- Industrial noise
- Noise involving sporadic high *L_{Amax}* or *SEL* values.

Little information is available regarding the influence on sleep of exposure to noise with special characteristics. Nevertheless, the Committee believes that in some cases the effects of exposure to such noise are greater than the effects of exposure to ‘ordinary’ traffic noise. With regard to noise with low-frequency components, low-frequency noise, tonal noise, and impulse noise, the Committee endorses the conclusions set out in the Health Council’s 1997 report *Assessing Noise Exposure for Public Health Purposes*. Hence, adjustment factors are proposed for use in the regulation of noise with low-frequency components, tonal noise and impulse noise, but it has not been possible to define an *L_{night}* adjustment factor for low-frequency noise. The values of the proposed factors are given in Annex F. Where noise from industrial activities is concerned, the Committee takes the view that research published since 1997 has demonstrated that no adjustment factors other than those referred to above are required.

It is not clear whether very loud sporadic noise events have any special implications for sleep. The Committee anticipates that the probability of such events having an *acute* effect (of whatever kind) is greater than the defined relationships might suggest, since the hearer will necessarily be unused to noise events of the kind involved, and anxiety is very likely to play a role. A single event of this kind can also have consequences for the hearer’s quality of sleep for the rest of the night and on subsequent nights. However, the Committee does not have sufficient research data at its disposal to develop these assumptions more fully. In questionnaire-based studies of self-reported long-term effects (such as awakening, diminished sleep quality and night-time noise-related annoyance), a one-year assessment period is typically used. The Committee is not aware of any research that has looked at the specific effects that noise events with relatively very high *SEL* or *L_{Amax}* values have on such self-reported parameters. The Committee cannot therefore make any scientifically justified statement about such effects.

5.7 Protection measures

Question 6: Could the public be protected by the use of a. performance-related or design requirements for residential buildings, b. personal protective gear, c. rules regarding sound pressure levels outside buildings, d. rules relating to vehicles and machinery, or e. a combination of these measures?

The Committee notes that the State Secretary does not mention publicity and dialogue as means of achieving protection. The Committee has nevertheless included publicity and dialogue in the response below, along with the measures that are referred to in the question. In its response, the Committee adheres to the standard strategy used in environmental management and occupational health and safety. This strategy involves first seeking to address a problem at source (which may entail reducing the number of sources), then exploring ways of intervening in the transfer from source to ‘recipient’, and considering recipient-oriented measures only as a final resort.

5.7.1 *Source-oriented measures*

The regulation of noise emissions from transport and industrial sources is a matter that has received increasing international attention. The ICAO* convention, for example, makes various provisions regarding noise production by aircraft^{123,124}. Newer aircraft that meet the requirements of Chapter 3 are significantly quieter than those that merely comply with Chapter 2**. Measures designed to reduce noise from cars and aircraft can sometimes be undesirable in the context of reducing exhaust-related atmospheric pollution³⁸. Furthermore, it is not sufficient to merely impose design requirements on vehicles and other machinery: maintenance and monitoring are also necessary in order to ensure that noise emissions are kept down in practice (buses are liable to become noisy with age, for example, while mopeds and scooters are sometimes ‘hotted up’ by their owners). In some cases, much more is technically possible than the regulations require, and social preferences (such as 4-wheel drive vehicles and wide tyres) often negate the ‘gains’ achievable through technological advancement.

5.7.2 *Intervention in the transfer from source to recipient*

Possible ways of controlling the transfer of noise from source to sleeper come under a number of headings: town planning measures (orientation of buildings and bedrooms, separation distances between noise sources and dwellings), acoustic screens and embankments, covers (tunnels) and domestic acoustic insulation. The Committee has restricted its detailed response to consideration of the last option.

An overview of published research into the effectiveness of domestic acoustic insulation as a means of controlling the influence of night-time noise is presented in section 4.3. Considering the large sums spent on fitting extra acoustic insulation to homes, the Committee finds it surprising that so little research has been done into the

* ICAO stands for International Civil Aviation Organization.

** Chapters 2 and 3 of Annex 16, Volume I of the ICAO convention.

effectiveness and efficiency of such modifications. As things stand, it is not possible to say more than that fitting acoustic insulation reduces sleep disturbance by night-time noise. It is clear that if steps are not also taken to enable householders to keep their bedrooms cool in hot weather, the benefit of acoustically efficient glazing is liable to be offset in the summer by people opening their windows.

Inventory research has revealed that many Dutch people are bothered by noise from their neighbours. The Committee regards this as indicative of shortcomings in the existing standards of inter-dwelling acoustic insulation. Since people are less tolerant of the noise their neighbours make at night-time than of their neighbours' evening or daytime noise, it may be assumed that much of the annoyance associated with noise from neighbours relates to the influence of such noise on sleep.

5.7.3 *Recipient-oriented measures*

It is possible for people to protect themselves against the effects of night-time noise by inserting ear plugs* of various kinds (plastic foam, moulded plugs, preformed and pre-sized plugs and mouldable plugs) into the auditory duct. Properly fitted, ear plugs can reduce lower-frequency traffic noises by 15 dB(A) or more. Some types of plug are soft and therefore not at all uncomfortable to use while sleeping.

Personal hearing protection can provide a solution only in specific cases. The Committee does not consider hearing protection appropriate for the general prevention of noise-related problems in the population at large. Not only would it be impossible to make sure that people actually used their ear plugs in the privacy of their own homes, but wearers would in many cases be unable or less readily able to hear important sounds, such their partners, children, alarm clocks, intruders or sirens.

5.7.4 *Publicity and dialogue*

Where environmental factors that have a demonstrable adverse effect on the quality of the human environment are concerned, it is certainly the case that publicity and dialogue are necessary to ensure that effective and efficient action is taken to keep such effects within acceptable bounds. Publicity involves the unilateral provision of information to the private citizen by the government or the party responsible for the environmental factor concerned. Dialogue is a bilateral communication process that often begins with listening to the private citizen^{38,125,126}.

In relation to the effects of noise on sleep, publicity and dialogue have two important aspects: the provision of information about the consequences of exposure to noise

* Headphone-style hearing protectors are not practical for use at night, and ordinary cotton wool offer no protection¹²³.

and the two-way exchange of information aimed at the reconciliation of scientific data with the experiences of the private citizen, as well as information about the advantages and disadvantages of source-oriented, transfer-oriented and recipient-oriented measures.

5.7.5 *The combination of various types of measures*

From what has been said in the preceding subsections, it will be clear that there is very little research data available on the effectiveness and efficiency of protection measures. It is not therefore possible to give evidence-based guidance on the form that any protection regime should take. Nevertheless, the Committee considers it inevitable that the control of noise-related problems will necessitate the combination of source-oriented, transfer-oriented and in some cases recipient-oriented measures. This is because measures of all types are difficult to realise, irrespective of how effective or efficient they may be. In practice, cost issues come into play as well ('Who pays?' and 'Who is best able to afford the cost?'), as do questions regarding the quality of the planning of the human environment. Also of relevance in this context is increasing mobility, which tends to negate the benefits of technological advancement to some extent.

Finally, the Committee wishes to highlight the fact that noise-related sleep disturbance is not an isolated issue. Night-time noise almost always occurs in tandem with daytime noise. Not only do some people sleep during the day (by choice or out of necessity), but also exposure to noise has health implications at any time. The environmental noise issue is part of the wider debate on the quality of the human environment. The quality of the human environment and its (positive and negative) influences on health and well-being are determined by numerous factors (see Chapter 2), some being characteristics of the physical environment and some being of a social or behavioural nature. However complicated it may be to do so, this wider context should be taken into account. This underlines once more the importance of dialogue.

5.8 **Recommendations for further research**

In his letter, the State Secretary did not enquire regarding problems relating to research into sleep, health and noise. While the Committee does not therefore see the definition of a research programme as part of its remit, it is felt appropriate that this advisory report should be concluded with a summary of the most important gaps in knowledge previously highlighted.

The *2002 Actieprogramma gezondheid en milieu, uitwerking van een beleidsversterking* (Environment and Health Action Programme, the Practical Reinforcement of Policy) concluded that, in the Netherlands as elsewhere, research into the relationship

between environment and health needed fresh impetus. The Action Programme identified a number of themes concerning which more scientific knowledge was required, and placed the themes in a general order of priority. In this context, the Health Council was asked to advise on an environment and health research programme³⁸. In the resulting advisory report, the Council highlighted the main gaps in knowledge regarding the influence that environmental factors have on health, and made recommendations regarding the research and reporting activities necessary to close those gaps. One of the themes addressed was exposure to noise. The report concluded that, in terms of their health implications, the themes exterior atmosphere, noise and indoor environment were of particular importance. The gaps identified in knowledge regarding the consequences of exposure to night-time noise were the effect that the level of insulation and the position of a person's bedroom have on the relationship between night-time noise exposure and consequences for health and well-being, the effectiveness of acoustic insulation on noise exposure and sleep disturbance, and the relationship between night-time road traffic noise exposure and effects on sleep and health. The present Committee feels it appropriate to elaborate on the research requirements referred to in the earlier report by highlighting the need for the following:

- Research into the long-term consequences of exposure for health and well-being, distinguishing between the effects associated with the noise exposure when sleeping, and those associated with the noise exposure during the daytime and evening. Most studies into effects such as hypertension, ischemic cardiovascular disease in adults and reduced cognitive performance by children have concentrated on relationships with daytime (and evening) noise exposure. However, recent research suggests that night-time noise and its effects on sleep and when sleeping play a much more significant role^{82,95,128}. Knowledge regarding such matters is particularly important for the formulation of intervention policies.
 - Research into the effects of night-time noise on children. Almost nothing is known about this subject. In the near future (summer 2004), the findings of the European research project *Road traffic and Aircraft Noise exposure and children's Cognition and Health* (RANCH) are to be published. RANCH is a field study looking at the relationship between, on the one hand, exposure to road and air traffic noise in the domestic environment and at school and, on the other, cognitive performance, blood pressure, general health, annoyance and sleep disturbance. It is not designed to shed light on the biological consequences in children of exposure to noise when sleeping. It is, however, expected to yield information about children's self-reported responses to night-time exposure to noise.
 - Questionnaire-based or field research into insomnia caused by exposure to night-time noise, making use of clinical concepts. Such research would serve to bring together medical and environmental health expertise relating to insomnia.
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- Research into the efficiency and effectiveness of acoustic insulation between dwellings and on or in exterior walls. Also of importance in this context is the position of the bedroom relative to the noise source and the influence of people's behaviour on the efficiency and effectiveness of insulation.
- Research into the effects of neighbourhood noise and noise from neighbours. Such research should be placed within the wider setting of research into the quality of the human environment.

Where the initiation of research is concerned, it is desirable to seek international alignment, as recommended by the Health Council in its report *Environmental Health: Research for Policy*.

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- A Request for advice
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- B The Committee
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- C Individuals and bodies who responded to the request for information
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- D Research into the consequences of night-time exposure to environmental noise when sleeping
-
- E Sleep disorders and sleeping problems
-
- F Health Council Advisory Report *Assessing Noise Exposure for Public Health Purposes* (1997/23)
-
- G The distribution of traffic-related noise exposure in the Netherlands

Annexes

The State Secretary's letter

The President of the Health Council received the following request from the State Secretary for Housing, Spatial Planning and the Environment in a letter dated 3 February 2003, reference no. LMV 2003003076.

I am writing to ask the Health Council to prepare an advisory report on exposure to night-time noise. The background to this request is outlined below. Following the outline, you will find a list of the specific questions that I would like the Council's advisory report to address.

Background

In several earlier reports, the Council has directly or indirectly addressed the issue of night-time noise. To a certain extent, therefore, this request is prompted by the possibility that new information may have become available, which can confirm or shed new light on advice given in the past.

In its first report on this topic in 1972, the Council unequivocally stated that 'Sufficient undisturbed sleep is extremely important to health.' In 1991, the Council turned its focus specifically to the question of aircraft noise in a report that was prompted by the heated debate then in progress concerning the proposed expansion of Maastricht Airport (*Airplane noise and sleep. Sleep disturbance by airplane noise at night*). The conclusion of the latter report was that 'Although not all the results lend themselves to clear interpretation, the indications are that the regular disturbance of sleep by noise has an adverse effect on health and well-being.'

The very thorough advisory report *Noise and Health* (1994) stated that there was sufficient evidence to attribute a number of phenomena to exposure to noise when sleeping. The phenomena in question were

changes in heart rate, changes in sleeping pattern, awakening, sleep stage changes and changes in the subjective quality of sleep. In relation to each of these effects, ‘observed effects levels’ – exposure levels at and above which effects were demonstrable – were calculated from the published data. Where other phenomena were concerned, the evidence for a causal relationship was less convincing, or an observation threshold could not be calculated.

The advisory report *Assessing Noise Exposure for Public Health Purposes* (1997) recommended that the index *LAeq* (covering an eight-hour overnight period) should be used when assessing (the seriousness of) night-time exposure to noise. However, the exposure-response relationships presented in the report for sleep disturbance and awakening attributable to traffic noise and noise from stationary sources were qualified as ‘provisional’.

Finally, the advisory report entitled *Public Health Impact of Large Airports* (1999) devoted considerable attention to the question of sleep disturbance. Although on the basis of recent research the Council described the evidence for a causal relationship between exposure to night-time noise and changes in stress hormone levels as limited, it was felt that there was sufficient reason to view sleep disturbance as a ‘moderately serious’ effect on health, similar to increasing respiratory illness. It was estimated that ‘a considerable proportion of exposed individuals’ were affected.

Recent developments

This request leads on directly or indirectly from a number of recent developments.

- The European Directive 2002/49 relating to the assessment and management of environmental noise (2002)* has been published, defining a separate index of night-time exposure to noise: the *LAeq* for an eight-hour period (*Lnight*). This index should at least be used for the compulsory strategic noise maps.
- The European Commission has completed a study of dose-effect relationships for the *Lnight*.
- The question of how best to quantify night-time exposure has also become topical in the context of the modernisation of the noise regulation policy tool set.
- In November 2002, the results of the field study of aviation noise-related sleep disturbance in the vicinity of Schiphol Airport** was published; a number of relevant studies have been reported by researchers in other countries***,****.

* Position paper on dose response relationships between transportation noise and annoyance, Luxembourg: Office for Official Publications of the European Communities, 2002, ISBN 92-894-3894-0, European Communities, 2002

** Sleep disturbance by aviation noise, TNO/RIVM, 2002

*** Epidemiological research on stress caused by road traffic noise and its effects on health 1 - Results for hypertension, Maschke, UBA, 2002

**** Nachffluglarmwirkungen, Forschungsbericht 26, DLR, Grezner, 2001

Specific questions

In view of the matters outlined above, I would like the Council to respond to the following questions in its advisory report:

- 1 What are the effects (expressed in quantitative terms as far as possible) of exposure to noise when sleeping?
- 2 How do such effects compare with other effects on health, in terms of seriousness and magnitude?
- 3 Is it necessary to take special account of any population groups that are at particular risk?
- 4 In view of the effects referred to, would it be advisable to introduce special rules, similar to those contained in Directive 2002/49 and the Aviation Act, for night-time noise from sources other than air traffic?
- 5 If so, is it sufficient for such rules to be based on *Lnight*, or are additional indexes of exposure required, with a view to regulating impulse-like noises and situations involving relatively infrequent but high-intensity noise events.
- 6 Could the public be protected by the use of a. performance-related or design requirements for residential buildings, b. personal protective gear, c. rules regarding sound pressure levels outside buildings, d. rules relating to vehicles and machinery, or e. a combination of these measures?

Timetable

I would be very grateful if the Council could present its advisory report in autumn 2003 or thereabouts.

Yours sincerely,

(signed)

PLBA van Geel,

State Secretary for Housing, Spatial Planning and the Environment

The Committee

-
- Professor JJ Heimans, *Chairman*
Department of Neurology, VU University Medical Center, Amsterdam
 - M van den Berg, *consultant*
Ministry of Housing, Spatial Planning and the Environment, Directorate General for Environmental Management, The Hague
 - Dr JJ van Busschbach
Erasmus Medical Centre, Institute for Medical Psychology and Psychotherapy, Rotterdam
 - JH Granneman
Peutz bv, Zoetermeer
 - Dr HME Miedema
TNO Inro, Department of Environment and Health, Delft
 - Professor FJN Nijhuis
Occupational Perspective Centre, Hoensbroek
 - Professor WF Passchier, *consultant*
Health Council, The Hague
 - Dr H Tiemeier
Erasmus Medical Centre, Institute for Epidemiology and Biostatistics, Rotterdam
 - Professor AJJM Vingerhoets
University of Tilburg, Psychology and Health, Tilburg
-

- Dr AW de Weerd
Haaglanden Medical Centre, Westeinde Hospital Site, Centre for Sleep and Waking Disorders, The Hague
- W Passchier-Vermeer, *Secretary*
TNO Inro, Department of Environment and Health, Delft, and Health Council, The Hague

Administrative support: M Bakker, Health Council, The Hague.

Layout: M Javarmardi/J van Kan, Health Council, The Hague.

Individuals and bodies who responded to the request for information

A letter was sent to more than fifty bodies with an interest in the subject matter concerning which the State Secretary had asked for advice. In addition, an advertisement was placed in the Government Gazette of 22 July 2003, inviting interested parties to submit any information that might be of value in the compilation of the advisory report.

Written responses were received from the following individuals and bodies:

- Greater Rotterdam Regional Health Service, General Healthcare Sector, Environment & Hygiene Department, R van Doorn
- Achterhoek Regional Health Service, CH Capel
- JJM Veraart, in a private capacity
- Kop van Noord-Holland Regional Health Service, JE de Leeuw den Bouter
- Noord-Kennemerland Regional Health Service, J Paulisse, enclosing a report entitled *Geluidhinder en slaapverstoring in Noord-Kennemerland (Noise-Related Annoyance and Sleep Disturbance in Noord-Kennemerland)*; OMNIBUSONDERZOEK 2000
- Amsterdam Airport Schiphol, Business Unit Airlines, M Bouwmeester, enclosing a final draft report entitled *Non-auditory Health Effects of Aircraft Noise With Special Reference to Sleep Disturbance*.

E-mail responses were received from the following bodies:

- Northern South Holland Regional Health Service, M Mooij
 - IPO BOAG, J Witteman
-

- Groningen Municipal Health Service, M Denekamp
- DCMR Rijnmond Environmental Service, Noise Bureau, RG de Jong
- ANWB, Department for Members' General Interests, P Clausing, enclosing a report entitled *Geluidbelasting in het Centraal Veluws gebied (Noise Exposure in the Central Veluwe Area)*

Research into the consequences of night-time exposure to environmental noise when sleeping

D.1 Introduction

This annex contains a more in-depth review of studies that have been conducted into the effects of night-time noise. The annex's division into sections reflects the structure of the main body of the report. Thus, the annex deals in turn with research into the acute biological effects of exposure to noise when sleeping, research into biological effects over the course of a night (before, while and after sleeping) and research into the consequences for health and well-being of chronic exposure to night-time noise.

Tables 12 to 14 list the effect parameters, the technique used to measure them and a selection of references to research reports. Where biological effects are concerned, distinction is made in the references between field research and laboratory research.

Table 12 Acute biological effect parameters, the technique used to measure them and a selection of references to field and laboratory research.

