Noise and Health

Aan de minister van Volksgezondheid, Welzijn en Sport
Sir Winston Churchilllaan 370
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Onderwerp	: aanbieding advies
Uw kenmerk	: PAO/GZ 945796
Ons kenmerk	: 3753/WPV/WB/360-A
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Gedateerd 17 mei 1994, kenmerk, PAO/GZ 945796 zond de toenmalige minister van Welzijn, Volksgezondheid en Cultuur mij, mede namens de bewindslieden van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer en van Sociale Zaken en Werkgelegenheid, een adviesaanvraag over de invloed van geluid op de gezondheid van de mens. Ik moge u hierbij dit advies - gehoord de Beraadsgroep Omgevingsfactoren en Gezondheid van de Gezondheidsraad - aanbieden. Het advies is opgesteld in het Engels; een Nederlandse vertaling treft u tevens hierbij aan.

In december 1993 publiceerde de Gezondheidsraad de rapportage van een achtergrondstudie 'Lawaai en gezondheid', die mevrouw drs W Passchier-Vermeer van TNO Preventie en Gezondheid op mijn verzoek verrichte. De concept-versie van dat rapport vormde de grondslag van het voorliggende advies, dat door een door mij ingestelde internationale commissie van deskundigen is opgesteld. In samenhang met hetgeen daaromtrent in het Werkprogramma van de Gezondheidsraad was vastgelegd en vooruitlopend op de officiële adviesaanvraag had ik aan de commissie verzocht om te rapporteren over de effecten van geluid op de gezondheid, rekening houdend met de diversiteit van blootstellingssituaties. Daarnaast vroeg ik de commissie aan te geven welke de omvang is van de in Nederland aan geluid blootgestelde bevolkingsgroepen en van de bij die groepen te verwachten effecten.

Mijn opdracht aan de commissie bevatte niet de vraag naar een vergelijking tussen vormen van op gezondheidskundige overwegingen gebaseerde advieswaarden voor blootstelling aan geluid, stoffen en andere agentia. Ik ben voornemens daarover in 1995 een advies te laten opstellen.

De bewindslieden vragen ook om aan te geven in hoeverre er internationale consensus bestaat over de invloed van geluid over de gezondheid en in hoeverre de kennis hierover doorwerkt in normstelling. In aanvulling op hetgeen de commissie in haar advies hierover opmerkt, meen ik dat het opstellen van het advies door een internationale commissie een additionele waarborg vormt dat het voorliggende rapport de (internationale) stand der wetenschap weergeeft. Over de mate waarin de huidige kennis doorwerkt in normstelling kan niet in zijn algemeenheid een uitspraak worden gedaan, daar normen immers niet alleen op gezondheidskundige overwegingen worden vastgesteld, maar de uitkomst zijn van een politiek afwegingsproces. Wel wil ik hier vermelden dat de in een recente ontwerprichtlijn van de Europese Unie voor de blootstelling aan fysische agentia op de werkplek gepubliceerde grenswaarden ter bescherming van het gehoor van werknemers, corresponderen met de gezondheidskundige aanbevelingen van de commissie ter zake.

Op verzoek van de commissie vraag ik in het bijzonder uw aandacht voor het volgende. Een commissie van de Gezondheidsraad, die in 1971 rapporteerde over de effecten van geluid op de gezondheid, kwam tot de conclusie dat blootstelling aan geluid in Nederland een belangrijk volksgezondheidsprobleem vormt. Sindsdien is het inzicht in de gevolgen van geluid op de gezondheid aanmerkelijk toegenomen; tot een wezenlijk andere zienswijze heeft dat echter niet geleid. Er valt te constateren dat ook thans blootstelling aan geluid nog steeds een belangrijk volksgezondheidsprobleem vormt, zoals de gegevens uit het advies illustreren. Dat betekent dat de in de afgelopen jaren getroffen maatregelen slechts een beperkt effect hebben gesorteerd, waaraan ook de toegenomen blootstelling debet zal zijn. De bestrijding van geluidhinder, gehoorschade door geluid en andere invloeden van geluid op de gezondheid verdienen daarom mijns inziens onverminderd een belangrijke plaats in een beleid gericht op de verbetering van de volksgezondheid.

