
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.

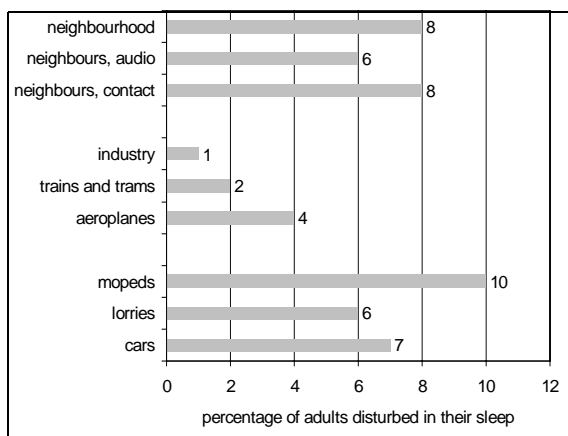
The consequences of exposure to night-time noise when sleeping have mainly been studied in relation to traffic noise. In the vast majority of cases, night-time traffic noise involves individually distinguishable noise events, such as the passage of a train, car or aeroplane.

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)*.