Variable	Measurement technique	Field research references	Laboratory research references (selection)
Probability of acute cardiovascular changes	ECG, plethysmography	58,129	64-67
Probability of acute changes in stress hormone concentrations in the blood	Immediate blood sampling		
Probability of sleep stage change, from deeper to less deep sleep, including EEG awakening	Polygraphy (EEG, EMG, EOG)	48,130-132	48
Probability of motility (onset)	Actimetry	12,50,51,77-79,96,133	
Probability of subject-registered awakening	Pressing a button	12,49,50,52,134,135	

Table 13 Biological effect parameters relating to the course of a night (before, while and after sleeping), the technique used to measure them and a selection of references to field and laboratory research.

Variable	Measurement technique	Field research references	Laboratory research references (selection)
Prolongation of the sleep inception period, difficulty getting to sleep	Polygraphy (EEG, EMG, EOG), actimetry, journal	12,75	136,137
Changes in cardiovascular activity	ECG, plethysmography	70,131,132,138-140	141-146
Change in average motility during the sleep period	Actimetry	12,66,75,79	
Changes in the duration of the various stages of sleep, in sleep structure, fragmentation of sleep	Polygraphy (EEG, EMG, EOG), actimetry	59,70-73	136,137,140,141
Changes in (stress) hormone concentrations	Blood, saliva and urine sampling	82,82,140,147-154 153, 155-163	
Changes in immunological parameters			84-87
Recalled frequency of awakening and premature awakening by noise	Journal and actimetry	12,51,66,75,96	74,129,164-166,75,76,167, 47,150
Self-reported sleep quality, self-reported sleep disturbance	Journal	12,17,147,168,169	
Drowsiness/tiredness during the day and evening	Test, journal	12,17,147	
Cognitive performance	Test	12,17,147,70	
Irritability	Test, journal	17,147	
Annoyance	Journal	12,17,147	

Table 14 Parameters studied in field and questionnaire-based research into the influence of chronic exposure to night-time noise on health and well-being.

Variable	Measurement technique	Field research references
<i>Sleep quality</i> : reduced perceived sleep quality, difficulty getting to sleep, difficulty staying asleep, sleep fragmentation, reduced sleeping time, increased motility when sleeping	Questionnaire, journals, actimetry	12,12,17,51,66,75,79,80,96,96,147,168,169
<i>Well-being</i> : self-reported sleep disturbance, self-reported health problems, use of somnifacient drugs and sedatives, daytime irritability	Questionnaire, test	12,51,66,75,97,168,169
<i>Social contacts and concentration</i> : impaired social contacts, impaired cognitive performance	Questionnaire, test	12,17,66,70,147
<i>Medical conditions</i> : insomnia, other investigated illnesses and medical conditions	Medical examination, questionnaire	12,89,170

D.2 Acute biological effects

D.2.1 Autonomous cardiovascular responses to noise events

Acute cardiovascular responses include raised (systolic) blood pressure, constriction of the blood vessels in the limbs and elsewhere, and accelerated heart rate. In this review, the Committee has restricted itself to acute heart rate accelerations in response to noise. The Committee is aware of only two field studies, both relating to road traffic noise^{58,129}. Laboratory research has been taken into consideration because it sheds light on:

- Possible differences between the effects of exposure to road traffic noise and the effects of exposure to noise from other sources
- Possible differences between the effects of exposure when sleeping and exposure during the day
- Personal characteristics that influence the effects

Field research

The Dutch researchers Hofman *et al* carried out a field study with twelve subjects who lived beside a motorway⁵⁸. They studied each subject in two situations, each for ten nights. The two situations differed in terms of the acoustic insulation provided by the fabric of the building, relating to the presence of double glazing, which provided an average attenuation of 9 dB(A). On each of the twenty nights that each subject was monitored, an EEG, two EOGs and an ECG were made and respiration was monitored. The

noise situation was described by the researchers as a gradually varying background level with superimposed noise peaks (when particularly noisy vehicles passed). A noise peak was defined as a noise event with an L_{Amax_i} of at least 10 dB(A) above the prevailing background level over a ten-minute interval (L_{90}). In each of the two study situations, there were approximately ninety-three noise peaks per night. L_{Amax_i} was generally between 30 and 65 dB(A). The variation in ECG-determined heart rate over time was compared with the distribution of noise peaks over time. For each noise peak, the maximum change in the heart rate (ECR: Event-related Cardiac Response) was determined from eight heart rate figures (four before and four after occurrence of the noise peak). For the purposes of comparison, a 'pseudo-ECR' was calculated for a peak-free interval immediately prior to the noise peak. In 80 per cent of cases, the ECR was greater than the pseudo-ECR. Analysis revealed that the ECR was not dependent on L_{Amax_i} , on the subject's sleep stage at the time of the noise peak, or on whether the bedroom had double glazing. However, the speed at which the noise increased in intensity did influence the ECR: faster rises in intensity were associated with higher ECRs. Figure 15 shows the results relating to noise peaks occurring while the subject was in sleep stage 3 or 4 (SWS). If it is assumed that, of the 80 per cent of ECRs that exceeded the associated pseudo-ECR, 20 per cent were higher purely by chance, just as 20 per cent of all ECRs were lower purely by chance, it follows that subjects' heart rates rose in response to 60 per cent of noise peaks, irrespective of sleep stage or L_{Amax_i} value.

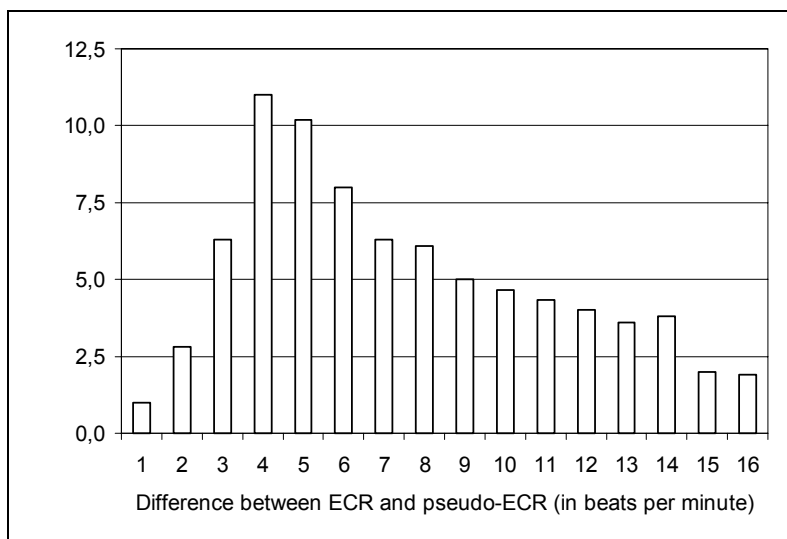


Figure 15 Percentage of cases in which the ECR (ECR: Event-related Cardiac Response) was higher than the pseudo-ECR, as a function of heart rate change involved in the ECR and pseudo-ECR. The various columns add up to a total of 80 per cent; in 20 per cent of cases, the difference between the ECR and pseudo-ECR was zero or negative.

A team led by Carter, a leading researcher in the field of the effects of noise on sleep, studied the effect of road traffic noise on seven older men, four of whom suffered from slight arrhythmia (simple premature ventricular contractions)¹²⁹. They observed that in two of the four men with arrhythmia, noise peaks (L_{Amax_i} of more than 70 dB(A) associated with lorries) induced a premature contraction 20 to 40 seconds later, especially if the men were in sleep stage 4 at the time. However, the researchers were unable to replicate this effect in a laboratory study involving road traffic noise¹⁵¹. In this context, Carter recounted an incident in which the sound of an alarm clock consistently induced ventricular fibrillation in a patient with a heart condition¹⁷¹. Carter argued that it was important that more research was done into the effects of noise on people with heart problems, since he anticipated that they were likely to be more than averagely sensitive to noise.

Laboratory research

Öhrström *et al* studied the acute effects of road traffic noise on heart rate in twenty-four subjects. Fifty-seven times a night for nine nights, subjects were exposed to the noise of a passing car or lorry with an L_{Amax_i} of between 58 and 60 dB(A)⁶⁶. The average increase in heart rate during the noise events was 1.5 beats per minute; among subjects who considered themselves sensitive to noise, the average increase was 1.8 beats per minute, while among subjects with no such self-perception, the increase was 1.1 beats per minute.

A French research team led by Muzet carried out a study in which twenty subjects were monitored for three nights, on one of which they were exposed to aircraft, lorry, moped and train noises⁶⁴. The L_{Amax_i} and noise event duration values were, for aircraft, 71 dB(A) and 21 seconds; for lorries, 66 dB(A) and 20 seconds; for mopeds, 56 dB(A) and 10 seconds; and, for trains, 62 dB(A) and 17 seconds. Over the course of the night, the noises were introduced randomly eight times per hour. In addition, subjects were exposed to similar noises of 15 dB(A) louder during the day. The results are presented in Figure 16. The increase in heart rate was not calculated in the same way as in the other publications referred to in this annex. Di Nisi *et al* worked on the basis of the difference between the highest heart rate and the slowest subsequent heart rate during a noise event (the latter rate generally being much lower than the average rate over an interval before or after the noise event).

The conclusion drawn by the researchers, which is illustrated by Figure 16, was that the response at night was much greater than that during the day. Furthermore, the day-time effects barely differed from one source to another. In addition to monitoring heart rate, the French team also used a finger plethysmograph to measure blood flow through subjects' finger tips. The plethysmography data also indicated that the most common

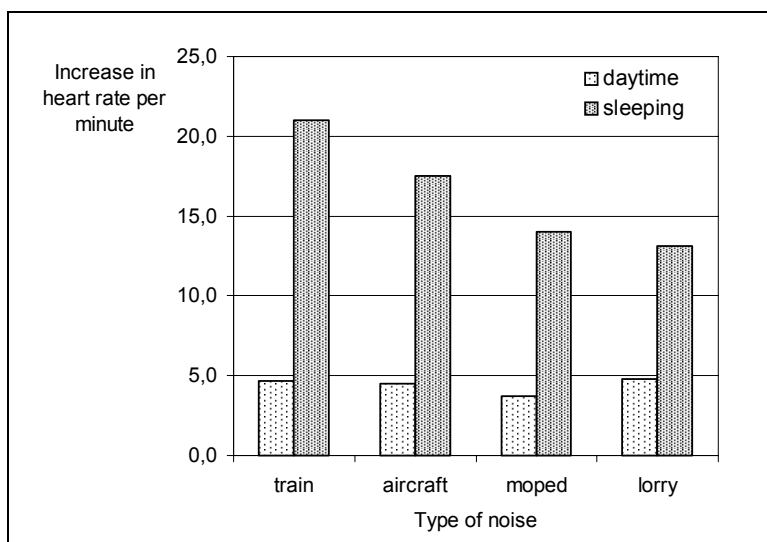


Figure 16 Comparison of the increase in heart rate during exposure to a noise event during the daytime and when sleeping. The daytime noises were 15 dB(A) louder than the noises subjects were exposed to when sleeping. From laboratory research by a French team⁶⁴.

response to the noise events, namely vasoconstriction, was also much more pronounced when sleeping than during the day. The subjects' score on a noise sensitivity scale did not appear to influence the magnitude of the heart rate response either during the day or at night, but was related to the degree of vasoconstriction during the day.

According to the data presented in Figure 16, aviation noise and lorry noise had a broadly similar effect on the sleeping heart rate. Because the train noise quickly rose to a maximum and remained at this level for almost the entire time until the train had passed, the SEL_i of the train noise was probably about the same as that of the aircraft and lorry noises. It is therefore plausible that, at a given SEL_i , the effect of train noise characterised by a rapid initial increase in intensity is slightly greater than the effect of noise from a passing aircraft or lorry. Comparing the data for the different sources, it is striking that mopeds – with a maximal level 10 to 15 dB(A) lower than the maximums of the other noise sources, and with the shortest duration – register quite high scores. The researchers did not investigate whether this was due, for example, to the faster rise in the intensity of moped noise or to aversion to the noise on the part of the subjects.

In view of the much greater heart rate responses observed in subjects exposed to noise when sleeping than in the same subjects during the day, the researchers suggested that more attention should be paid to protecting the general public against higher night-time noise exposures.

An Australian research team exposed nine subjects over three sleep periods to various types of noise: low-flying military jets, lorries, landing civil aircraft, and a five-sec-

ond 1000-Hz sound⁶⁷. Each type of noise event was generated at L_{Amax_i} values of 55, 65 and 75 dB(A). The time taken to reach maximum intensity (build-up period) and the overall duration of the noise event varied with the L_{Amax_i} value; the values are given in Table 15.

Table 15 Details of the noise events featured in the research by Carter *et al*⁶⁷.

Noise event	Build-up period (seconds)			Overall duration (seconds)			
	L_{Amax_i} (dB(A))	55	65	75	55	65	75
Low-flying military jet		1	1	1	1	2	6
Civil aircraft		13	14	16	8	18	25
Lorry		10	19	20	10	20	27
1000-Hz sound		0	0	0	5	5	5

Subjects were exposed to a total of approximately 1300 noise events. The increase in heart rate during the noise events did not appear to be related to the type of noise involved. At L_{Amax_i} values of 55 and 65 dB(A), the increase in heart rate averaged 1.5 beats per minute, while at 75 dB(A) it was approximately three beats per minute. Expressed in the form of SEL_i values, the civil aircraft and lorry noise events were very similar at each of the three exposure levels. At the lowest exposure, the SEL_i value of the 1000 Hz sound was approximately the same as those of the lorry and civil aircraft noises, while at the higher exposures it was roughly 3 to 5 dB(A) lower. Because of its short duration, the military jet noise had an SEL_i value approximately 10 dB(A) lower than those of the lorry and civil aircraft noises at the two lower exposures, and about 5 dB(A) lower at the highest exposure. It follows that, at a given SEL_i , the increase in heart rate induced by the 1000 Hz sound and the military jet noise is greater than that induced by the lorry and civil aircraft noises.

In Germany, Griefahn carried out an experiment in which twenty subjects were exposed in their sleep to a reproduction of the noise of shots from a tank, with an L_{Amax_i} value of between 78 and 82 dB(A)⁶⁵. A total of 1209 impulses were distributed over sixty-eight person-nights. On average, subjects' heart rates rose from 66 to 77 beats per minute, measured three seconds after the 'shot'. This increase by an average of eleven beats per minute was greater than the increase induced by road traffic noise under similar circumstances, albeit at lower L_{Amax_i} values.

In 1967, Semczuk investigated the effects of exposure to noise when sleeping, by using thoraxgraphy to monitor breathing in a study group of fifty children (five to seven years old) and a hundred adults⁶⁸. The trigger level for respiratory changes associated with an aural stimulus (sound of a particular pitch) was 10 to 15 dB(A) lower in children than in adults. The researcher accordingly concluded that a child's autonomous nervous

system is more readily activated by noise when sleeping than an adult's, and that children are therefore physiologically more sensitive to night-time noise than adults.

D.2.2 *Acute changes in hormone levels*

The lower four graphs in Figure 17 show how the concentrations in the blood of the stress hormones cortisol, adrenaline and noradrenaline and of the growth hormone (GH)⁸⁸ normally change in the course of a night.

The Committee is not aware of any field or laboratory research into acute changes in hormone concentrations in response to exposure to noise.

D.2.3 *Sleep stage change, including EEG awakening*

Reference has already been made in the main body of the report to the meta-analysis performed by Pearsons *et al*⁴⁸; see Figure 7. The relationships between exposure and the probability of EEG awakening and the probability of sleep stage change were presented by Pearsons, using both *L*A_{max}_{*i*} and *SEL*_{*i*} as indexes of exposure. Only three of the five field studies reviewed by Pearsons involved EEG scans¹³⁰⁻¹³²; one other was a questionnaire-based study⁶⁶ and another involved monitoring movements of the bed in which subjects slept¹⁷². The latter two studies entailed very few observations, so their results had only a marginal influence on the outcome of Pearsons' meta-analysis. The relationships defined from the field study data were based on a total of 213 subject-nights with EEG scans and 2770 noise events. The noise sources in the three studies were civil air traffic and rail traffic.

The Committee traced only three reported studies that had looked at the effect of night-time noise on children's sleep EEG⁵⁵⁻⁵⁷. Lukas exposed twenty-two people, six of them children (five to seven years old) to aviation noise and sonic booms once they had entered stage 3 or 4, as registered on an EEG. He observed that the children's EEGs showed less response to noise while in deep sleep than the adults' EEGs. Eberhardt⁵⁶ reported the effects of exposure to road traffic noise on thirteen children. Eight of the children lived on a quiet street, but on several nights during the study period were exposed to recorded lorry noise (sixty-eight times per night); the other five children slept beside a busy road. EEG awakening occurred in the first group of eight children in response to 0.2, 0.8 and 2.1 per cent of noises with *L*A_{max}_{*i*} values of, respectively, 45, 55 and 65 dB(A). The only other statistically significant difference revealed by the EEG analysis was a six-minute increase in the time spent in a waking state (W) on the nights with the higher noise exposures. The children also reported that, on the nights when they were exposed to road traffic noise, they found it harder to go to sleep, found that they woke up more often, recalled being awoken more often by road traffic noise, felt less

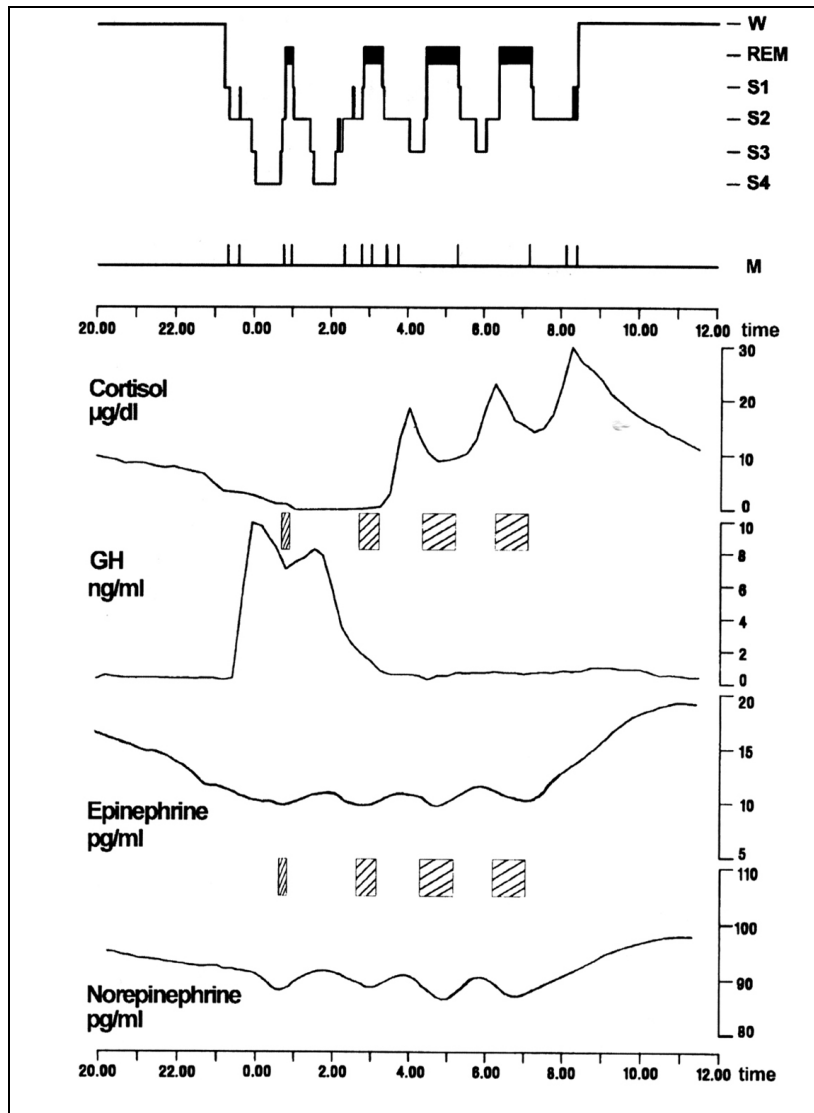


Figure 17 Sleep EEG and changes in the concentrations of cortisol, growth hormone (GH), epinephrine (adrenaline), and norepinephrine (noradrenaline) in the blood, as a function of the time from 8pm to 12 noon; typical patterns for healthy young adults⁸⁸.

well rested the following day and perceived the quality of their sleep to have been diminished.