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To the minister of Health, Welfare and Sports
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Subject	: submission of report
Your ref.	: PAO/GZ 945796
Our ref.	: 3753/WPV/WB/360-A
Enclosures	: 2
Date	: 15 September 1994

In her letter of May 17, 1994, no. PAO/GZ 945796, the former minister of Welfare, Health and Culture requested the Health Council to prepare, also on behalf of the ministers of Housing, Spatial Planning and Environment and of Social Affairs and Employment, an advisory report on the effects of noise on human health. I herewith submit this report to you, after having consulted the Standing Committee on Health and Environment. The original text of the report is in English; a translation into Dutch is also enclosed.

In December 1993 the Health Council published a study on 'Noise and health', authored on my request by Mrs Passchier-Vermeer of TNO Prevention and Health. The international committee that prepared the present advisory report, had a draft of the TNO study at its disposal and based its report on the study's data. Given the project description in the Health Council Work Programme and in anticipation of the formal request for advice I asked the committee to report on the effects of noise on health in relation to the variety of exposure situations. I also asked the committee to estimate the size of the population groups exposed to noise in the Netherlands and the health effects expected in these people.

The committee's mission did not include a comparison between types of health based exposure limits for noise, chemicals and other agents. In 1995 the Health Council envisages to publish a report on this subject.

The ministers' question also pertain to the international consensus on the effects of noise on health and to the extent to which this consensus has been carried over to standard setting. The committee treats this question in its report. I would like to add, that the international composition of the present committee guarantees that the advisory reports represents the (international) state of the art. A general answer to question on the

relationship between this scientific evaluation and standard setting, is not possible, as standards are the result of a political decision process. However, the exposure limits for the protection of the hearing of workers, that were proposed in a recent draft directive of the European Union, do correspond to the health based recommendations of the committee in this respect.

The committee has asked me to draw your attention to the following. A Health Council committee concluded in 1971 that noise exposure is an important public health problem. Since then the knowledge about the effects of noise on health has increased considerably. However, this has not lead to new insights. Also today, noise exposure presents a considerable public health problem, as the data in the committee's report illustrate. This implies that the measures that have been taken in the last decades have had only a limited effect, which is partly due to the increase in exposure. In my opinion abatement of noise annoyance, of noise induced hearing loss and of other effects of noise on health should be an important part of a public health policy.

(signed)

Prof dr L Ginjaar
President of the Health Council of the Netherlands

Noise and Health

Report by a committee of the Health Council of the Netherlands

To

The Minister for Health, Welfare and Sports

The Minister for Housing, Spatial Planning and Environment

The Minister and State Secretary for Social Affairs and Employment

The Minister for Transport

No. 1994/15E, The Hague, 15 September 1994

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Executive Summary

This report

This report from the committee on Noise and Health of the Health Council of the Netherlands reviews the results of scientific research into the effects of noise on health. The report evaluates the evidence for causal relationships between exposure to noise and specific health effects. Trends are given for the extent of noise exposure in the Netherlands and effects of this exposure in the population are estimated.

Request for advice and method of work

Also on behalf of the Minister of Housing, Spatial Planning and the Environment and of the Minister of Social Affairs and Employment, the Minister for Welfare, Health and Culture requested the Health Council to review the available scientific data on noise exposure and its effects and to discuss more specifically some subjects such as the impact of environmental and occupational noise exposure on the health of the population of the Netherlands.

As preparation for the requested report, the President of the Health Council commissioned a background study to the Netherlands Institute of Preventive Health Care TNO, which was published separately. The background study was used by the Committee on Noise and Health, which consisted of experts from the Netherlands and abroad, as a basis for its report. A draft report was discussed by the committee in plenary session in June/July 1993 and the report was completed and approved by correspondence.

Health

According to the World Health Organisation health not only concerns the absence of disease or infirmity but other physical, mental and social aspects also. This concept is at the base of the review of the effects on health of exposure to noise. The exposure-effect chain can be divided into three phases: exposure to noise, appraisal by the organism and health effect. Exposure to noise is affected by factors, such as double glazing for indoor exposure and restriction of night-flights in the case of aircraft noise. Several factors may modify and determine the appraisal by the organism. Examples of these factors are the extent to which the noise interferes with personal activities and the relation of the individual or their community to the noise source. The severity of the effect on the state of health is influenced by endogenous factors.