Double glazing was fitted to the bedroom windows of the second group of just five children, thus attenuating the noise by an average of 10 dB(A). The only statistically significant effect of this intervention observed in the very small study group was a seven-minute reduction in sleep inception period. Eberhardt concluded that children exhibited

less strong responses to noise when sleeping than adults; he estimated that a noise needed to be about 10 dB(A) louder to induce a given EEG response in a child than was necessary to induce the same response in an adult.

In a laboratory study, Busby exposed twenty-four boys (eight to eleven years old) to three-second bursts of sound of successively increased volume (each sound being 2 to 5 dB(A) louder than the last), until EEG awakening occurred. It was possible to reproduce the sound at up to approximately 95 dB(A) above the perception threshold. The percentages of EEG awakenings from SWS, stage 2 and REM sleep were, respectively, 4.5, 34 and 50 per cent. When the night was divided into three phases, the percentages of awakenings and arousals in the first phase (characterised mainly by SWS) were 12 and 14 per cent, respectively; the corresponding figures in the second phase of the night were 30 and 20 per cent, respectively, and in the third phase (mainly REM sleep) 50 and 8 per cent, respectively. Comparing responses to noise in hyperactive children, hyperactive children on medication and non-hyperactive children, Busby observed no differences. From the findings, Busby concluded that, in the latter phase of the sleep period, children were very sensitive to noise, and that much more research was needed to build up a full picture of how children responded to noise when sleeping.

D.2.4 *Motility*

Over the last ten years, various large-scale field studies have been carried out, in which subjects wore actimeters when sleeping in order to record motility. In the USA, there have been two studies focusing on aviation noise^{49,50,134}, in Germany there has been one study concerned with road and rail traffic noise^{60,77,78}, in the UK there have been a further three studies on aviation noise^{51,54,80,173}, and finally one study into aviation noise has taken place in the Netherlands^{12,13,174}. In several studies, noise events were linked over time with motility, as indicated by the actimeter data, in order to shed light on the acute motility responses. In four of the studies, it was thus possible to define the relationship between L_{Amax_i} or SEL_i and acute motility during and attributable to aircraft noise events^{12,49,51,134}. In the other studies, the researchers focused on average motility during the sleep period.

Figure 18 shows the increase in the probability of acute motility attributable to aviation noise in the fifteen-second interval with L_{Amax_i} as deduced from the Dutch research. Acute motility was induced by the noise of a passing aeroplane from an

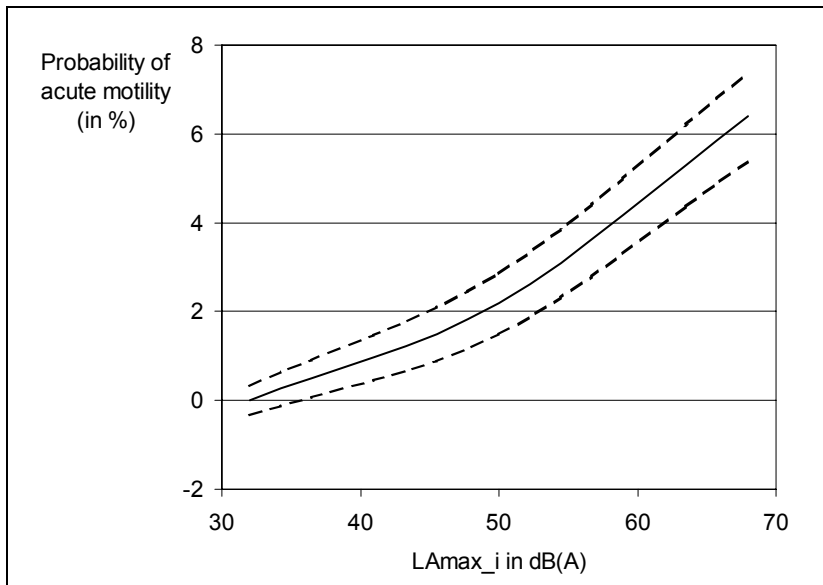


Figure 18 Probability (as a percentage) of acute motility being induced by an aircraft passage, as function a of the LA_{max_i} of the noise event, in the fifteen-second interval with LA_{max_i} . The figure also shows the so-called '95 per cent prediction-intervals'^{12,13}.

LA_{max_i} of 32 dB(A)*; an LA_{max_i} of 32 dB(A) is therefore the observation threshold for motility.

The curve shown in Figure 18 represents the average effect. The effect is strongly dependent on Li ; as Li increases, so the probability of acute motility being induced by aviation noise decreases. In other words, people who are exposed to the sound of a passing aircraft numerous times while sleeping respond less to a single passage than people who are exposed to the sound only occasionally. The relationship between the probability of aviation noise-induced motility and exposure to aviation noise was not found to be gender-dependent and was barely age-dependent. The study findings also indicated that, at a given LA_{max_i} value, the type of aircraft manoeuvre (landing or taking off) did not affect the probability of aviation noise-induced motility. The researchers also asked subjects about their attitude to air traffic and to the expansion of Schiphol Airport. Attitude was found to have no influence on the probability of acute motility induced by aviation noise.

* In the Dutch study, LA_{max_i} was not measured in fast mode; rather LA_{max_i} was the maximum indoor equivalent sound pressure level measured over a one-second interval during an aircraft passage. Theory suggests that LA_{max_i} measured in fast mode should be 0.2 to 1 dB(A) higher than the maximum indoor equivalent sound pressure level measured over a one-second interval. The observation threshold for acute motility is therefore an LA_{max_i} in fast mode of 33 dB(A)

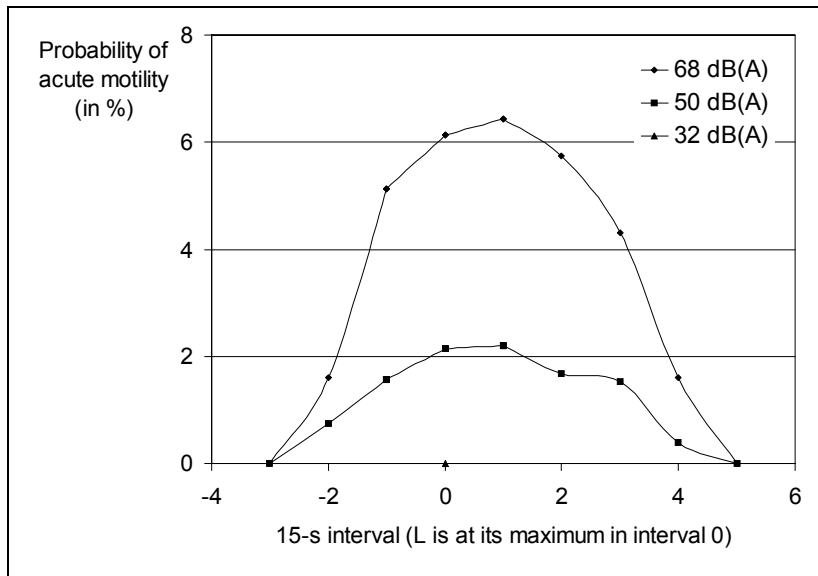


Figure 19 Probability of acute motility in three fifteen-second intervals before the interval in which the L_{Amax_i} of an aircraft noise event occurred, in the interval of occurrence, and in five fifteen-second intervals after the interval of occurrence, for three flight passages with L_{Amax_i} values of 68, 50, and 32 dB(A).

The Dutch researchers additionally calculated the probability of motility onset by aviation noise in the fifteen-second interval with L_{Amax_i} . The observation threshold for motility onset also worked out at an L_{Amax_i} for the aircraft passage of 32 dB(A).

Increased probability of acute aircraft noise-induced motility was sometimes observed both before and after the fifteen-second interval in which the L_{Amax_i} occurred. This phenomenon is illustrated in Figure 19. Overall, the probability of motility being induced by aviation noise in any fifteen-second interval was more than four times that probability in the fifteen-second interval in which L_{Amax_i} occurred.

The Dutch study's findings are consistent with those of the first US study, by Fidell *et al*⁴⁹. This study focused exclusively on people exposed to (very) high night-time aircraft noise exposures. The researchers established that the observation threshold for motility was 45 dB(A). This figure is broadly in line with the 42 dB(A) calculated by the Dutch research team for subjects with an L_i of 40 dB(A). In the second US study, which was much smaller-scale than the one just referred to, no statistically significant relationship could be demonstrated¹³⁴.

The relationship established in the British study between motility onset in a thirty-second interval and the L_{Amax} of an aircraft passage differed considerably from the pattern illustrated in Figure 18, even allowing for the facts that the British researchers looked at the probability of motility in thirty-second intervals and that the relationship

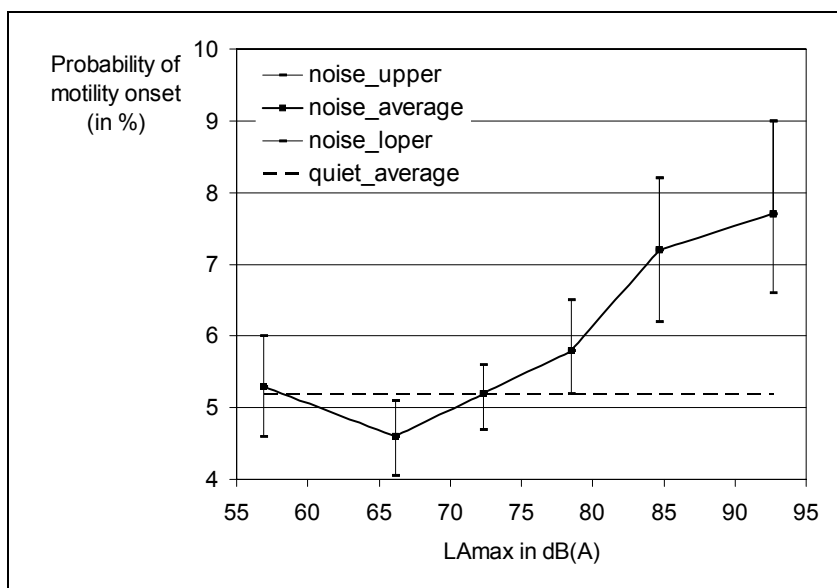


Figure 20 The relationship between the average probability of motility onset in the thirty-second interval in which LA_{max} occurs during an aircraft passage (noise_average) and LA_{max} of the passage, with the probability of motility onset outside these intervals also illustrated (quiet_average), based on research by Ollerhead⁵¹. The 95 per cent prediction interval (from noise_lower to noise_upper) is also given for each value.

between the probability of motility onset and the LA_{max} of an aircraft noise event is based on outdoor LA_{max} values. Various TNO reports have looked at this point^{12,13,79,97}. Some of the findings of the British study are illustrated in Figure 20.

The British researchers came to the conclusion that the probability of motility onset by an aircraft passage began to increase from an LA_{max} of 82 dB(A)⁵¹. Even when this outdoor value is reduced by 25 dB(A) (the figure quoted by the researchers⁵⁴ as the difference between outdoor and indoor levels), the observation threshold works out at an LA_{max_i} of 57 dB(A). This is 25 dB(A) higher than the corresponding figure established by the Dutch team for the probability of aircraft noise-induced motility or motility onset. The Committee believes that the main reasons for the differences in the findings of the British and Dutch studies are as follows:

- In the British study, aviation noise levels were established on the basis of *outdoor* measurements only. The instruments used by the researchers were positioned so as to be directly exposed to the noise. The outdoor sound pressure levels on subjects' bedroom walls will in some cases have been (much) lower, particularly where there was screening in the form of objects such as other buildings and trees. The outdoor measurements therefore represent the upper values in a wide range of outdoor sound pressure levels on subjects' bedroom walls. The distribution of indoor values will

have been even greater, since the sound attenuating characteristics of each room will have differed, and the window aperture status will have varied from subject to subject and from night to night. In the Dutch research, where the average difference between the outdoor and indoor L_{Amax} values of more than 63,000 aircraft passages during subjects' sleep periods was 21 dB(A), outdoor values as high as 82 dB(A) were sometimes associated with indoor values as low as 32 dB(A). These considerations suggest that, at a measured outdoor noise exposure of 82 dB(A), the actual exposure inside the subject's bedroom may well have been much lower. The Dutch study, by contrast, made use of measured indoor values.

- The British researchers considered whether there had been an aircraft passage only if their instruments registered a noise event with a sound pressure level of more than 60 dB(A) lasting for at least two seconds. If the timing of such a noise event coincided with the timing of a registered aircraft passage, the event was 'recognised' as an aircraft passage. Furthermore, any aircraft passage occurring within five minutes of the previous passage was excluded from the analyses. Then 'noise' was defined as any thirty-second interval in which the L_{Amax} of a recognised aircraft passage occurred, and 'quiet' as all other thirty-second intervals. In other words, quiet included all intervals in which relatively quiet aircraft passages occurred, all intervals in which there were aircraft passages within five minutes of a previous passage, and all intervals during an aircraft passage before and after the interval of L_{Amax} occurrence. The researchers then worked out the average probability of motility onset during 'quiet' periods (see Figure 20). However, this average will have been higher than a typical value for a genuinely quiet thirty-second interval, since all non-aircraft noises, all aviation noise outside the thirty-second intervals of L_{Amax} occurrence and all 'quieter' and 'non-recognised' passages, plus the associated motility, were ignored. In consequence, the probability of motility onset *by aviation noise* (*noise – quiet*) was underestimated. In the Dutch study, an aircraft passage was included if its L_{Amax} was 40 dB(A) or higher. Furthermore, distinction was made in the analyses between intervals characterised by the background sound pressure level only and intervals characterised by the presence of the background sound pressure level plus a non-aviation noise. Hence, the model takes account of the additional chance of motility or motility onset attributable to non-aviation noise, so that only the probability of extra motility caused by aviation noise is attributed to this source.
 - The British study focused exclusively on *motility onset*, whereas monitoring *motility* would also have taken account of the duration of the effect. Furthermore, the Dutch researchers found that the probability of motility was more closely related to the L_{Amax_i} (and SEL_i) than the probability of motility onset was.
 - The British study looked only at *the thirty-second intervals of L_{Amax} occurrence*. However, it was found in the Dutch study that, overall, motility onset was more
-

- likely *in the intervals before and after the interval of LAmax occurrence* than in the interval of occurrence itself.
- The scope for performing calculations was more limited in 1992, with the result that not all the British team's data could be analysed. Hence, the relationship between the probability of motility onset and exposure to aviation noise was defined on the basis of data concerning the period 11.30pm to 5.30am only. However, it is apparent from both the Dutch study and the British study that aircraft passages became more likely to be associated with motility or motility onset as the subject's sleeping time progressed and the absolute time got later. Furthermore, limited calculation capacity obliged the British team to group aircraft passages into noise categories (see Figure 20). For each category, the average probability of motility onset was then calculated and a check made to establish whether there was a statistically significant difference between the calculated value and the average probability of motility onset during quiet. An analysis method involving the processing of all the data at once would undoubtedly have led to the definition of a much lower threshold value.

The original purpose of the German study was not to establish acute-level exposure-effect relationships, so the data from the study has recently been re-analysed with a view to defining such relationships for road and rail traffic noise⁷⁹. Where rail traffic noise is concerned, the relationship has been defined between the probability of acute concurrent motility or motility onset and the *SEL* of a rail traffic noise event lasting up to two minutes. From these calculations, it appears that exposure to rail traffic noise does not increase the probability of acute motility or motility onset as much as exposure to aviation noise. After conversion of the German data to fifteen-second interval values, a 40 dB(A) *SEL* increase, from 60 to 100 dB(A), was estimated to be associated with roughly a 2.5 per cent increase in the probability of motility or motility onset. The corresponding figure for aviation noise is approximately 7 per cent.

In the German study, the exposure patterns for road traffic noise proved to be very different from the patterns for rail and aviation noise. Rail and aviation noise both involve distinct noise events, with an aircraft passage rarely lasting more than one minute and a train passage rarely longer than three minutes. (In the German study, 2.6 per cent of the nearly 69,000 train passages lasted longer than three minutes.) In total, nearly 17 per cent of thirty-second intervals included train noise. By contrast, nearly 53 per cent of thirty-second intervals involved road traffic noise in excess of the background level (i.e. three times the percentage for rail traffic noise).

In addition, a relationship has been established between acute motility during a thirty-second interval featuring road traffic noise and the equivalent sound pressure level during the interval⁷⁹. The probability of acute motility during a given thirty-second interval featuring road traffic noise was found to rise to a small but statistically signifi-

cant extent as noise exposure increased: a rise in the equivalent sound pressure level over a thirty-second interval from 40 to 70 dB(A) was associated with a 0.3 per cent increase in the probability of motility. However, in the first thirty-second interval of a period featuring road traffic noise, the probability of acute motility was on average 3.4 per cent higher than in a given thirty-second interval without road traffic noise or in another thirty-second interval during a period featuring road traffic noise. In other words, the effect at the start of a period featuring road traffic noise is quite strong.

D.2.5 *Subject-registered awakening*

Over the last ten years, various meta-analyses have been performed on data from eight or nine field studies, with a view to establishing the relationship between the probability of noise-induced subject-registered awakening (awakening recorded by the subject during his/her sleep period, by pressing a button) and a noise index (SEL_i) for the event^{52,134,135,175-179}. Two of the analyses – those by Finegold and Elias¹³⁵ in 2002 and Passchier-Vermeer⁵² in 2003 – used the same database, previously assembled by Fidell¹³⁴. Passchier-Vermeer additionally included in her analysis data from the Dutch study into sleep disturbance caused by aviation noise. In contrast to Finegold's meta-analysis, the secondary analysis performed by Passchier-Vermeer took account of the following:

- The type of noise source: civil aircraft, military jets, trains, other environmental noise events
- Differences in the probability of subject-registered awakening, EEG awakening and motility onset associated with a noise event of a given intensity (see Figure 8)
- The number of observations per subgroup (with subgroups formed on the basis of the SEL_i of the noise event, with the result that the number of observations per subgroup varied by a factor of 100)
- Differences in the time windows around a noise event within which the different researchers looked for evidence of awakening or arousal
- The probability of waking up in a period without noise events.

From the analyses, it was apparent that a statistically significant relationship was demonstrable between civil and military aircraft noise and subject-registered awakening, but not between rail traffic noise or 'other environmental noise events' and such awakening⁵². Since the relationship between the noise of military jets and subject-registered awakening is based purely on data relating to people living near to a single military air base, the findings should be verified by further research.

The database used by Passchier-Vermeer for her analyses included data on noise levels in the bedrooms of more than a thousand subjects in seven studies into the effects

of civil air traffic noise, involving more than 170,000 aircraft passages. In these seven field studies, the data on the aircraft passages was aggregated to seventy-eight points on the basis of SEL_i . This data was cross-referenced to the data on subject-registered awakenings to determine whether subjects recorded waking up within a five-minute window around an aircraft passage (from one minute before to four minutes after the L_{Amax}_i of the passage).