Evaluating noise-induced health effects

For each health effect, the committee has rated, on the basis of the results of epidemiological studies, the evidence of a causal relationship between noise exposure and effect according to four categories: sufficient evidence, limited evidence, inadequate evidence and evidence suggesting lack of causality. For the category of health effects with sufficient evidence of a causal relation with noise exposure, there is special emphasis on exposure-effect relations and on *observation thresholds*. The observation threshold is the lowest exposure value at which, on average, an effect from exposure to noise was observed in epidemiological studies. Where appropriate, sensitive groups have been identified.

Characterisation of noise exposure

A great many noise exposure measures have been developed and applied in the literature to describe noise exposure. At present, in most exposure-effect relations and observation thresholds, noise exposure is characterised by the A-weighted equivalent sound level during a (specific part of a) 24-hour day. The A-weighted equivalent sound level over a period of T hours is denoted by $L_{Aeq,T}$.

$L_{EX,occ}$ is used for occupational noise exposure. It is the equivalent sound level during a representative workday, with the duration of the workday set at 8 hours.

In many publications and regulations from outside the Netherlands L_{dn} (the day-night level) is used as a measure for environmental noise exposure. It is computed from the L_{Aeq} value during the day (07-22h) and that during the night (22-07h), applying a penalty of 10 dB(A) to the night-time value. In the Netherlands, for most noise sources, environmental noise exposure is specified by the 'etmaalwaarde' (etm). L_{etm} is the highest of the following three values: $L_{Aeq,\,07\text{-}19h}$, $L_{Aeq\,19\text{-}23h} + 5$ and $L_{Aeq,\,23\text{-}07h} + 10$. For many purposes exposure to air traffic noise is expressed by the quantity B in Kosten Units (Kosteneenheid: Ke).*

The sound exposure level (SEL) is used to characterise the noise from a more or less isolated event, such as a passing truck or an overflying aeroplane.

Terms and definitions are presented in annex C.

Noise exposure in the Netherlands and its effects

This report gives estimates of the exposure to noise in the Netherlands and of the health effects in the population of the Netherlands attributable to these exposures. The numbers of people involved in the Netherlands are specified in seven consecutive classes differing by one order of magnitude (factor of 10). The classification relates only to the incidence of effects attributable to noise exposure, and not to the severity of the effects.

Classes are specified as:

1 no effect
2 < 100 affected persons ($<10^2$)
3 100 - 1000 affected persons (10^2 - 10^3)
4 1000 - 10 000 affected persons (10^3 - 10^4)
5 10 000 - 100 000 affected persons (10^4 - 10^5)
6 100 000 - 1 000 000 affected persons (10^5 - 10^6)
7 > 1 000 000 affected persons ($> 10^6$).

Noise exposure is specified with respect to the environment in which persons are exposed: the living environment, working environment and exposure during leisure. Regarding the living environment, a further distinction is made between noise sources:

* The following approximations of relations between noise exposure measures used in the Netherlands and L_{dn} are applicable:

$L_{etm} \approx L_{dn}+3$, for traffic noise

$B \approx 2\,(L_{dn}-42)$, for air traffic noise with B values of at least 30 Ke. This approximation is applicable only for aircraft noise around main airports and only when the distribution of aircraft noise events is 80% during the day, 15% during the evening and 5% during the night.

road traffic, rail traffic, air traffic, industry and other sources in the neighbourhood. Exposure during leisure has also been classified according to noise sources: pop music, games and sports and childrens' toys.

Noise-induced health effects

The report examines the following effects on health in relation with noise exposure

- permanent hearing loss
- stress-related health effects: hypertension, cardiovascular diseases, effect on birthweight
- psycho-social effects: annoyance, effects on psycho-social well-being
- sleep disturbance
- effects on performance

The report also considers combinations of different noise sources and interaction of noise with other agents.

The results for each of the various noise-induced health effects are presented as follows. Tables list the evidence for a causal relation between noise and effect. If there is sufficient evidence for a causal relationship, an observation threshold is given where possible and the prevalence of the effect in the population in the Netherlands in 1993 is estimated in classes.