The frequency of subject-registered awakening was also established for five-minute time windows in which no aircraft noise events occurred. The probability of *subject-registered awakening attributable to a noise event* was then calculated by subtracting the probability of *awakening in time windows without noise events* from the probability of *awakening in time windows with noise events*.

The average probability of subject-registered awakening in a five-minute interval without aviation noise was 1.73 per cent. Figure 21 shows the probability (as a percentage) of subject-registered awakening *attributable to aviation noise* during a five-minute interval, as well as the probability of *awakening for any reason during a five-minute interval* in which an aviation noise event occurred. The observation threshold for aviation noise-induced subject-registered awakening is an SEL_i of 54 dB(A). This is estimated to correspond with an L_{Amax}_i (measured in fast mode) of 42 dB(A).

In principle, a noise with a very low sound pressure level can be audible in a very quiet environment. In young people, the binaural perception threshold (the threshold for the perception of a sound using both ears) is close to 0 dB(A). Although the threshold

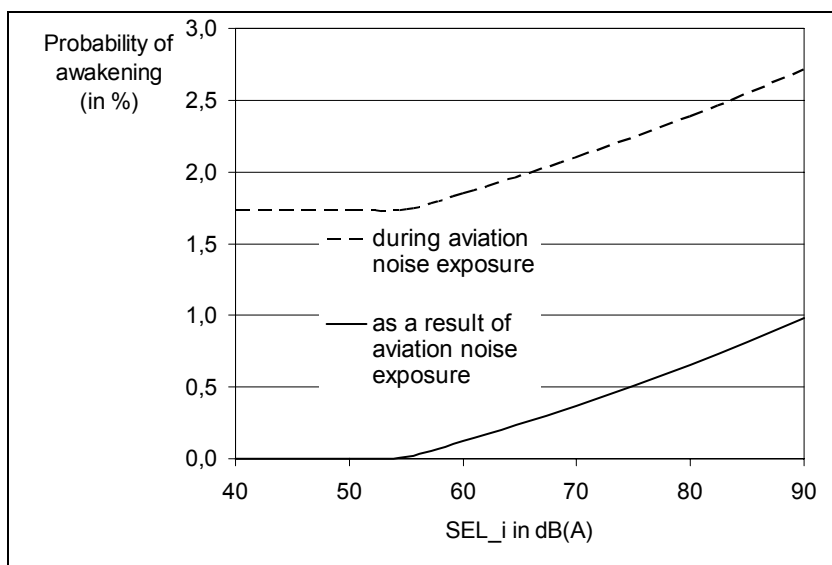


Figure 21 Percentage of subject-registered awakenings during a five-minute interval in which aviation noise occurs and percentage of subject-registered awakenings due to aviation noise as a function of indoor measured SEL (in dB(A))⁵².

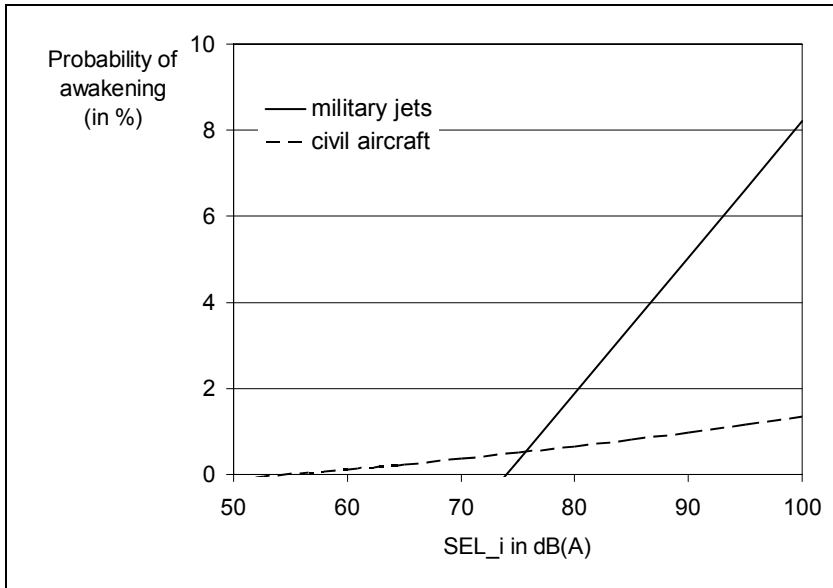


Figure 22 The probability of noise-induced subject-registered awakening associated with civil aircraft and military jets, as a function of indoor measured *SEL* (in dB(A))⁵².

for the perception of higher frequencies (above about 2000 Hz) increases as a result of normal age-related loss of acuity, the ability to hear lower-frequency noises, such as aircraft noise, does not decline nearly as much. Not many people's bedrooms are so quiet that special sounds of close to 0 dB(A) can be heard, since such sounds are liable to be masked by normal background noise. Generally speaking, aviation noise can be heard in an otherwise quite bedroom when the level is more than about 15 to 20 dB(A). This implies that, when a person is awake, the noise of a distant aircraft can be heard if it is more than about 15 to 20 dB(A), provided that the bedroom is otherwise sufficiently quiet.

Figure 22 shows the probability of noise-induced subject-registered awakening associated with civil aircraft and military jets⁵². Although the data relating to military jets requires further verification, the Committee considers it appropriate to highlight the data, as it illustrates the effect of exposure to noise events characterised by a rapid initial rise in intensity.

D.2.6 Acute annoyance and inconvenience

The Committee is not aware of any field or laboratory research into acute annoyance or other acute problems due to night-time noise.

D.2.7 Summary

The results of the research into the acute biological effects of exposure to night-time noise described in this section can be summarised as follows:

Acute heart rate change

- In people who had been exposed to road traffic noise for years, heart rate accelerations occurred in response to road traffic noise peaks with L_{Amax_i} values typically in excess of 30 dB(A). The observation threshold for heart rate acceleration is therefore likely to be below an L_{Amax_i} of 30 dB(A).
- Noise is much more likely to induce heart rate acceleration at night than during the day.
- People with cardiovascular problems and people who consider themselves to be particularly sensitive to noise may well be more liable to experience noise-induced heart rate accelerations.
- The field research carried out by Hofman indicates that there is a cardiac response to roughly 60 per cent of motorway traffic noise peaks, irrespective of the hearer's sleep stage or the L_{Amax_i} value of the noise peak (lorry).
- From laboratory research data, one can deduce that lorry passages and aircraft passages with similar SEL_i values have approximately the same effect on the heart rate.
- The results of the various laboratory studies referred to all indicate that, at a given SEL_i , a noise event characterised by a (very) rapid initial rise in intensity is more likely to affect the heart rate than a noise event that rises in intensity more gradually at the beginning. It is not possible to quantify this effect, however.
- Data from the only study involving children (five to seven years old) suggests that children's physiological responses to noise events during sleep are indicative of a 10 dB(A) higher sensitivity to noise.

Acute changes in hormone levels

Not investigated.

Sleep stage change, including EEG awakening

- Among people who are accustomed to exposure to night-time aviation noise, the observation threshold for EEG awakening is an SEL_i of 40 dB(A); the observation threshold for sleep stage change is probably slightly lower.

- The effect of night-time noise on children has been studied in the context of laboratory studies with just twenty-four, eight and six children, and in one field study of five children in a domestic setting. One of the researchers indicated that children were less sensitive than adults to the onset of acute EEG-registered changes by night-time noise. Another researcher who studied children observed that, in the last phase of the sleep period, noise peaks of up to 95 dB(A) induced EEG awakenings (excluding EEG arousals) 50 per cent of the time and EEG arousals 8 per cent of the time.

Motility, motility onset

- Among people who are accustomed to exposure to night-time aviation noise, the average observation threshold is an L_{Amax_i} of 32 dB(A) both for acute motility and for acute motility onset (with SEL_i values of 38 and 40 dB(A)). The observation threshold for acute motility is comparatively high among people who have been habitually exposed to higher levels of night-time aviation noise, and comparatively low among people who are only occasionally exposed to the sound of night-time aircraft passages. People in the latter group consequently respond more to a single aircraft passage.
- Among people who are accustomed to exposure to night-time rail traffic noise, the observation threshold for motility is estimated to be an L_{Amax_i} of about 30 to 35 dB(A).
- Among people who are accustomed to exposure to night-time road traffic noise, the probability of acute motility during a given thirty-second interval featuring road traffic noise barely increases at higher noise exposures. However, in the first thirty-second interval of a period featuring road traffic noise, the probability of acute motility is higher than in a given thirty-second interval without road traffic noise or in another thirty-second interval during a period featuring road traffic noise.

Subject-registered awakening

- Among people who are accustomed to exposure to night-time aviation noise, the average observation threshold for subject-registered awakening is an SEL_i of 54 dB(A), which corresponds to an L_{Amax_i} of 42 dB(A).
- The one study into the relationship between noise from military jets and subject-registered awakening indicated that, at higher exposures, military jets are much more likely to induce subject-registered awakening than civil aircraft.

Acute annoyance and other acute problems

Not investigated.

D.3 Biological effects over the course of a night (before, while and after sleeping)

D.3.1 Introduction

Very few field studies have looked specifically at the relationship between an effect measured over the course of or following a sleep period and the noise exposure during sleep. Furthermore, data from the studies of acute noise-induced changes described in D.2 has not in most cases been aggregated to provide full-night figures.

In 2003, the RIVM performed a review of field studies that had specifically sought to shed light on the effects of night-time road traffic noise on sleep⁶⁹. For this review, the researchers collated literature published since 1970. The reviewers found thirty-four field studies, of which twenty-three focused entirely on self-reported effects over an extended assessment period (e.g. a year). The results of these twenty-three studies are considered in the section of this annex devoted to the chronic consequences of exposure to (road traffic) noise. Ten of the other eleven studies used EEG, ECG or actimetry monitoring of sleeping subjects, sometimes supported by journal entries, to investigate effects over the course of a single night. In most cases, noise levels were also measured (in subjects' bedrooms) during the study nights. The eleventh study monitored effects on the basis of journal entries only. These eleven studies are considered in D.3.2.

In an article published in 2003, Babisch⁸¹ provided an overview of research into stress hormone levels associated with exposure to noise, both in a domestic setting and in an occupational setting. He referred to approximately a hundred studies, twenty-three of them epidemiological. Eleven of these twenty-three studies were concerned with the effects of occupational exposure to noise, while twelve studies looked at the effects of exposure to noise in the domestic environment. In eight of these studies (three of which focused on exposure to road traffic noise and five on exposure to aviation noise), stress hormone levels were determined by analysing urine samples collected during and after sleep, or saliva samples collected after the subjects had woken up. These eight studies are considered below.

The eleven field studies mentioned in the RIVM report⁶⁹ and the eight field studies referred to in Babisch's article⁸¹ were concerned almost exclusively with road and air traffic noise; just one of the studies looked at both road and rail traffic. No similar studies into the effects of stationary noise sources were traced. In the following subsections, first the results of the field studies of road traffic noise are dealt with, then the field studies of aviation noise, and finally the one field study of rail traffic noise. The subsection on aviation noise field studies also takes account of data from one quasi-field study.

This section concludes with an inventory of (laboratory) studies into the influence of night-time noise on the immunological properties of blood cells.

D.3.2 Road traffic noise

The eleven field studies referred to in the RIVM report⁶⁹ were as follows:

- 1 Four very small studies. These studies involved very small numbers of subjects and subject-nights (three, six, seven, and twelve people) and do not lend themselves to generalisation. They are not therefore considered further here^{129,164-166}.
- 2 Research from the USA⁴⁹. This research into the effects of aviation noise included only a control group that was exposed to road traffic noise. The report does not include any aggregated single-night data relating to this group.
- 3 Four European studies conducted around 1980 in the Netherlands, Germany, France and the UK on behalf of the European Commission^{58,59,70-73}.
- 4 Research carried out in Germany^{77,78}. This is the same research referred to in D.2.4, into the differences between the effects of night-time exposure to road traffic noise and rail traffic noise.
- 5 Research undertaken in Sweden by Öhrström⁷⁴, which monitored effects purely on the basis of journal entries.

The four European studies mentioned in list item 3 were intervention studies, in which road traffic-related noise exposure was reduced by approximately 10 dB(A) by various means: double glazing of bedroom windows, gap sealing, use of personal hearing protection, and temporary bedroom relocation to the quiet side of the house^{58,59,70-73}. The four studies involved a total of seventy subjects and 922 subject-nights. Jurriëns drew the following conclusions regarding the effects observed in relatively noisy situations (compared with quieter situations):

- The average duration of REM sleep is 6.5 minutes shorter
- In reaction time tests, the average reaction time is twelve milliseconds (12 ms) longer than the overall average reaction time of 350 ms, and more mistakes are made (8 per cent)
- Self-reported quality of sleep is less (7 per cent)
- The W (waking) time recorded by EEG is 7 minutes longer (determined in two of the four studies)
- The average heart rate when sleeping is higher. In the Dutch research, the rate was 3.2 beats per minute higher (71.5 bpm, compared with 68.3 bpm)⁵⁸.

In the German research referred to in list item 4^{77,78}, 188 subjects were exposed mainly to road traffic noise and a similar number mainly to noise from passing trains. The num-

ber of subject-nights with usable data on motility was 1710 in the road traffic group. A recent analysis⁷⁹ of the data indicated that, among people exposed to road traffic noise, average motility for a single sleep period increased as the equivalent indoor or outdoor traffic sound pressure level was higher during the period in question.

The research by Öhrström referred to in list item 5⁷⁴ involved 106 subjects. Analysis of their journal entries revealed the following: 37 per cent of subjects in noisy environments had difficulty getting to sleep, compared with 8 per cent in quiet environments; the percentages of subjects in the two types of environment who were woken in the night by road traffic noise were 57 per cent and 4 per cent; average sleep quality, as rated on an eleven-point scale (where 0 equals very poor and 10 equals very good) was 6.2 for the noisy environments and 8.2 for the quiet ones; morning fatigue/alertness scores, as rated on an eleven-point scale (where 0 equals very tired and 10 equals not at all tired) were 5.0 and 7.0; the average scores for morning irritability, as rated on an eleven-point scale (where 0 equals very irritable and 10 equals not at all irritable) were 6.5 and 7.8. In other words, all parameters values were less favourable in the noisy situation.

Swedish researcher Öhrström recently made a longitudinal study of the change in noise-induced effects on sleep following realisation of a scheme designed to reduce road traffic noise by the enclosure of a road in a tunnel. The report on elements of the study⁷⁵ will shortly be followed by two publications in *J Sound Vib*^{**}. The forthcoming data will show that the study was modest in scale: at each of two locations (one noisy, one quieter), thirteen subjects were monitored on each of three occasions, once before and twice after completion of the tunnel, which has reduced indoor noise by 10 dB(A) at the noisy location. Within the exposed group, no statistically significant change was detected in various parameters monitored before and after completion of the tunnel, the parameters in question being average motility, minutes spent in bed, sleep inception period, sleep duration, number of 'awakenings', and number of waking intervals of more than five minutes. Not surprisingly, in view of the small number of subjects, there is considerable variation in the average values; notably, there was an increase in the values of various parameters – i.e. a deterioration – in the third monitoring round, a year after completion of the tunnel, relative to the values measured in the second phase.

At the ICBEN2003 Congress, Öhrström presented a provisional report on those results from the international RANCH study that related to night-time noise. The subjects were seventy-nine children between the ages of nine and twelve, plus one parent of each child⁷⁶. The equivalent sound pressure level of the road traffic over a twenty-four-hour period, as determined on the outside of the most heavily exposed wall, varied from less than 55 to more than 64 dB(A). The sleep parameters monitored were sleep quality

* Öhrström, personal communication.

(overall quality, as established by questionnaire, and nightly quality, as recorded in a journal), sleep inception period and average motility. Although marked differences were observed between the parameter changes in children and those in their parents, the changes did not appear to be dependent on the noise exposure.

Table 16 summarises data from the three field studies^{82,152-154} referred to by Babisch⁸¹, which sought to establish the effects of noise on hormone concentrations, as determined from urine samples collected over the course of a night or blood samples collected after awakening. Strictly speaking, the results do not show whether the observed changes are the result of exposure to road traffic noise during the night in question, or (at least partly) the result of exposure the previous day, or the result of chronic daytime or night-time exposure.

Table 16 Summary of data from the three field studies referred to by Babisch⁸¹, which sought to establish the effects of noise on hormone concentrations^a.

Publication	Outdoor noise exposure (<i>L_{Aeq}</i> in dB(A))	Subjects	Adrenaline	Noradrenaline	Cortisol	Monitoring method
Babisch, 2001 ⁸²	45-75, during the night	234 women	=	+	x	Urine collection during the night
Evans, 2001 ¹⁵³	Less than 50 or more than 60 over the twenty-four-hour period	115 children	=	=	+	Urine collection during the night
Ising, 2002 ¹⁵⁴	L _{max} = 40 or L _{max} = 66 dB(C) over the twenty-four-hour period	56 children	x	x	+	Urine collection during the night

^a Relative effect at higher noise exposure: + statistically significant change in the anticipated direction, = no significant change in the anticipated direction, x not monitored.

Working at the Berlin Environmental Department, Babisch *et al* studied the effect of road traffic noise on the excretion of adrenaline and noradrenaline in the night-time urine of 234 women (thirty to forty-five years old)⁸², some of whom lived in homes with the bedroom on the street side, and some in homes with the living room on the street side. The volume of passing road traffic varied considerably from dwelling to dwelling. The analyses took account of numerous distorting variables. Among the women with bedrooms on the street side, a statistically significant increase was observed in noradrenaline levels as the logarithm of the traffic volume rose. (The logarithm of the traffic volume is approximately proportional to the equivalent sound pressure level.) Changes in adrenaline level were not associated with changes in traffic volume, however. Among women with the living room on the street side, no effect was observed on either adrenaline or noradrenaline levels. The fact that it was mainly noradrenaline concentrations that were raised is consistent with Ising's model, which predicts that the noradrenaline

concentration is particularly likely to increase in response to noises to which a person is exposed for a long time⁸³. The effect of road traffic noise on noradrenaline concentration was particularly pronounced in women who indicated that they slept with the bedroom window closed to prevent their sleep being disturbed by road traffic noise, and nevertheless experienced noise-related annoyance. Among women who experienced no noise-related annoyance when their windows were closed, no statistically significant increase in noradrenaline concentrations was observed. The researchers explain these findings as the result of a coping mechanism: among women who are able to prevent noise-related sleep disturbance by closing their windows, noradrenaline levels are not affected, but among women who are not able to cope in this way, they rise. If a raised noradrenaline level may be regarded as predictive of cardiovascular problems, the authors argue that only those people who are highly sleep disturbed due to environmental noise and are not able to take corrective action are at increased risk of developing cardiovascular problems. However, the research results do not exclude the possibility that the observed effect is a reversible change.

Evans and Lercher studied 115 children around the age of seven who were exposed to road and rail traffic in Austria^{153,155}. Half of the children lived in an environment with relatively little road and rail traffic noise (*Lden* less than 50 dB(A), average 46 dB(A)), while the other half lived in an environment where noise levels were typically more than 60 dB(A) (average 62 dB(A)). The researchers compared various endocrine and cardiovascular functions: daytime diastolic and systolic blood pressure and heart rate, plus adrenaline, noradrenaline, cortisol and 20A-dihydrocortisol levels, as determined from urine samples collected in the course of the night. A statistically significant difference of more than 25 per cent was observed between the cortisol and 20A-dihydrocortisol concentrations of the two groups. In a test that involved asking the children to solve impossible puzzles, girls exposed to higher noise exposures performed less well than girls in the low-exposure group.

D.3.3 Aviation noise

D.3.3.1 Field research

Table 17 summarises the findings of Babisch's review⁸¹ of research into aviation noise-related changes in hormone levels over the course of a night.