Noise-induced hearing loss

In the case of occupational noise exposure the International Standard, ISO 1999, gives exposure-effect relations for the determination of noise-induced permanent hearing loss in populations exposed to noise during working hours. If exposure is expressed in terms of $L_{EX,occ}$, the exposure-effect relations are the same for all types of noises (steady-state, intermittent or impulse), except for shooting noise at equivalent sound levels above 85 dB(A) where shooting noise may be more damaging than other types of noises at the same equivalent sound level.

Taking into account the exposure-effect relations given in ISO 1999 and the extent of occupational noise exposure in the Netherlands, the number of workers with a noise-induced permanent hearing loss of at least 10 dB, averaged over the two frequencies, 2000 and 4000 Hz, falls into exposure class 6.

A pregnant woman's exposure to noise may affect the hearing of the unborn child: an occupational noise exposure with $L_{EX,occ}$ values of 85 dB(A) and over appears to be detrimental. The committee recommends that further research be undertaken to determine the observation threshold (which will be below 85 dB(A)).

Table S1 Noise-induced hearing loss.

Classification of the evidence for a causal relation between noise and effect supplemented with data on observation thresholds.

effect	classification of evidence for causal relation with noise	observation threshold		
		population	situation	value in dB(A)[a]
hearing loss	sufficient	adults	living env.	$L_{Aeq,24h}$: 70
		adults	leisure	$L_{Aeq,24h}$: 70
		workers	working env.	$L_{EX,occ}$: 75
		unborn babies	working env.[b]	$L_{EX,occ}$: <85

Estimated number of people affected in the Netherlands in 1993.

effect		population	situation	class
hearing loss		adults	living env.	1
	> 10 dB	workers	working env.	6
		unborn babies	working env.[b]	3
		young people	leisure	
			. pop music:	6
	5-10 dB		playing in group	6
	2-3 dB		attending pop concerts and discotheques	6
	10-15 dB		headphones	6

[a] Values measured at a location close to the head of the persons.

[b] Working environment of pregnant women.

The committee is of the opinion that the exposure-effect relations given in ISO 1999 are also applicable to (non-occupational) noise exposure in the living environment and during leisure. This implies that the observation threshold equals a $L_{Aeq,24h}$ value of 70 dB(A).

Stress-related health effects

Experimental research and epidemiological studies show that noise should be considered a non-specific stressor that stimulates the central nervous system and hormonal activity. However, long-term noise-induced stress-related health effects have been shown to occur only at relatively high occupational and environmental noise levels: the increased risk of ischaemic heart disease and hypertension due to exposure to

Table S2 Noise-induced stress-related health effects.

Classification of the evidence for a causal relation between noise and effect supplemented with data on observation thresholds.

effect	classification of evidence for causal relation with noise	observation threshold		
		population	situation	value in dB(A)[a]
hypertension	sufficient	adults	working env.	$L_{EX,occ}$: <85
		adults	living: road/air traffic	$L_{Aeq,06\text{-}22h}$: 70
ischaemic heart disease	sufficient	adults	living: road/air traffic	$L_{Aeq,06\text{-}22h}$: 70
hormonal system	limited	adults	working env.	-
			living env.	-
immune system	limited	adults	working env.	-
			living env.	-
birthweight	limited	babies	working env.	-
			living env.	-
congenital	lack	babies	working env.	-
			living env.	-

Estimated number of people affected in the Netherlands in 1993.

effect	population	situation	class
hypertension	workers	working env.	4
	pregnant women	working env.	2
	adults	living env.	4
ischaemic heart disease	adults	living env.	3

[a] $L_{Aeq,06\text{-}22h}$ measured outdoors, $L_{EX,occ}$ measured at the workplace.

traffic noise in the living environment starts at $L_{Aeq,06\text{-}22h}$ equal to 70 dB(A). Only people in situations with very specific noise exposure (e.g. living close to an airport under a flight path or living close to a very busy road) have such an increased risk due to noise exposure. These effects are preventable by enforcement of regulations laid down in the Noise Nuisance Act with respect to mitigation.