Table 17 The findings of research^{156-159,162,163} into changes and differences^a in stress hormone levels, as reviewed by Babisch⁸¹.

Publication	Noise exposure (<i>L_{Aeq}</i> in dB(A))	Subjects	Adrenaline	Noradrenaline	Cortisol	Monitoring technique
Evans, 1995 ¹⁵⁶	59-65 24 hours	135 children	+	+	=	Urine collection during the night
Evans, 1998 ¹⁵⁷	53-62 24 hours	217 children	+	+	=	Urine collection during the night
Ising, 1999 ¹⁶³	56-70 over the day	40 children	=	=	=	Urine collection during the night
Haines, 2001 ^{158,159}	53-62 24 hours	204 children	=	=	=	Urine collection during the night
Stansfeld, 2001 ¹⁶²	<57->66 over the day	238 children	x	x	=	Saliva collected in the morning

^a Relative effect at higher noise exposure: + statistically significant increase, = no significant change, x not monitored.

The Bristol-based team of Smith *et al*⁸⁰ made a phased investigation of the interrelationships between aviation noise, sleep disturbance and health.

In the final phase, the motility of ninety people (forty-five couples) was monitored using actimeters for three nights, during which sound pressure levels were measured in the subjects' bedrooms. The sources of the noises audible in the subjects' bedrooms were not determined using an external identification system, nor were any outdoor sound pressure levels measured. Noise events were divided into two groups: prolonged noise events (more than one minute above the background level) and brief noise events (less than one minute above the background level, with an equivalent sound pressure level of more than 50 dB(A) over at least one five-second interval). The number of brief noise events averaged 8.2 per night (with an average *SEL_i* of 59 dB(A)), and the number of prolonged noise events averaged 6.4 per night (with an average *SEL_i* of 65 dB(A)). No association was found between noise exposure and actimetric activity. The researchers suggested that this was due to the low noise exposures that subjects were exposed to, even though there was considerable inter-individual variation in exposure values. The team reported having nevertheless observed statistically significant associations between noise exposure and motility among subjects on board a ship. The observed associations were:

- between the *number of* noise events and an index of sleep disturbance derived from several variables;
- between higher sound pressure levels during the sleep latency period and difficulty getting to sleep; and
- between higher sound pressure levels towards the end of a subject's sleeping time and premature awakening.

However, because the sources of the noises were not identified, the researchers could not exclude the possibility that the increased disturbance levels were related to the subjects' waking activities and were not therefore the effects of noise on sleeping patterns.

Passchier-Vermeer¹² identified four functions that she considered indicative of the effect of aviation noise over the course of a sleep period. The functions in question (see Figure 23) were:

- High average motility during sleep. This was quantified as follows. The data was analysed to calculate a level of motility as a function of age, which was exceeded by 5 per cent of subjects when not exposed to aviation noise when sleeping. A figure was then worked out for the percentage of subjects who on a given research night exhibited higher average motility than the 'normal' value for their age; the percentage of people who would exceed the normal motility value in the absence of aviation noise (approximately 5 per cent) was then deducted from the percentage for the night. The analysis revealed that average motility increased with rising night-time noise exposure, but this is not illustrated in Figure 23.
- Recalled awakening. In the journal that they were asked to write each morning, subjects indicated whether they had been woken by aviation noise in the night.
- Subject-registered awakening at least three times a night. Awakenings were recorded by the subject pressing a button on his or her actimeter.
- Use of somnifacient drugs. In their journals, subjects indicated each morning whether they had taken any sleeping pills the night before. The use of somnifacient drugs proved to be strongly age-related. Up to the age of about sixty, the use of somnifacient drugs was quite modest; above that age, use increased sharply with rising exposure to aviation noise.

Figure 23 shows night-time noise exposures in the form of *Lnight* values. The noise exposure was originally expressed as the equivalent sound pressure level during the sleep period. However, the equivalent sound pressure level data was converted to *Lnight* values on the basis of what is known about the relationship between equivalent sound pressure and *Lnight*. Because some effects are age-related, Figure 23 is based on the age profile of the adult Dutch population.

D.3.3.2 Quasi-field research

A research team at Berlin's Robert Koch Institute performed a quasi-field study with sixteen subjects living in the vicinity of Fuhlsbüttel Airport near Hamburg. The study involved observation of the effects induced by aviation noise reproduced in subjects' bedrooms using loudspeakers^{47,150}. There were almost no night flights into or out of the

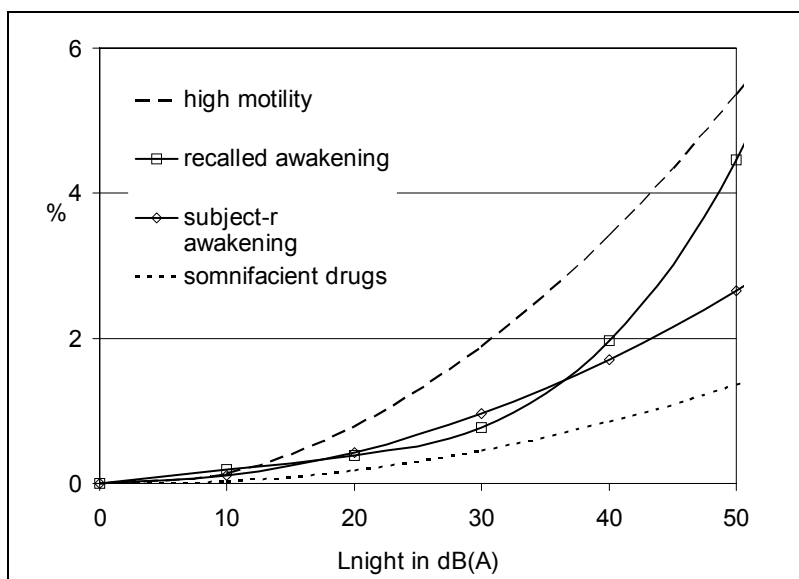


Figure 23 Prevalence of four effects of aviation noise, as a function of L_{night} . The prevalence values express the following percentages, as attributable to exposure to aviation noise: percentage of people exhibiting high motility levels for their age, percentage of people who recalled being awoken by aviation noise, percentage of people who registered awakening at least three times in a night, and percentage of people who recorded using somnifacient drugs¹².

airport, so at the start of the study the subjects were unused to night-time aviation noise. After two nights without the introduction of any artificial noise, the subjects were exposed to recorded aviation noise with an L_{Amax_i} of 65 dB(A) thirty-two times a night for thirty-eight nights. During and immediately after each sleep period, urine samples were collected and the total amount of cortisol present was determined. The researchers distinguished three adaptation patterns over the thirty-eight nights: total cortisol almost stable (observed mainly in female subjects); a large initial rise in total cortisol to a peak on the third night of exposure, followed by a gradual decline for the remainder of the study period; an initial decline in total cortisol, followed by a large peak on the third night of exposure, followed by a gradual increase for the remainder of the study period. With all three patterns, there were fluctuations in the course of the week, which were more pronounced in men than in women.

It is particularly interesting to note how the well-being scores recorded each day using a questionnaire changed over the study period. The scores were given using a scale, designed so that the average for the general population is zero, and 95 per cent of recorded values are between -3 and $+3$. Before the recorded aviation noise was introduced, in each of the three subsequent adaptation pattern groups the average well-being score was approximately 0.5 (i.e. a little better than normal for the population as a

whole). In the stable cortisol group, well-being during the first fourteen days of the study fell from 0.5 to zero, where it remained. In both the other groups, well-being scores continued to fall, from 0.5 to -1 in the increasing cortisol group and from 0.5 to -2.5 in the declining cortisol group.

D.3.4 *Field research rail traffic noise*

In the above-mentioned German research^{77,78} 188 subjects were exposed mainly to noise from passing trains. The number of subject-nights characterised by motility was 1581. A recent analysis⁷⁹ of the data indicated that, among people exposed to *rail traffic noise*, average motility for a single sleep period was unrelated to the equivalent indoor or outdoor traffic sound pressure level during the period in question.

Evans¹⁵³ reported that the noise measurements included not only the road traffic noise exposure experienced by children, but also the train noise exposure. Although the article does not indicate the breakdown between road and rail traffic noise, it seems reasonable to assume that road traffic noise was predominant.

D.3.5 *Laboratory research into changes in immunological parameters*

Between 1968 and 1974, Osada *et al*⁸⁴⁻⁸⁷ investigated the relationship between exposure to noise and changes in the *number* of cells in the blood with roles in the body's immune functions. They performed four laboratory experiments with twenty-one subjects, in which they monitored changes in leukocyte and (eosinophilic and basophilic) granulocyte levels in the blood associated with exposure to various types of noise (road, air and rail traffic noise, industrial noise, white noise and pink noise). When data from noise exposure nights was compared with data from non-exposure nights, major differences were observed in the average values and wide distributions around the average changes. However, shortcomings have subsequently been highlighted in the study design^{**}, which almost certainly explains the observed changes.

In their survey article *The Neuroendocrine Recovery Function of Sleep*, Born and Fehm devoted a section to the possibility that night-time exposure to noise might affect the immune system⁸⁸. In two experiments, subjects were either deprived of sleep or allowed to sleep 'normally', then certain blood cells (monocytes) were examined to determine whether they exhibited an immune response to a particular stimulus (production of interleukin-1 and TNF- α (tumour necrosis factor α), which affect the production of T-cells, which in turn are important for the production of interleukin-2). Contrary to what had been expected, the immune response of the monocytes was much stronger

* Marth, personal communication.

after a sleepless night than after an ordinary night. On the other hand, there were far fewer monocytes present in the blood after a sleepless night, and production of interleukin-2 by T-cells was much more vigorous after a normal night than after a night of sleep deprivation. On the basis of their findings, the two authors postulate that night-time noise exposure may have a negative influence on the immune system. They add, however, that a great deal more research would be necessary to confirm such a hypothesis.

D.4 Effects on health and well-being

The first two subsections below (D.4.1 and D.4.2) deal with research into the association between chronic exposure to *traffic noise* and medical conditions, sleep quality and well-being. Subsection D.4.3 is concerned with data on (the effects of) *noise from neighbours* and the associated topic of acoustic insulation between dwellings. Finally, subsection D.4.4 described a Dutch inventory study of traffic noise, industrial noise, neighbourhood noise and noise from neighbours.

D.4.1 Medical conditions

D.4.1.1 Insomnia

A group of Japanese researchers carried out a questionnaire-based survey of 3600 adult Japanese women (aged between twenty and eighty) living on eight study sites to gather information about the factors that contribute to insomnia⁸⁹. Some 11 per cent of subjects were found to be affected by insomnia. (The researchers adopted a definition of insomnia based on the *ICD-10 classification of mental and behavioral disorders: clinical description and diagnostic guidelines*⁹⁰.) One of the factors whose relationship with insomnia was investigated was the volume of traffic on the road where the subject lived. It was found that a high traffic volume (a nightly average of more than two thousand vehicles per hour, with a lorry counting as ten vehicles) was an insomnia risk factor. Women living on busy roads were considerably more likely to suffer from insomnia than the other women. Analysis of the survey data took account of various distorting variables, such as age, number of (small) children in the family, social status, receipt of medical treatment, regularity of bedtimes, apnoea-like problems and serious unpleasant experiences in the six months prior to completing the questionnaire. When the percentage of insomniacs in each of the three areas with the highest exposures was compared with the percentage in the low-exposure areas, the ratios worked out at, respectively, 1.4 (2100 vehicles per hour, *L*_{night} of around 65 dB(A)), 2.1 (2400 vehicles per hour,

Lnight of around 67 dB(A)) and 2.8 (6000 vehicles per hour, *Lnight* of around 70 dB(A)). The most frequently reported problem was difficulty getting to sleep.

D.4.1.2 Health diminution

A research team at Berlin's Robert-Koch Institute produced a 400-page report on the findings of the Spandauer Gesundheits Survey⁹⁵: a longitudinal study, in the context of which the health of adults in Berlin's Spandau district has been surveyed every two years since 1982. The ninth survey round involved 2015 subjects, of whom 1714 were participating for at least the fifth time. In addition to going through the usual tests and questionnaires, these subjects were asked about noise-related annoyance from road, rail and air traffic, as well as from industrial sources. Noise maps were also produced showing the road traffic-related noise exposure on the homes of the 1718 people subjects who chose to complete the questionnaire on noise-related annoyance. The research into the effects of traffic noise was therefore essentially a cross-sectional cohort study. Furthermore, outdoor sound pressure levels were measured in front of ninety-six homes. However, it was not possible to take recent aircraft noise exposures into account. Most aircraft flying over the area were going to or from Tegel Airfield, which is closed at night (from 10pm for takeoffs and 11pm for landings, to 5am for both takeoffs and landings).

The analyses took account of twelve variables with the potential to distort the results. The presence and treatment of illnesses and medical conditions in the two years since the previous survey round (period prevalence), and in the research period as a whole (total prevalence) were investigated. The probability of a subject receiving medical treatment for a given illness or condition was determined for subjects whose road traffic-related *Lnight* was less than 50 dB(A) and expressed as an odds ratio (OR); in addition, 95 per cent confidence intervals (CIs) were stated in the report. The statistically significant results for subjects with a road traffic-related *Lnight* of more than 55 dB(A) were as follows:

- *Treatment for hypertension*: OR = 1.9 (CI = 1.1 – 3.2) (period prevalence)
- Treatment for hypertension if bedroom window was normally open: OR = 6.1 (CI = 1.3 – 29.2) (period prevalence)
- *Treatment for hypertension*: OR = 1.8 (CI = 1.1 – 2.9) (total prevalence)
- *Asthmatic bronchitis*: OR = 1.5 (CI = 0.9 – 2.5) (total prevalence)

With regard to people who were annoyed by road traffic noise, the following statistically significant association was found with daytime road traffic noise:

- *Treatment for psychological problems*: OR = 2.7 (CI = 1.3 – 5.6) (period prevalence)

Comparison of people exposed to a high exposure of aviation noise over a twenty-four-hour period with people exposed to a lower exposure revealed the following statistically significant association:

- *Treatment for thyroid problems*: OR = 3.8 (CI = 1.3 – 11.3) (period prevalence)

The researchers warn that their findings regarding non-cardiovascular illnesses and medical conditions (asthmatic bronchitis, thyroid problems) are potentially liable to distortion by variables other than the twelve that have been taken into account. Hence, the only conclusion that may be drawn regarding medical conditions is that, within the studied population, night-time exposure to road traffic noise is associated with treatment for hypertension.

The researchers also point out that the study population was made up largely of people who were very conscious of their health. If this population was more or less than averagely prone to hypertension, or inclined towards a lifestyle that increased or decreased the probability of hypertension, the association between hypertension and night-time noise exposure might not be reflective of the population at large.

Where the above-mentioned findings regarding hypertension and night-time road traffic noise were concerned, the OR for people exposed to a noise exposure of between 50 and 55 dB(A) was calculated to be between 1.0 and the PR given in the summary for road traffic noise exposures of more than 55 dB(A).

The researchers were not surprised to find that hypertension was demonstrably associated with night-time noise, but not with daytime noise, partly because people are often elsewhere during the day and partly because people are more sensitive to noise at night than during the day.

A methodological assessment of the research is made in the main body of this report.

D.4.2 *Sleep quality and well-being*

D.4.2.1 Increased motility

The British field study into the effect of aviation noise on sleep found that, over a sleep period, average motility and motility onset increased with rising exposure to aviation noise⁹⁶. Horne reported that there was a strong inverse relationship between average motility and perceived quality of sleep. The Dutch field study into the effect of aviation noise on sleep and the German study regarding the effect of road traffic noise also found that average motility increased with noise exposure when sleeping^{12,13}. The researchers found that average motility over the course of a night was strongly associated with the number of times that a subject recalled waking during his/her sleeping time, with the

number of times that a subject registered awakening during his/her sleeping time, and with the following variables regarding which subjects provided information by completing a questionnaire at the beginning of the study: number of medicines used, sleep quality, number of sleeping problems, frequency of aviation noise-induced awakening, weekly frequency of aviation noise-induced adverse effects on sleep, and number of health problems. The secondary analysis of the German research into road and rail traffic noise (involving 1710 subject-nights characterised by motility in the road traffic subject group and 1581 such subject-nights in the rail traffic group) also indicated that average motility increased with rising road traffic noise exposure⁷⁹. Exposure to rail traffic noise had no demonstrable effect on average motility. Where both aviation noise and road traffic noise were concerned, the increase in motility with *Li* (the equivalent sound pressure level during sleeping time over an extended period) was much greater than would have been expected solely on the basis of the increase in the probability of noise-induced acute motility. The average increase in motility per dB(A) increase in noise exposure appeared to be between 1.3 and 1.5 times greater for road traffic noise than for aviation noise⁷⁹.

In the first main phase of a British study of aviation noise, sleep disturbance and health conducted by Smith *et al*⁸⁰, 543 subjects from Bristol were asked to answer a questionnaire. Due to lack of information about the noise exposure experienced by respondents, their subjective perceptions of the problems they had experienced getting to sleep were used to estimate levels of exposure to aviation noise when sleeping. Questions were posed regarding health (based on the abbreviated version of the General Health Questionnaire), self-reported health, sensitivity to noise, sleep disturbance and negative affectivity (utilising the Neuroticism Scale in Eysenck's Personality Inventory). Significant health differences and differences in sleep disturbance experience were detected between the subjectively defined high-exposure and low-exposure groups. However, once adjustment was made for the influence of age and degree of neuroticism on health and sleep disturbance, no statistically significant difference was found to exist between the two groups.

In a follow-up survey, some of the respondents from the first main phase completed a further questionnaire. When the findings from the second questionnaire were compared with information regarding the same subjects gathered from the first questionnaire, it was found that diminished health, increased sleep disturbance and increased sensitivity to noise were all associated with an increase between the survey dates in the noise exposure perceived by the respondents. However, no link was found between change in sleep disturbance and change in health. The researchers explained the findings of the follow-up study as follows. If the original effect measured during the first main phase is eliminated (by concentrating on the differences) and there is little situational

change between the time of the first survey and the time of the second, (minor) changes will not be correlated.

A further survey with an improved design was subsequently carried out. For this survey, a number of locations in the vicinity of four airports were selected, some with a relatively high aviation noise exposure, and some with a lower exposure. A total of 1121 subjects were questioned orally and a further 658 subjects completed a written postal questionnaire. Differences between the higher exposure and lower-exposure subjects were detected in relation to the following parameters: perceived level of aviation noise when trying to get to sleep, sleep disturbance, physical health and well-being, particularly in terms of irritability, anxiety, depression and sadness. Even after making allowance for other variables, sleep disturbance and health remained closely related. From their findings, the researchers concluded that they were unable to demonstrate a causal relationship between sleep disturbance and health. They added that it was also possible that sleep disturbance was symptomatic of poor health.

D.4.2.2 Self-reported sleep disturbance, self-reported sleep quality diminution, and other self-reported effects of exposure to noise

On the basis of TNO's Disturbance Knowledge Base, exposure-response relationships have been defined for self-reported sleep disturbance by road, rail and air traffic^{97,98} for use in an EU position paper. The main body of this report gives details of the relationships involving self-reported high sleep disturbance and includes a discussion of the findings.

The RIVM produced a report⁶⁹ which considered the question of whether a quantitative meta-analysis could be made of the results of research into the influence of road traffic noise on perceived sleep quality and difficulty staying asleep. Although the RIVM described several studies as being good quality, the researchers decided that it was not possible to perform a meta-analysis because of discrepancies in the studies' nomenclature, methods, exposure determination techniques and approaches to adjustment for distorting variables. Nevertheless, the Dutch researchers were of the opinion that there were qualitative indications that road traffic noise was associated with diminished perceived sleep quality and more difficulty staying asleep.