A noise-induced increase in the risk of hypertension was also shown for workers in industrial working environments. This effect has been shown to occur at equivalent sound levels of at least 85 dB(A) during the working day. The available data are insufficient to allow for an accurate estimate of the observation threshold to be established, but this threshold might well be lower than an equivalent sound level of 85 dB(A) during working hours for industrial situations. There are no data demonstrating noise-induced increased risk of hypertension in office workers.

The limited number of epidemiological studies on biochemical effects usually demonstrate changes in the hormonal composition of the blood of people exposed to very high environmental and occupational noise levels. These changes are to be expected if noise acts as a stressor. Other biochemical factors, such as the magnesiumion contents of blood plasma, have also shown changes due to very high noise exposures, which may indicate an increased risk of ischaemic heart disease. The only epidemiological investigation into the effects of road traffic noise on the immune system did show an increased concentration of leucocytes in blood. No epidemiological studies have been reported concerning noise-induced effects on diseases such as infectious diseases and possibly cancer which might ultimately result from effects on the immune system.

It is uncertain whether noise exposure of pregnant women to air traffic noise affects the birthweight of the baby. This effect at least does not occur at noise exposures with L_{dn} below 62 dB(A). Should an effect start to occur at slightly higher noise exposures, then the number of babies affected in the Netherlands is about 25 per year.

The available data virtually exclude a noise-induced risk of occurrence of congenital effects from environmental or occupational noise exposure of pregnant women. Pregnant women exposed to high levels of occupational noise, however, do show an increased risk of hypertension during pregnancy.

Psycho-social effects

Adverse psycho-social effects from noise in the living and working environment are very widespread. People become annoyed by noise in the living environment from many noise sources, such as road, rail or air traffic and industrial sources. Currently, noise from activities of people in the neighbourhood and indoor noises from neighbouring homes are major constituents of annoyance in the living environment.

Recently defined exposure-effect functions relate annoyance to exposure to various types of traffic noise (aircraft, highway traffic, other road traffic and railroad traffic) and industrial noise in the living environment. For traffic noise sources severe annoyance starts to occur at L_{dn} values of 42 dB(A), measured outdoors. Above this level a higher percentage of people is annoyed by aircraft noise than by road traffic and railroad noise comparing the effects of these noises at the same L_{dn}. Noise from stationary sources, such as industry, shunting-yards and artillery-ranges is more annoying than traffic noise, especially when the stationary sources contain impulse components.

Table S3 Psycho-social effects.

Classification of the evidence for a causal relation between noise and effect supplemented with data on observation thresholds.

effect	classification of evidence for causal relation with noise	observation threshold		
		population	situation	value in dB(A)[a]
severe annoyance	sufficient	workers	offices	$L_{EX,occ}$: <55
			industrial	$L_{EX,occ}$: <85
		adults	living env.	L_{dn}: 42[b]
psychiatric admissions	limited	adults	living: air traffic	-
psycho-social well-being	limited	adults	living: road traffic	-
absenteeism	limited	workers	working:	
			industrial	-
			offices	-

Estimated number of people affected in the Netherlands in 1993.

effect	population	situation	class
severe annoyance	adults	living:	
		road traffic	7
		civil air traffic	6
		military air traffic	7
		rail traffic	6
		industries	6
		other sources	7

[a] L_{dn} measured outdoors, $L_{EX,occ}$ measured at the workplace.

[b] Observation thresholds for traffic and industrial noise; the observation threshold is lower for environmental impulse noise.

Whether people who live in very noisy surroundings show increased social disorientation, decreased social activity and increased depression compared to people living in quiet surroundings is, as yet, uncertain. There is also only limited evidence that relatively more admissions to psychiatric hospitals might occur from areas with very noisy conditions, due to aircraft noise with L_{dn} of more than 70 dB(A), than from more quiet surroundings. Should such an effect occur, the number of noise-related admissions in the Netherlands would be low: the best estimate is 5 per year.

No observation thresholds or substantial exposure-effect relations are available for noise annoyance in the workplace. It is evident that an observation threshold for annoyance due to office noise will be (much) lower than that for industrial noise. Of office workers exposed to 55 to 60 dB(A) equivalent sound level during the working day, 35% to 40% were severely annoyed, while for industrial workers similar percentages of severely annoyed workers were found at equivalent sound levels of more than 85 dB(A).

It has not yet been conclusively demonstrated that noise exposure is of importance with respect to absenteeism from work. Noise-induced increase in absenteeism seems to be likely for workers in both industrial situations and offices.

Effects on sleep

Noise during the sleep period can impair several aspects of the quality of sleep. It becomes increasingly clear that in evaluating the results of sleep research, a distinction has to be made between results of laboratory studies with test subjects and those of epidemiological investigations, in which people are studied in their normal living situations with the usual night-time noises in their bedrooms. Comparison of results of laboratory and epidemiological studies shows that habituation to night-time noises occurs to a large extent with respect to awakening, but not, or to a much lesser extent, with respect to changes in sleep stage and heart rate.

The subjectively experienced quality of sleep decreases with moderate levels of night-time noise, even for persons who are used to sleeping in these situations. This phenomenon occurs at outdoor equivalent levels above 40 dB(A) during the night (23-07h). Exposure-effect relations have not yet been determined.

The effect of night-time noise on the endocrine system and on the immune system has so far not been investigated in epidemiological studies. Although noise exposure during sleep may affect these systems, as may daytime noise exposure, confirmation of effects by epidemiological research is still lacking.

Noise-induced effects on mood and presumably also on the functioning of people during the day following their nighttime noise exposure, have been shown to occur due to high levels of night-time noise. The available data, however, do not allow the determination of observation thresholds.

Data on noise-induced sleep disturbance are largely limited to effects from intermittent noise sources, such as airplanes and heavy vehicles. For a number of aspects studied, an effect such as awakening, due to one (intermittent) noise event has been related to a noise measure related to that event only, such as the SEL value. Therefore, observation thresholds and exposure-effect relations for these aspects are not established in a format that can be used readily to estimate the extent of these effects on the Netherlands population. This is applicable to awakening, sleep stage changes and heart rate.

Table S4 Sleep disturbance.
Classification of the evidence for a causal relation between noise and effect and data on observation thresholds.

effect	classification of evidence for causal relation with noise	observation threshold		
		population	situation	value in dB(A)[a]
change in:				
sleep pattern	sufficient	adults	sleeping	
awakening	sufficient	adults	sleeping	SEL: 60
sleep stages	sufficient	adults	sleeping	SEL: 35
subjective sleep quality	sufficient	adults	sleeping	$L_{Aeq,night}$: 40
heart rate	sufficient	adults	sleeping	SEL: 40
hormonal system	limited	adults	sleeping	
immune system	inadequate	adults	sleeping	
mood next day	sufficient	adults	sleeping	$L_{Aeq,night}$: <60
performance next day	limited	adults	sleeping	

Estimated number of people affected in the Netherlands in 1993.

effect	population	situation	class
decreased sleep quality	adults	sleeping	7?

[a] SEL values measured indoors, $L_{Aeq,night}$ measured outdoors.

A relation between the number of awakenings and sleep stage changes and the equivalent sound level during the night (Pas94) has been derived, using epidemiological data on the relation between SEL for a single event and these effects as a basis, but only with respect to night-time *aircraft* noise. Together with data on the night-time equivalent sound levels around Schiphol Airport, the extent of the population at risk of noise-induced awakenings and sleep stage changes could be estimated for the Schiphol situation only. Since that situation encompasses a presumably very limited part of the total sleep disturbance for the total population of the Netherlands, it is concluded that only a very rough estimate can be presented for sleep disturbance.

Effects on performance

Children exposed to very high levels of aircraft or road traffic noise during the schoolday show impaired performance in cognitive tasks. They have been shown to be distracted more easily and to make more mistakes when they are exposed daily during the school-day to equivalent sound levels over 70 dB(A), measured outside the school. The data do not allow establishment of an observation threshold and exposure-effect relations.

Noise of sufficient intensity may mask speech, impair communication, distract attention from social cues and interfere with concentration.

When a task involves auditory cues, and when these auditory signals are masked by noise, there will be an effect on the performance of the task.