At the ICBEN2003 congress, the Dutch researcher Vos presented data from a questionnaire-based study of effects of gunshot noise on sleep¹¹¹. Some of the findings are illustrated in Figure 24. The graph shows the percentage of people who indicated they were woken by gunshot noise (as established in Germany by Buchta) as a function of the average *SEL* (in dB(C)) of the noise discernible in the domestic environment. Informa-

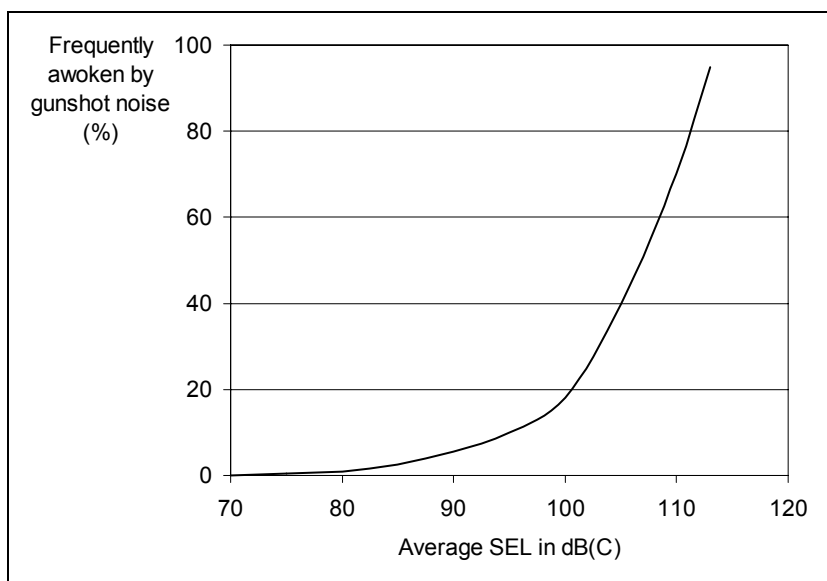


Figure 24 The percentage of people who in a questionnaire-based study indicated being frequently awakened by gunshot noise, as a function of the average *SEL* (in dB(C)) of the noise events¹¹¹.

tion about the number of noise events per night was not given, so it has not been possible to convert the data to *Lnight* values to enable comparison with the dose-response relationships for other noise sources. Vos was not (yet) able to make dose-response data other than that illustrated in Figure 24 available*.

D.4.2.3 Health problems

The Dutch field research into the effects of aviation noise on sleep established a relationship between personal noise exposure when sleeping (*Li*) and the frequency of health problems included on the abbreviated Health Perceptions Questionnaire^{12,13}. Compiled on the basis of stress research, the Health Perceptions Questionnaire identifies thirteen health-related problems, such as headache, stomach-ache, tiredness and digestive problems. It will be apparent that these are not life-threatening conditions. A rise in aviation noise-related *Li* from 0 to 35 dB(A) is associated with a two-fold increase in the frequency of problems. The researchers considered whether a causal relationship existed, or merely a relationship. The latter might be the case if, for example, people with health problems were liable to get up later and were therefore exposed to the higher high aircraft noise exposures that occur in the morning, resulting in relatively high *Li*

* Vos, personal communication.

values. However, analysis revealed that neither the moment of awakening nor any of the other possible sources of bias investigated by the team had any influence on the relationship between the frequency of health problems and *Li*.

D.4.2.4 Making official complaints about noise

The submission of a complaint about noise may be regarded as symptomatic of reduced well-being. Numerous factors influence a person's inclination in a given situation to make an 'official' complaint about a noise-related problem. These factors include not only the level of annoyance or inconvenience experienced, but also to some extent whether the person knows who to complain to, how easy it is to make a complaint, whether the person believes his/her complaint is likely to be acted upon, and if it is known or suspected that other people are also making complaints. In the Netherlands, people who have experienced problems caused by the noise from aircraft on their way to or from Amsterdam's Schiphol Airport used to be able to complain to the Problem Desk at the Schiphol Airport Committee on Noise-Related Annoyance (now superseded by the Problem Desk at Cros, the Schiphol Airport Liaison Body). The RIVM performed an analysis of complaints to the Problem Desk^{180,181} and linked the data to the findings of a questionnaire-based study¹⁸². Figure 25 illustrates the position between 1986 and 2001, showing the number of problems, the number of complainants and the number of aircraft movements. Approximately 15 per cent of problems were found to relate to noise during the night (11pm to 7am). From the data in Figure 25, it is also apparent that some people complain repeatedly in the course of a year; in 2001, for example, the average number of problems per complainant was thirty-seven.

The number of problems per thousand aircraft movements was 680 in 1997 and 410 in 2001. In 2003, the so-called 'Polder Runway' came into use, despite considerable opposition from people living near the airport. Provisional figures indicate that the number of problems in 2003 was double the number reported the previous year.

Approximately 15 per cent of all problems involved noise during the night (11pm to 7am). Night flights (11pm to 6am) accounted for 4 per cent of the total number of flights, and it is estimated that the number of aircraft movements occurring between 11pm and 7am was 8 per cent of the total¹⁸³. It follows that night flights were linked to approximately twice as many problems as flights during the day and evening, even though the noisiest aircraft are not allowed to take off at night, so that night flights should on average be a little quieter than flights during the day and evening.

In Figure 26, the prevalence of problems is shown as a function of *Lden*. Notably, problems are less prevalent at the highest noise exposure than at a noise exposure of 61 to 62 dB(A). The researchers attribute this to the extra acoustic insulation fitted to homes in the most heavily exposed areas. Below an *Lden* of 50 dB(A), hardly any

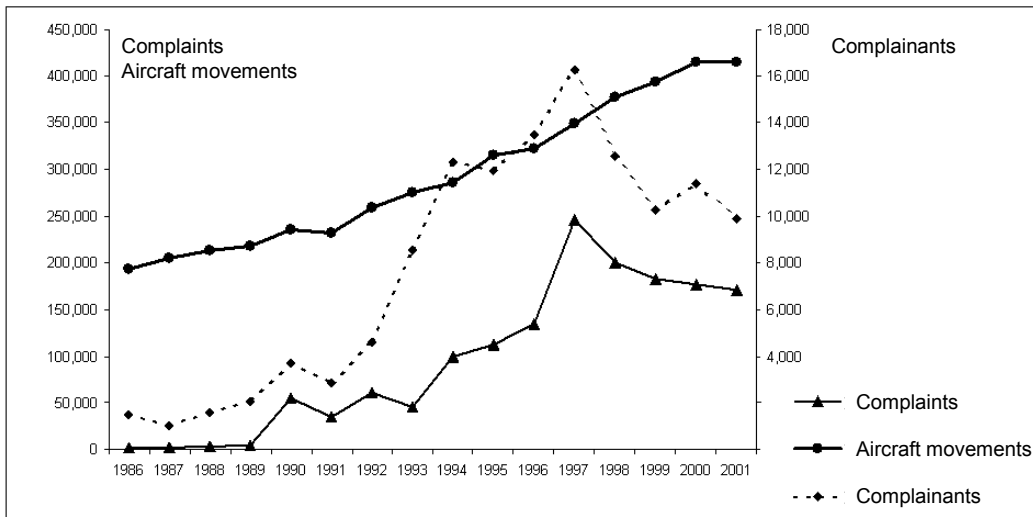


Figure 25 The number of people complaining about flights into and out of Schiphol Airport and the number of problems complained about, together with the number of aircraft movements between 1986 and 2001^{180,181}.

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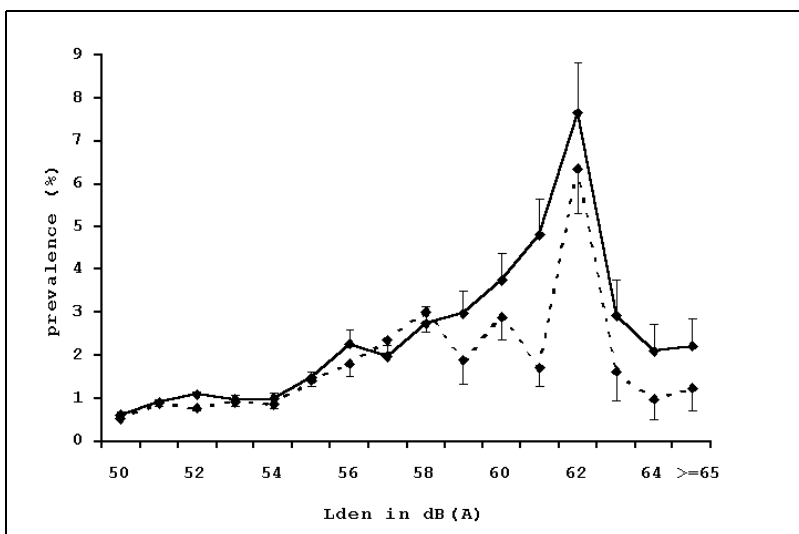


Figure 26 Prevalence of problems relating to particular flights into and out of Schiphol Airport in 1998 (solid line) and 1999 (dotted line), with an estimate of the uncertainty regarding the measurement points (half 95% prediction intervals), as a function of L_{den} ^{180,181}.

omes have extra insulation; at an exposure of less than 60 dB(A), 20 per cent of homes have better insulation; at 61 and 62 dB(A), the figure rises to approximately 55 and 70 per cent, and from 63 dB(A), approximately 90 per cent of homes are well insulated.

A questionnaire-based study¹⁸² has shown that the inclination to complain about aviation noise is linked to levels of annoyance, sleep disturbance, health worries and worry about air crashes.

DCMR runs a problem desk for people in the Rijnmond area who are experiencing problems due to environmental noise associated with industrial activities, road, rail and air traffic, etc¹⁸⁴. Data on the complaints received in 2003 is presented in Table 18.

A total of 8303 problems were reported, of which 1265 (15 per cent) related to noise during the night (midnight to 7am). The heading 'Other noise' covers low and high-frequency machinery noise from unknown sources. Air traffic was the biggest cause of problems during the day and over a twenty-four-hour period. Although there were no regular scheduled night flights into or out of Rotterdam Airport, night-time aviation noise accounted for 25 per cent of all problems during the night. Industrial noise caused the fewest problems. It is interesting to note that relatively few complainants were concerned about (road and rail) traffic, but a lot of people complained about noise from events and bars, clubs and the like.

Table 18 Inventory of noise-related problems in the Rijnmond area reported to the DCMR Problem Desk in 2003¹⁸⁴.

	Number of problems per year			Percentage of problems		
	Day and evening: 7am to midnight	Night: midnight to 7am	Twenty-four-hour period	Day and evening: 7am to midnight	Night: midnight to 7am	Twenty-four-hour period
Traffic & transport	539	144	683	7,7	11,4	8,2
Air traffic	3423	316	3739	48,6	25,0	45,0
Industrial activities, etc	310	78	388	4,4	6,2	4,7
Bars, clubs, events, etc	892	342	1234	12,7	27,0	14,9
Other noise	1874	385	2259	26,6	30,4	27,2
Total	7038	1265	8303	100	100	100

D.4.3 Domestic acoustic insulation and influence on the effects of traffic noise

D.4.3.1 Domestic acoustic insulation

The Building Decree makes requirements regarding the sound attenuating characteristics of new homes and other noise-sensitive buildings¹⁴. For protection against industrial, road and rail traffic noise, each type of noise has to be limited to a twenty-four-hour value of 55 dB(A). This implies an outdoor night-time equivalent sound pressure

level of no more than 45 dB(A). If the characteristic attenuation provided by the building's outside wall is 20 dB(A), in relation to the spectrum of the noise source in question, this equates to an *L_{night_i}* value of no more than 25 dB(A). If the outdoor twenty-four-hour value is higher than 55 dB(A), more stringent requirements apply. For protection against air traffic noise, requirements are made regarding the sound attenuating characteristics of new homes and other noise-sensitive buildings exposed to aviation noise exposures of more than 35 Ke*. The characteristic attenuation required depends on the 'sensitivity class' of the building and on the noise exposure in Ke, but is always at least 27 dB(A)**.

D.4.3.2 The influence of additional acoustic insulation on the effects of traffic noise

In the Netherlands, there have only been a small number of isolated studies into the efficiency and effectiveness of acoustic insulation in the reduction of perceived road and aviation noise levels, or into people's views regarding such insulation¹¹⁴⁻¹¹⁹. Bitter *et al* looked at the effects of fitting additional acoustic insulation to flats beside busy motorways carrying 70,000 vehicles per twenty-four-hours in Dordrecht¹¹⁴ and Amsterdam¹¹⁵. In the Amsterdam study, 347 people completed an extensive questionnaire 2.5 years after extra insulation had been fitted to their homes to protect against road traffic noise (average additional attenuation 9 dB(A)). The questionnaire addressed matters such as the levels of noise-related annoyance being experienced at the time and previously experienced before the extra insulation was fitted. The findings confirmed that the insulation did reduce annoyance. Feedback regarding non-acoustic matters (humidity, ventilation and ease of cleaning) indicated dissatisfaction with the new insulation, however. Respondents were also asked about annoyance at different times during the twenty-four-hour period. The findings are illustrated in Figure 27. *

From Figure 27, it is clear that, while night-time noise-related annoyance was reduced by the fitting of extra acoustic insulation, the final outcome is less than ideal. A similar picture emerged from the Dordrecht study¹¹⁴.

Van Dongen *et al*¹¹⁶ carried out an exploratory study into sleep quality in homes fitted with additional acoustic insulation in the vicinity of Amsterdam's Schiphol Airport. The team determined the relationships between the percentages of people 'sleep disturbed' and 'highly sleep disturbed' and the outdoor noise exposure; the data was then compared with the provisional relationships¹⁸⁵ at the time for homes without special

* Ke stands for 'Kosteneenheid' (Kosten Unit, named after the Committee with professor Kosten as president), the standard unit of air traffic noise exposure in the Netherlands until recently.

** The Building Decree also makes requirements regarding acoustic insulation to protect against noise from installations in the same or adjoining premises, regarding resonant sounds, and regarding inter-dwellings sound attenuation, expressed in terms of *Ilu;k*, *Ilu*, and *Ico*.

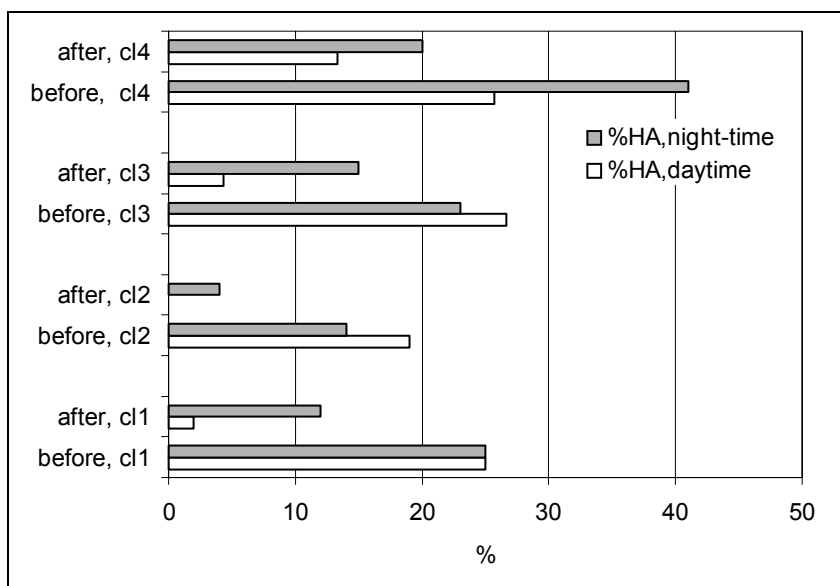


Figure 27 Percentage of people who, 2.5 years after the fitting of extra acoustic insulation to their homes, were highly annoyed by daytime and night-time noise at the time of questioning ('after') and prior to the fitting of extra acoustic insulation ('before'), attributable to four classes of noise (cl4 being the highest road traffic noise exposure, and cl1 the lowest).

insulation. From this comparison, it emerged that percentages sleep disturbed and highly sleep disturbed were slightly lower in the better-insulated dwellings than in 'ordinary' dwellings. However, the design of the study precluded the drawing of definitive conclusions.

Three reports were published between 1994 and 1999¹¹⁷⁻¹¹⁹ regarding people's general views concerning modifications made to homes near Schiphol with a view to reducing aircraft noise-related problems. In 1994, opinion was gauged regarding the additional insulation fitted in the first phase of the Schiphol Insulation Plan. The modifications were made before introduction of the Building Decree of 01-10-1992¹¹⁷. In 1996, a comparison was made between satisfaction with the insulation packages installed before the Building Decree, and satisfaction with the 'scaled down' packages installed since the Building Decree¹¹⁸. The third report recounted the proceedings of an experts' workshop at which the problems associated with the insulation plan were addressed with a view to framing more flexible rules regarding acoustic insulation options¹¹⁹. General feelings about acoustic insulation fitted before and after implementation of the 1992 Building Decree were broadly similar: 75 per cent of subjects felt the insulation was good, 20 per cent rated it moderate, and 5 per cent thought it was poor. Some 85 per cent of subjects reported that the insulation had reduced noise-related annoyance indoors. Nevertheless, people in more than 55 per cent of the homes contin-

ued to experience at least slight noise-related annoyance, and people in 15 per cent of the homes reported to be highly annoyed since the modifications were made. The distribution patterns of both overall and night-time levels of aircraft noise-related annoyance were clearly seasonal: on (cold) winter nights, 10 per cent of subjects often or always experienced annoyance during the sleep period, compared with 40 per cent on (warm) summer nights. The differences were closely related to the use of windows: only 25 per cent of respondents said they slept with the bedroom window at least slightly ajar in the winter, whereas 70 per cent did so in the summer.

Fidell and Silvati¹²⁰ investigated what effect the fitting of insulation to attenuate aviation noise had on levels of being annoyed and being highly annoyed. However, they did not look specifically at annoyance during the sleep period.

In the UK, an extensive study was done to establish how effective extra acoustic insulation was in reducing exposure to road traffic noise¹²¹. The average sound attenuation achieved was 34 dB(A). Subjects whose bedrooms were adjacent to busy roads experienced night-time noise exposures with an *Lnight* value of between 57 and 77 dB(A). In the specially insulated homes, 23 per cent of subjects whose bedrooms faced the street reported being very highly or highly annoyed by night-time road traffic noise; 25 per cent had difficulty getting to sleep because of the noise, and 30 per cent said they were woken up at night by road traffic noise. The results proved to be influenced to a considerable extent by whether the subject felt that, without the window open, his or her bedroom was too hot in the summer: 37 per cent of those who felt unable to sleep with the window closed in warm weather were very highly or highly annoyed by night-time road traffic noise, whereas only 15 per cent of those who didn't mind having the window closed experienced similar problems. Some 85 per cent of subjects who said their bedrooms were too hot in the summer felt it necessary to sleep with the window open.