For adults, there is only limited evidence for a causal relationship between noise exposure in normal life and decreased performance of cognitive tasks not involving auditory signals or speech, although significant acute effects on performance of test subjects in laboratory studies have been shown to occur.

Combinations of noise exposures

One of the most important gaps in the research into effects of noise on man is the lack of an integrated approach in which all noise exposures over 24 hours and their resulting effects are studied together. Only for the noise-induced effects hearing loss and annoyance is information available which allows the determination of the effect of a combination of noise exposures. Concerning noise-induced hearing loss, it was found appropriate to estimate the effect of any exposure to several noise sources from the equivalent sound level over the total exposure period. For annoyance from two or more environmental noise sources acting together in the same situation, there is a calculation scheme for the determination of annoyance from these combined exposures.

With respect to the occurrence of ischaemic heart disease, it was shown that exposure to high levels of occupational noise may be considered a risk factor for people exposed to high levels of environmental noise. The data, however, do not allow such a combined effect to be generalised.

Interaction of noise with other agents

There has only been little epidemiological research into the effects of combined exposure to noise and other physical or chemical agents. Investigations have usually been carried out in the laboratory, with test persons or with animals. The available epidemiological data are mainly limited to effects on hearing. These effects have been studied for a combined exposure to occupational industrial noise and to one of the following other industrial agents: carbon monoxide, solvents, heavy metals, hand-arm and whole-body vibration. However, the number of studies and the size of the populations studied are too small to provide sufficient evidence for interactive effects.

Noise exposure characteristics

In the report, observation thresholds and exposure-effect relations for all noise-induced health effects, with the exception of some aspects of sleep disturbance, are expressed in an equivalent sound level determined over a selected representative period during the 24 hour day. However, these representative periods are different from one another, depending upon the noise effect. Since there is no generally applicable relation between the equivalent sound levels over different periods, the committee is not able to adopt one noise measure, representative of the 24 hours exposure of populations, from which all noise-induced health effects can be estimated without any further information. With regard to sleep disturbance, the committee is of the opinion that estimation of this noise-induced effect needs a noise measure describing night-time noise exposure exclusively.

In conclusion

The committee concludes that the most important noise-induced health effects in the Netherlands are annoyance from exposure to environmental and occupational noise, hearing loss induced by occupational noise, and sleep disturbance.

Noise-induced hearing loss due to occupational noise may be prevented by implementation of existing regulations with respect to occupational noise control. There are no such regulations for noise exposure during leisure. Therefore, in the future, exposure to noise during leisure might have a relatively much greater impact on the hearing threshold levels of populations than will occupational noise exposure.

Most other effects of exposure to noise, such as ischaemic heart disease, hypertension and admission to psychiatric hospitals, occur at relatively high noise exposure levels. These effects might be prevented by enforcement of present regulatory limits in the living and working environment.

Chapter 1

Noise as a public health problem

1.1 Introduction

Noise is omnipresent in our industrialised and motorised society. Noise has a number of unique physical properties and is suspected of causing both acute and long-term adverse health effects. Among these effects are hearing damage, cardiovascular disease and annoyance.

In the Netherlands, as well as elsewhere, regulations have been issued and measures have been enforced to limit noise exposure of the population. The Health Council contributed to the policy decisions of the Netherlands government by providing it with relevant scientific information (GR71). In the present advisory report the Health Council again presents an overview of knowledge concerning the effects of noise on health, and also estimates the extent of noise-induced adverse health effects in the Netherlands population. It answers questions put forward by the Minister of Housing, Spatial Planning and the Environment, the Minister of Social Affairs and Employment and the Minister for Well-being, Health and Culture.

1.2 Background

1.2.1 The 1971 Health Council report and the Noise Nuisance Act

In 1971 the Health Council advised the Netherlands government on measures for reducing noise nuisance and limiting noise production, in order to protect health and on the issuance of a law concerning adverse noise-induced health effects, such as noise annoyance (GR71). In 1980 the Noise Nuisance Act came into force. According to this Act, nuisance encompasses annoyance and health damage. The Act gives a framework for public health related measures concerning noise exposure in the living environment. However, aircraft noise is not dealt with either in the Noise Nuisance Act or in regulations based on this act. Measures to protect people against aircraft noise are presented in the Decree on noise exposure from main airports, based on the Aviation Act.