In Japan¹²², people living in the vicinity of Kaneda Air Base and consequently exposed to very high night-time noise exposures caused by military jets were asked about the effectiveness of the additional acoustic insulation fitted to approximately 60 per cent of homes in the area, and about their satisfaction with the insulation. Scores for both effectiveness and satisfaction declined as noise exposures rose, from 80 and 60 per cent at a noise exposure with an estimated *Lden* of 65 dB(A), to 30 and 13 per cent at an estimated *Lden* of 85 dB(A). The seven investigated aspects of sleep disturbance (difficulty getting to sleep, waking up, difficulty getting to sleep after waking up, inconvenience caused by being woken too early in the morning, sense of having slept badly, and doubt about the prospects for a good following night's sleep) all proved to be related to outdoor noise exposure, but no difference was found between people living in specially insulated homes and people living in 'ordinary' homes. The researchers took the view that other forms of intervention, such as reducing night flying and switching to

alternative flight paths, were necessary to reduce the impact of noise on the sleep of people living in highly affected areas near the base.

D.4.4 *Inter-dwelling acoustic insulation and noise from neighbours*

D.4.4.1 Inter-dwelling acoustic insulation

The Building Decree makes requirements regarding the ability of new homes to attenuate sound from adjoining dwellings¹⁴. Sound attenuation between dwellings can be expressed using an index for the attenuation of airborne noise (I_{lu}); where account is taken of the volume of the reception room and the area of the common screening structure, it can be expressed using an index of characteristic sound attenuation ($I_{lu,k}$). The attenuation of contact noise between two dwellings is expressed using the contact noise index (I_{co}). For new homes, an airborne sound attenuation requirement ($I_{lu,k}$) of at least 0 dB applies. At an $I_{lu,k}$ of 0 dB, ordinary conversation in an adjoining home is audible, but incomprehensible. The quality of airborne sound attenuation is rated on a three-level scale:

- Minimum: $I_{lu,k}$ of 0 to +5 dB (normal conversation in an adjoining home is audible, but not comprehensible)
- Good: $I_{lu,k}$ of +5 to + 10 dB(A) (normal conversation in an adjoining home is not audible, the footsteps of a person in hard-soled shoes on a hard floor are readily audible and sometimes annoying)
- Very good: $I_{lu,k}$ greater than + 10 dB(A) (musical instruments, parties and the footsteps of a person in hard-soled shoes on a hard floor may be audible but are not annoying).

D.4.4.2 Noise from neighbours

Leidelmeijer and Marsman⁹⁹ published a report entitled *Geluid van buren: horen, hinderen sociale normen (Noise from Neighbours: Audibility, Annoyance and Social Norms)* regarding the findings of an interview-based study of 1242 households in the Netherlands, designed to shed light on the audibility of and annoyance associated with noise from neighbours during the day and at night. As a follow-up to the questionnaire, noise measurements were made in fifty homes. The researchers distinguished between five types of noise:

- Noise from sanitary and heating systems
 - Contact noise
 - Noise from audio equipment
 - DIY (Do-It-Yourself) noise
-

- Noise from pets.

Distinction was also made according to the part of the house where the noise was audible or caused annoyance. The results are summarised in Table 19. ‘Percentage for whom audible’ is the percentage of respondents who reported hearing the type of noise in question. ‘Percentage tolerant’ is the percentage of the respondents for whom the given noise was audible who did not report being annoyed by it.

Table 19 Percentage of survey respondents able to hear and tolerant of each of five types of noise (where ‘tolerant of’ means able to hear but not annoyed by, i.e. 100 - percentage of hearers reporting annoyance)⁹⁹.

Part of house	Sanitary and central heating systems		Contact noise		Noise from audio equipment		DIY noise		Pets	
	% for whom audible	% tolerant	% for whom audible	% tolerant	% for whom audible	% tolerant	% for whom audible	% tolerant	% for whom audible	% tolerant
Living room	18	80	37	86	35	85	15	67	12	88
Kitchen	12	93	16	87	12	91	8	80	5	88
Master bedroom	19	76	22	73	12	74	8	65	6	76
Other bedrooms	5	88	8	75	3	57	2	75	2	70
Bathroom	13	97	6	83	3	100	2	89	1	100
Other rooms	4	95	3	87	1	80	1	100	0	100
Landing/hall/stairs	9	80	8	100	5	100	2	100	2	100
Throughout house	10	91	14	71	5	73	28	89	8	86

Clearly, respondents were least tolerant of noise from their neighbours that was audible in the master bedroom. Subjects were also asked whether they considered it acceptable for the various noises to be audible by day, by evening or by night. Where each of the five investigated types of noise were concerned, roughly 10 to 15 per cent of subjects indicated that they felt it was unacceptable for the noise to be audible during the day (for pets, the figure was 20 per cent; DIY noise was rated unacceptable on weekdays by 5 per cent of respondents and on Sundays by 17 per cent; for noise from audio equipment, the figure was 15 per cent). In each case, a higher percentage said the noise should not be audible in the evening, and a still higher percentage did not want to hear the noise at night (between 11pm and 7am). Overall, nearly 30 per cent of subjects said that sanitary fittings should not be audible at night, while approximately 50 per cent felt each of the other four types of noise was unacceptable by night.

The researchers concluded that audible noise from neighbours was by no means always perceived to be annoying. Whether annoyance is caused depends on the timing, the part of the house where the noise is audible, the volume, whether the noise is expected, how often the noise is audible, the duration of the noise, whether the noise is considered avoidable, and the number of sources.

Subjects were also asked whether they could hear voices in neighbouring homes. While the percentage of affirmative answers varied according to the type of dwelling, ordinary speech was to some extent audible in an average of 35 per cent of dwellings, and partially or readily comprehensible in approximately 8 per cent of dwellings. Raised voices could be heard, at least some to extent, in approximately 65 per cent of dwellings; they were at least partially comprehensible in 27 per cent of homes and readily comprehensible in approximately 10 per cent.

The results of the acoustic insulation tests in fifty homes indicated no statistically significant relationship between the airborne and contact sound attenuation indexes and the audibility of (airborne) noise from neighbouring dwellings.

In 1993, Kranendonk *et al* produced a synthesis of the research conducted up to that point in time into the annoyance associated with noise from neighbours¹⁰⁰. Their synthesis covered four Dutch, one Swedish, one British and one French study. The various studies used a variety of effect indexes (annoyance scoring systems) and a variety of means of determining airborne and contact sound attenuation. Although it was, the researchers reported, difficult to assess all the data on the same basis, they were able to produce a table of synthesised findings (see Table 20). The average annoyance score was determined on a seven-point scale, where 7 equated to not annoyed and 1 to highly annoyed. As will be apparent from Table 20, an I_{lu} of zero corresponds to an average annoyance score of 5, to 10 per cent of people experiencing to be highly annoyed and to 25 per cent of people experiencing some annoyance.

Table 20 Acoustic performance of a dwelling (in terms of I_{lu} and I_{co}) and the corresponding average annoyance scores and percentages of people experiencing to be annoyed or highly annoyed¹⁰⁰.

I_{lu}	I_{co}	Average annoyance score	% people highly annoyed	% people annoyed (including highly annoyed)
-13	-5	3	50	75
-7	0	4	25	50
0	+6	5	10	25
+7	+11	6	2,5	10
+13	+17	7	0,5	2,5

TNO produced a report¹⁰¹ on the relationship between noise from neighbouring dwellings and the airborne and contact noise attenuating indices I_{lu} , $I_{lu,k}$, and I_{co} , drawing on data from a questionnaire-based survey of the residents of six hundred dwellings, whose acoustic quality was determined in 202 cases. It was established that nearly half of the respondents heard at least some noise from neighbouring dwellings every day. Approximately 10 per cent of subjects found their neighbours' noise highly annoying.

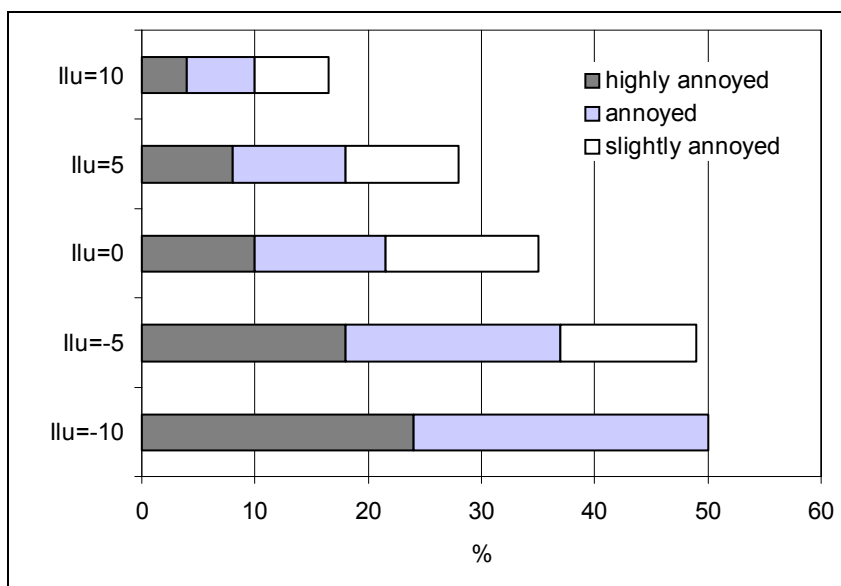


Figure 28 Percentages of subjects slightly annoyed, moderately annoyed and highly annoyed by noise from neighbouring dwellings¹⁰¹.

The chief causes of annoyance were loud radios, hi-fis and TVs, the slamming of doors and footsteps on floors and staircases. Nearly all respondents said that in their own behaviour they were considerate of their neighbours and 80 per cent regarded themselves very tolerant of noise from their neighbours.

No relationship was established between contact noise-related annoyance and I_{co} value. This was not considered surprising by the researchers, because there was not a great deal of spread in the contact noise index values of the dwellings.

The correlation between the percentages of people experiencing annoyance and I_{lu} value is illustrated in Figure 28.

The percentages of people identified by the team as experiencing being annoyed and highly annoyed at a given I_{lu} value are broadly in line with the findings of Kranendonk *et al*¹⁰⁰. At an I_{lu} of zero, the percentages are identical, while at higher and lower I_{lu} values there is a small difference.

D.4.5 Data from inventory studies

The national inventory study⁹ carried out in 1998 asked respondents to indicate the extent to which their sleep was disturbed by noise from various sources, by giving a number between 0 and 10, where 0 = not disturbed at all and 10 = very highly disturbed. A standardised method was then used to calculate the percentage of respondents reporting sleep disturbance and high sleep disturbance. This involved transforming the eleven-

point scale into a continuous scale from 0 to 100. Respondents who scored 50 or more on this scale were deemed to suffer from self-reported sleep disturbance, and those who scored 72 or more to suffer from high self-reported sleep disturbance. This implies that the number of respondents affected by sleep disturbance includes the number affected by high sleep disturbance.

Table 21 gives the percentage of respondents reporting sleep disturbance and high sleep disturbance due to each noise source. It is not possible to make comparisons between source groups by simply aggregating the source group percentages, because it is not reasonable to assume that the percentage of people affected by (high) sleep disturbance due to a particular group of sources is the sum of the percentages for the individual sources within that group. Where road, rail and air traffic is concerned, passenger cars, lorries and mopeds are the sources to which most sleep disturbance is attributable (affecting, respectively, 7, 6, and 10 per cent of respondents). Where neighbour noise and neighbourhood noise are concerned, the predominant sources are contact noise (footsteps on stairs, slamming of doors), radio, hi-fi & TV, and the noise from other human activities, which were referred to by, respectively, 8, 6, and 8 per cent of respondents. Sleep disturbance due to noise from air or rail traffic, or to industrial noise is (much) less common than sleep disturbance due to the above-mentioned sources.

Table 21 Noise-related sleep disturbance associated with sources of various types⁹.

Source group	Noise source	Percentage of respondents reporting sleep disturbance	Percentage of respondents reporting to be highly sleep disturbed
Road traffic	Passenger cars and taxis	7	2
	Delivery vans	3	1
	Lorries	6	3
	Buses	2	1
	Motor cycles and motocross cycles	5	2
	Mopeds	10	4
	Motor-assisted bicycles	4	2
	Military vehicles	0	0
Air traffic	Passenger and cargo aircraft	4	2
	Recreational, executive and advertising aircraft	0	0
	Military aircraft (other than helicopters)	2	1
	Helicopters	1	0
Rail traffic	Trains	2	1
	Trams	0	0
	Light rail vehicles	0	0

Shipping	Commercial shipping	0	0
	Pleasure craft	0	0
Commercial, industrial and professional activities	Retail areas	0	0
	Factories and business premises	1	0
	Loading/unloading sites, etc	1	1
	Lorry parks	1	0
	Shunting yards and rail yards	1	0
	Building and demolition sites	1	0
	Road building	1	0
	Agricultural tractors	1	0
	Civilian shooting ranges	0	0
	Military exercise areas, shooting ranges, etc	0	0
Recreational activities	Fairs, circuses, amusement parks, etc	3	1
	Discos, dance halls, etc	2	1
	Musical practice facilities	0	0
	Sports fields, stadiums, sports halls, swimming baths, tennis courts	1	0
	Racing, motocross and carting circuits	0	0
	Ultra-light aircraft	0	0
	Model aircraft	0	0
	Mass-participation open-air events	2	1
Noises from neighbouring dwellings	Noises from sanitary and heating systems	3	1
	Contact noise (footsteps on stairs, slamming of doors)	8	3
	Radio, hi-fi, TV	6	3
	DIY equipment	4	2
	Pets	5	2
Other noises in the residential environment	Neighbours gardening noises	1	0
	Noise from public spaces around one's home	1	0
	Noise from children playing outside	2	1
	Noise from street/public greenery maintenance	3	1
	Other human noises	8	3
	Noise from neighbours' pets/animals	5	2
	Church bells, mosques	3	2
	Bottle banks	1	0

In 2000, the Noord-Kennemerland Regional Health Authority carried out a written inventory study¹⁸⁶, in which 7728 people were invited to participate. The response rate was 68 per cent, meaning that approximately 5250 people completed the questionnaire. The subjects came from nine municipalities in the Noord-Kennemerland region (Akersloot, Alkmaar, Bergen, Egmond, Graft de Rijp, Heiloo, Limmen, Schermer and Schoorl). The questionnaire included a number of questions identical to those used for the national inventory study⁹. The levels of high sleep disturbance reported by the respondents are given in Table 22, along with the corresponding data from the national study (for comparison). The percentages of people reporting high sleep disturbance in Noord-Kennemerland are twice the corresponding national figures. Since no noise exposure data is available for Noord-Kennemerland, it is not possible to establish whether the high levels of disturbance are, at least to some extent, the result of noise exposures that are above the national averages. Data from 2000/2001 for the province of North Holland as a whole indicates that 6.3 per cent of homes in the province have an air traffic-related *Lnight* value of 40 dB(A) or higher, compared with 1.9 per cent nationwide¹⁵. Where noise from motorways, municipal roads and rail traffic is concerned, exposures in North Holland are close to the national averages. The correction of an RIVM report released on 24-05-2004 does not contain a provincial breakdown of urban road traffic levels (i.e. the largest source of noise exposure in the Netherlands)¹⁵, so it is not possible to determine how the noise exposure due to urban road traffic in North Holland compares with that in the country as a whole.

Table 22 Noise-related sleep disturbance in Noord-Kennemerland¹⁸⁶.

Source	Percentage of Noord-Kennemerland respondents reporting to be highly sleep disturbed	Percentage of national survey respondents reporting to be highly sleep disturbed
Mopeds	10	4
Noise from neighbours	7	3
Motor cycles	6	2
Lorries	5	3
Passenger cars	5	2
Aircraft	4	2
Other	3	

Sleep disorders and sleeping problems

In this annex, the Committee presents an overview of sleep disorders and sleeping problems. Particular attention is paid to insomnia, but other sleep disorders are also considered, albeit in less detail.

E.1 What is insomnia?

Insomnia can occur without being triggered by a particular illness or condition; such insomnia is known as primary insomnia. Secondary insomnia, on the other hand, is a consequence of some other illness or condition. Definitions of primary insomnia are given in the *ICD-10 classification of mental and behavioral disorders: clinical description and diagnostic guidelines* published by the WHO⁹⁰, in the *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV)* of the *American Psychiatric Association*¹⁸⁷, and in the *Beknopte handleiding bij de Diagnostische Criteria van de DSM-IV (Guidance Notes to Accompany the Diagnostic Criteria of the DSM-IV)* produced by the Netherlands Association for Psychiatry (NVvP)¹⁸⁸. In the latter publication, primary psycho-physiological insomnia is defined as a condition that satisfies the following criteria:

- The principal complaint is difficulty getting to sleep or staying asleep, or not feeling refreshed after sleep, persisting for at least a month.
 - The sleep disorder (or the associated daytime tiredness) causes significant suffering or impairment of the sufferer's social or occupational performance or ability to function in some other important field.
-

- The sleep disorder does not only occur in the context of narcolepsy, sleep-related respiratory disorder, circadian rhythm-related sleep disorder or parasomnia.
- The sleep disorder is not a consequence of the direct physiological effects of a substance (narcotic, medication) or a somatic condition.
- The sleep disorder does not only occur in the context of another psychological disorder (such as a depressive disorder, generalised anxiety disorder, or delirium).

The occurrence of chronic primary psycho-physiological insomnia is seen as the coincidence of endogenic causal factors, initiatory factors and sustaining factors¹⁸⁹. Endogenic causal factors are physiological factors such as raised heart rate, increased muscle tension and raised body temperature, together constituting a raised physiological state of arousal, and psychological factors such as anxiety, nervousness and the inability to clear the mind¹⁹⁰.

Factors that sustain insomnia and therefore act as obstacles to recovery include poor (non-adapted) sleeping habits (inappropriate use of somnifacient drugs, staying in bed too long, keeping irregular hours, excessive napping during the day) and worrying about the possible consequences of not getting enough sleep (anxiety about failure during the day, anxiety about losing control over situations, acquired sense of helplessness).

According to Vgontzas *et al*¹⁹¹, their epidemiological research supports the hypothesis that primary insomnia mainly involves chronic hyper-arousal, which is evident not merely at night, but around the clock. They take the view that relatively little research has been carried out into the effects of primary insomnia on the cardiovascular system. They argue that their results indicate that people with primary insomnia are not only more likely to suffer from psychological conditions, but also from physical conditions such as hypertension and obesity (plus the associated metabolic abnormalities). Accordingly, the researchers argue that the focus of treatment should be the hyper-arousal, rather than the insomnia, which is merely a consequence of the hyper-arousal.

According to the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV)¹⁸⁷ and the NVvP's *Guidance Notes*¹⁸⁸, secondary insomnia (insomnia in association with another psychological disorder) is a condition that satisfies the first four criteria given above for primary insomnia, is additionally associated with a so-called 'Axis I' or 'Axis II' disorder (such as a depressive disorder, a generalised anxiety disorder, or an adjustment disorder accompanied by anxiety), and is sufficiently serious to warrant separate medical attention.

Secondary insomnia can also be a consequence of other medical conditions, such as pain, depression, night-time restless legs syndrome and alcoholism. Working variable shifts, including night shifts, can induce or aggravate chronic insomnia.

E.2 How prevalent is insomnia?

Ohayon describes more than fifty studies concerned with the prevalence of insomnia in a broad sense (i.e. not merely primary psycho-physiological insomnia) in the population at large¹⁹². The reviewed studies include estimates of the prevalence of insomnia, based on four distinct criteria: difficulty getting to sleep or staying asleep, night-time manifestations of insomnia accompanied by daytime problems arising from lack of sleep, self-reported dissatisfaction with sleep quality, and insomnia diagnosed on the basis of DSM-IV. Approximately a third of the general populace is sometimes affected by insomnia satisfying the first criterion. When the second definition is applied, 9 to 15 per cent of the population are reckoned to be affected. Under the third definition, 8 to 18 per cent of the population suffer from insomnia. By application of the DSM-IV classification, one arrives at a figure of 6 per cent for the average prevalence of insomnia in the population at large. However insomnia is defined, it is more prevalent among women than among men. Furthermore, insomnia becomes more common with increasing age, except when defined on the basis of self-reported dissatisfaction with sleep quality.

Prevalence can also be expressed in terms of the estimated probability of suffering a significant sleep disorder at some time in one's life. On this basis, the prevalence of insomnia is put at roughly 30 per cent¹⁹³; in other words, the average Dutch person has approximately a one-in-three chance of falling victim to a significant sleep disorder at some time or other.

A German study involving two thousand adult subjects looked at the possibility of a link between insomnia (as defined in the DSM-IV) and quality of life (as measured using the abbreviated SF-36 questionnaire)¹⁹⁴. Some 22 per cent of insomniacs rated their quality of life as 'poor' and 28 per cent as 'good', while the corresponding figures for subjects without sleeping problems were, respectively, 3 and 68 per cent. These figures must be treated with caution, however, since subjects' quality of life will have been influenced not only by their insomnia, but also by other illnesses and conditions.

Sleeping problems are not confined to adults. Kim *et al*¹⁹⁵ asked 1365 Chinese youngsters aged twelve to eighteen about any sleeping problems they might have. Nearly 17 per cent reported symptoms of insomnia, including difficulty getting to sleep (11 per cent), waking up in the night (6 per cent) and waking up too early in the morning (2 per cent).

A great deal of research has been carried out into the prevalence of insomnia not only in the population at large, but also in particular groups. Hence, insomnia is known to be much more common among people affected by certain illnesses and medical conditions than in the overall population¹⁹⁶⁻²²¹. For example, women who are pregnant or have been pregnant in the last twelve months or so are at increased risk of insomnia²²².

E.3 The consequences of insomnia and sleeping problems; association with other illnesses and medical conditions

E.3.1 The direct consequences of insomnia

According to Stolk *et al*⁹¹, insomnia has a substantial negative effect on quality of life. In the quality-of-life weighting system developed by this team, insomnia, as diagnosed by a GP, has a quality-of-life weighting of 0.83. In other words, a year suffering from insomnia ‘costs’ 0.17 years of healthy life. Various other authors have also reported negative effects of insomnia on quality of life^{18,194,223-226}. People with chronic insomnia of any kind also tend to perform less well at work and suffer memory and concentration problems²²⁷. Insomniacs make disproportionately great use of healthcare facilities and medications, including somnifacient drugs and sedatives^{18,194,223,224}.

E.3.2 Association of insomnia with other medical conditions and illnesses

When considering the relationships between insomnia and other medical conditions and illnesses, it is important to distinguish between an association and a causal relationship. Many researchers have reported an association between certain abnormalities, but have failed to demonstrate the link between cause and effect. Schwartz *et al* made an extensive survey of insomnia, *cardiovascular disease* and *mortality risk* on the basis of epidemiological research data²²⁸. They consider it likely that insomnia and the associated daytime tiredness are part of a more general syndrome that is associated with chronic stress, causes autonomous dysfunction and brings an increased risk of cardiovascular disease. Shaver *et al*²⁰¹ drew a similar conclusion on the basis of a study of middle-aged women.

Age is not in itself a determining factor in the occurrence of insomnia^{209,225,229-231}, which is attributable more to age-related phenomena, such as increasing lack of physical activity, changes involving other lifestyle factors (obesity, use of alcohol), dissatisfaction with the social environment, and illnesses and abnormalities.

With a view to establishing whether chronic insomnia increased the risk of *hypertension*, Suka *et al* conducted a five-year longitudinal study involving 4,800 Japanese workers²³². Their conclusion was that people who have difficulty getting to sleep and people who have difficulty staying asleep are more likely to develop hypertension (OR respectively 1.9 and 2.0).

Numerous studies have been carried out into the link between *depression* and (sometimes ill-defined) insomnia^{196,198,201,206,207,211,212,215,218,220,221,224-226,233-246}. In most of these studies, a statistically significant association was found, but no causal relation-

ship demonstrated. One exception in this regard was the twelve-year longitudinal study by Mallon *et al*²²⁰. Among women, insomnia at the start of the research period proved to be a statistically significant predictor of the development of depression during the course of the study (*odds ratio* = 4.1). Insomnia was not found to be a predictor of subsequent depression in men, however.

E.3.3 Association of sleep disorders and sleeping problems with road traffic accidents

Ohayon *et al*, who have carried out a large number of epidemiological studies^{192,213,214,231,244,247-255}, take the view that *dissatisfaction with sleep quality* is much more closely related to sleep pathology than the phenomena of insomnia as such.

It is often assumed that sleeping problems play a role in *road traffic accidents* (RTAs). In this context, it is important to distinguish between sleeping problems and incidental sleep deprivation. Having analysed data from the 1985 *CARfile study*, Webb²⁵⁶ concluded that drowsiness was the primary cause of 1.6 per cent of accidents.

Connor²⁵⁷ produced an extensive survey of the significance of sleep disorders in RTAs. Analysis of data from the cross-sectional studies produced no evidence of an association between insomnia and the probability of involvement in an RTA. However, the case-control study²⁵⁸ did show up a statistically significant association between sleep apnoea and the probability of injury in an RTA.

E.3.4 Association of sleep disorders and sleeping problems with occupational accidents

A number of studies indicate that sleeping problems increase the probability of involvement in a (fatal) occupational accident^{256,259-263}. Over a twenty-year period, Akerstedt *et al*²⁵⁹ interviewed 47,860 people (men and women) by phone regarding sleep and health factors and regarding specific work-related factors. By studying a register of deaths (from which cases of suicide were excluded), the researchers identified 166 fatal occupational accidents. Analysis found the following to be statistically significant predictors of involvement: gender, sleeping problems in the two weeks prior to the interview (relative risk 1.6, 95 per cent confidence interval 1.2 to 2.9) and working outside normal daytime working hours (relative risk 1.9, 95 per cent confidence interval 1.1 to 2.5).

A study of 880 construction workers by Chau and Gauchard²⁶⁰ revealed that sleeping problems increased the probability of involvement in an accident with a moving object on site (*odds ratio* 2.3, 95 per cent confidence interval 1.3 to 4.1).

The same researchers²⁶¹ made a comparison between 427 women who had taken sick leave as a result of falling at work after (physically) losing their balance, and a control group of 427 women. On the basis of interviews conducted by industrial doctors, it

was concluded that there was an association between sleeping problems and the risk of falling at work.

Lindberg *et al*²⁶² undertook a prospective study, in which 2,874 men completed a questionnaire at the outset, and 2,009 completed a follow-up questionnaire ten years later. Information about occupational accidents was obtained from a national register; it was found that 247 of the 2009 men who completed both questionnaires had been involved in a total of 345 accidents. Men who at the beginning of the study reported both ‘napping’ and feeling sleepy during the day proved to have been involved in more occupational accidents; the link was statistically significantly, even after correcting for numerous other factors capable of influencing the association between sleeping problems and occupational accidents (odds ratio 2.2, 95 per cent confidence interval 1.3 to 3.8). No statistically significant association was found involving men who napped but did not feel sleepy during the day, or involving men who felt drowsy during the day but did not take naps.

Melamed and Oksenberg²⁶³ interviewed 532 industrial workers in order to gather information on the influence of drowsiness on the probability of involvement in an accident at work. By asking numerous questions, the number of accidents in the two years prior to the interviews was determined. Analysis of the responses revealed that the probability of involvement in an occupational accident was higher, to a statistically signifi-

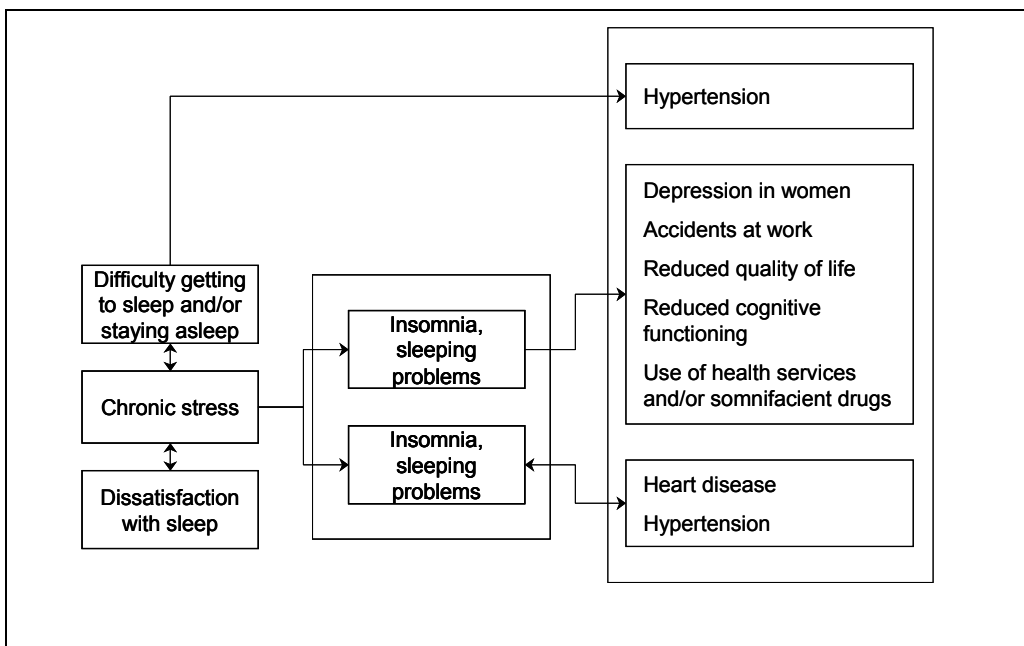


Figure 29 Causes and backgrounds of insomnia and sleeping problems (chronic stress, dissatisfaction with sleep, difficulty getting to sleep and/or staying asleep), consequences of insomnia/sleeping problems (indicated with s) and the associations between insomnia/sleeping problems and other illnesses and medical conditions (indicated with s).

cant extent, among workers who reported feeling drowsy at work than among those who did not (odds ratio 2.2, 95 per cent confidence interval 1.3 to 3.8).

Figure 29 illustrates the causes and consequences of insomnia and sleeping problems, as well as the association that insomnia and sleeping problems have with other illnesses and medical conditions.

E.3.5 Conclusions

On the basis of the foregoing, the following conclusions may be drawn:

- Insomnia has a negative effect on quality of life. People with chronic insomnia perform less well at work and experience memory and concentration problems. Insomnia increases usage of healthcare facilities and the consumption of medications, such as somnifacient drugs and sedatives. Insomnia and the associated daytime tiredness are part of a more general syndrome that is associated with chronic stress and causes autonomous dysfunction.
- People who are affected by insomnia are more likely to suffer depression (women), obesity (plus the associated metabolic abnormalities) and cardiovascular disease.
- People with sleeping problems are more likely to develop hypertension.
- People with general sleeping problems (difficulty getting to sleep, difficulty staying asleep, waking spells at night) are more likely to be involved in occupational accidents.

In addition, the following conclusions may be drawn regarding heightened sensitivity to insomnia:

- Because of the association of insomnia with depression, hypertension, obesity and cardiovascular disease, people with these conditions may be regarded as particularly sensitive to insomnia. Women who are pregnant or have been pregnant in the last twelve months or so are also more likely than the average person to experience a period of insomnia.
- Age is not in itself a determining factor in the occurrence of insomnia^{209,225,229-231}, which is attributable more to age-related phenomena, such as increasing lack of physical activity, changes involving other lifestyle factors (obesity, use of alcohol), dissatisfaction with the social environment, and illnesses and abnormalities. As a result, older people may also be regarded as particularly sensitive to insomnia and sleeping problems.

Health Council Advisory Report *Assessing Noise Exposure for Public Health Purposes (1997/23)*

Methodology

In the Health Council's 1997 advisory report *Assessing Noise Exposure for Public Health Purposes*⁸, the 'Uniform environmental noise exposure metric' Committee of the Health Council proposed a system for determining noise exposures representative of the twenty-four-hour daily cycle (EEL) and the overnight period (ENEL). This method involves five steps:

- 1 *Frequency weighting of acute sound pressure levels*
The Committee opted for A-weighting, i.e. sound pressure levels expressed in dB(A), for both the twenty-four-hour daily cycle and the overnight period
- 2 *Adjustment for special characteristics and combinations of sound pressure levels*
The Committee assigned adjustment factors, as described below, to noises and noise situations involving characteristics a, b, and c in a twenty-four-hour daily cycle or an overnight period:
 - a Exposure to low-level industrial noise without impulse components: adjustment factor above 60 dB(A), 0 dB(A); at 40 dB(A), 10 dB(A); in the range between, calculated by linear interpolation
 - b Situations in which the noise includes audible tones: adjustment factor between 0 and 5 dB(A), depending on the frequency of the tone and the difference

between the sound pressure level of the tone and the prevailing background sound pressure level

- c Situations in which the noise includes (strong) impulse components: adjustment factor 5 dB(A) for impulse noise (such as the sound of a low-flying military jet, a car door slamming or church bells ringing) and 12 dB(A) for very impulse-like (such as gunshot noise, metal beating, pneumatic hammering, shunting of rail rolling stock).

The Committee attached certain qualifications to its proposal of the adjustment factors for use in the assessment of a situation over a twenty-four-hour daily cycle. With regard to assessment of the overnight period, the Committee indicated that consideration should be given to further adjustments to take account of the possibility of sleep disturbance. "Although scientific evidence is lacking, the Committee considers it likely that night-time exposure to noise with the characteristics listed above would result in increased sleep disturbance. It therefore considers it prudent to provisionally apply these adjustments also in deriving the *ENEL* metric, and recommends further research on this matter."

For the combination of sound pressure levels for parts of a day, including the application of adjustment factors for intervals in which sound with special characteristics occurs, the Committee recommended working on the basis of the equivalent sound pressure level over a given period.

- 3 The combination of (corrected) equivalent sound pressure levels for parts of a day to give a value that is representative for a twenty-four-hour daily cycle

The Committee recommends adjustment factors of 0 dB(A) for the daytime (7am to 7pm), 5 dB(A) for the evening (7pm to 11pm) and 10 dB(A) for the night (11pm to 7am). The corrected equivalent sound pressure levels are exponentially averaged. Step 3 is not necessary when calculating an ENEL, since the combination of day, evening and night values is clearly not relevant in relation to a night-only metric.

- 4 *The combination of daily exposure values to give a value that is representative for a year*

No seasonal or weekday/weekend adjustment factors are proposed. The equivalent sound pressure levels for each twenty-four-hour daily cycle of a year are exponentially averaged. This results in a $L_{adjusted,den}$ value. For $L_{adjusted,night}$, the Committee also recommends the exponential averaging of equivalent sound pressure levels for the overnight period.

- 5 *Noise source-related adjustments*

The final step in the construction of uniform exposure metrics for the twenty-four-hour daily cycle and the night involves adjusting $L_{adjusted,den}$ and $L_{adjusted,night}$ so that the exposure-response relationships of the various noise sources are in line

with that of a selected source. The particular reference source selected by the Committee was road traffic. The proposed effect metric for the twenty-four-hour exposure was the percentage of people experiencing high annoyance. However, other effect metrics are generally used in other countries (in Germany for example, the percentage of people experiencing annoyance is used). Consequently, the Committee, being made up of experts from various countries, developed the EEL on the basis of the high annoyance percentage merely as an example. Using road traffic noise as the reference source, differences between EEL and $L_{adjusted,den}$ are given for aviation and rail traffic noise. Depending on the noise exposure involved, these differences are between +3 and +5 dB(A) for air traffic, and between -1 and -8 dB(A) for rail traffic. The effect metrics given by the Committee for the night are the percentage of people reporting high sleep disturbance and the annual frequency of awakening due to a noise source. Because the information available at the time regarding the exposure-response relationships for road, rail and air traffic noise was not considered sufficiently reliable, the Committee decided against constructing an ENEL.

Applicability

The 'Uniform environmental noise exposure metric' Committee considered the methodology valid for the assessment of noise in most more or less stable situations, but not for the assessment of changes in noise situations over the short term. The Committee also pointed out that the method was not designed for use in relation to low-frequency noise, noise from incidental sources (such as rescue helicopters, ultra-light aircraft and advertising aircraft), neighbourhood noise or noise from neighbours.

The distribution of traffic-related noise exposure in the Netherlands

Enclosure accompanying letter (reference 1034/04 LOK/HD/wh) from HSMA Dieren, Environmental and Nature Planning Office, RIVM, dated 23 June 2004 to the Health Council.

Updated distributions for *Lden* and *Lnight*

Table 1 *Lden* % of dwellings per noise category, cumulative distribution of road traffic, rail traffic and air traffic.

	0-50 dB	51-55 dB	56-60 dB	61-65 dB	66-100 dB
NBG2001 ^a	32	31	25	9	3
2003 ^b	37	31	22	8	2

^a Corrected memorandum *Nachtelijke Blootstelling Geluid (Night-time Exposure to Noise)*, dated 24-5-2004; noise maps 100 m resolution.

^b Noise maps 25 m resolution.

Table 2 *Lnight* % of dwellings per noise category, cumulative distribution of road traffic, rail traffic and air traffic.

	0-40 dB	41-45 dB	46-50 dB	51-55 dB	56-60 dB	61-100 dB
NBG2001 ^a	23	27	30	15	4	1
2003 ^b	29	29	26	12	3	1

^a Corrected memorandum *Nachtelijke Blootstelling Geluid (Night-time Exposure to Noise)*, dated 24-5-2004; noise maps 100 m resolution.

^b Noise maps 25 m resolution.

With regard to *Lden* and *Lnight*, we advise adhering to the distributions given for 2003 in Tables 1 and 2 above. These figures are the best estimate we can currently make, on the basis of the most recent information and modelling.

Explanatory notes

The distributions given above are based on noise maps plotted using RIVM's EMPARA model. This model makes use of data files with information on the positions of roads and railways, from which the associated noise exposures are calculated for grid squares using standard mathematics techniques. Noise maps for air traffic have also been obtained from NLR.

Since the start of 2004, noise exposures have been calculated for grid squares of 25 by 25 metres (as opposed to the old 100 by 100 metre squares). The finer resolution allows for more accurate reflection of the spatial variation in sound pressure levels actually occurring in the vicinity of roads and railways. The updated distribution data therefore differs from the distribution data published in 2001, but not to a particularly great extent.

The method we have used is described in the Ministry of Housing, Spatial Planning and the Environment's publication *Naar een Landelijk Beeld van Verstoring (Towards a National Picture of Disturbance)*, publication no. 12, 1997. The accumulated noise exposure includes the values for road traffic, rail traffic and air traffic.

The reliability of the distribution data in Tables 1 and 2 depends not only on the scale used, but also on the current validity of the traffic data. Hence, it is worth stating that the data for motorways (obtained from AVV), railways (obtained from ASWIN), provincial roads (obtained from ERC) and air traffic (obtained from NLR) was updated for the 2004 Environmental Balance (based on the situation in 2003) and are therefore up to date.

The basic data that we used for municipal roads, however, was incomplete and somewhat out of date. To enable us to nevertheless obtain a full picture, we estimated the current traffic volumes on the majority of municipal roads using information about road types and a limited set of data from recent traffic counts. Because the municipal traffic data is to a large extent not based on recent volumetric figures and takes no account of features such as screens and quiet asphalt, the calculated noise exposures for a given location may differ considerably from the values that proper acoustic tests would return. However, it is assumed that any anomalies will, statistically speaking, balance one another out, so that the picture for the country as a whole and the associated distribution pattern constitute a reasonable approximation of the actual situation.