The 1971 Health Council report identifies six noise-induced health effects: hearing loss, annoyance, sleep- and rest-disturbance, effects on the central nervous system, disturbance of communication and effects on performance. Exposure-effect relations are given only for hearing loss due to occupational noise exposure and a 'safe' noise limit* of 80 dB(A) was quoted. The report specified maximum allowable outdoor sound levels** for environmental noise:

- areas with noise sensitive objects: 35 dB(A)
- areas with dwellings: 40 dB(A)
- industrial areas: 55 dB(A)
- areas with highway traffic: dependent upon the local situation.

In 1973 the Health Council Committee which had prepared the 1971 report evaluated the criteria for exposure to aircraft noise. In response to the statement of the governmental Committee on Aircraft Noise, which considered 40 Ke (Kosten Units, see annex C for definitions) acceptable as the maximum noise exposure in living environments, the '1971' Health Council Committee stated that severe annoyance would occur at 15 to 20 Ke and higher. It was, however, acknowledged by the Health Council Committee that it would not always be feasible or easy to reduce noise exposures to below 20 or even 15 Ke.

1.2.2 *Other reports of the Health Council*

In recent years the Health Council has published four documents related to the subject of the present report:

- review on noise and its effect on the hearing of young people (Pas89b)
- review on aircraft noise, sleep and health (Hof91)
- advisory report on sleep disturbance by airplane noise at night (GR91)

* Noise measures unspecified; it is presumed to be the equivalent sound level during the day. For definitions, see annex C, and for a description par 2.2.

** Noise measures unspecified; it is presumed to be the equivalent sound level during the day. For definitions, see annex C, and for a description par 2.2.

- review on stress and health (GR92).

The data and conclusions presented in these documents were taken into account in the present report.

1.2.3 *Other regulations in the Netherlands and in the European Union*

Since the Health Council report dating from 1971 a number of regulations aimed at protecting people against noise exposure were imposed, in addition to the Noise Nuisance Act and its Decrees. Occupational noise exposure was dealt with by the 'Arbeidsomstandighedenwet' (Health and Safety at Work Act) together with specific regulations laid down in the' Veiligheidsbesluit voor fabrieken of werkplaatsen' (Decree on safety in factories or workplaces). Although the 'Arbeidsomstandighedenwet' deals with all adverse effects associated with working conditions, only regulations concerning the prevention of noise-induced hearing loss are specified. Other health effects from occupational noise exposure were not dealt with.

On the European level, Directive 86/188/EEG of the Council of the European Union specifies regulations concerning protection of the hearing of workers exposed to occupational noise, and Directive 89/392/EEG specifies safety requirements concerning noise emitted by machinery and other equipment.

In December 1992, the Commission of the European Union proposed to the Council a directive on the minimum requirements regarding safety and health as related to the exposure of workers to physical agents (including noise). With respect to noise, the regulations only deal with the prevention of noise-induced hearing loss. The directive states

> as regards the problem of non-auditory effects of noise (which vary from physiological disorders to interference with the proper execution of tasks requiring attention and concentration) the Commission feels that knowledge is not sufficiently advanced to justify a quantitative limitation of exposure (which would involve levels far below 75 dB(A)); moreover, without wishing to play down the non-auditory effects it should be acknowledged that they are often less significant socially than the isolation resulting from loss of hearing and that there is a point where the profitability of an occupational activity soon has to be taken into account.

As already mentioned, requirements concerning environmental noise are given in the 'Wet geluidhinder' (Noise Nuisance Act) and in the 'Besluit Geluidbelasting Grote Luchtvaartterreinen' (Decree on exposure to noise from main airports) based on the 'Luchtvaartwet' (Aviation Act). The latter decree has been amended to include regulations concerning night-time flights at Maastricht Airport. At the moment of publication of this report, legal requirements concerning night-time flights at all main airports are in the process of being adopted.

Simultaneously with refinement of regulations, electronic equipment for measuring noise and noise exposure has been greatly improved. Internationally accepted standards for measuring methods for noise emitted by several types of machinery and equipment have been published by the International Organisation for Standardisation (ISO). Many of these documents are now being adopted by the European Committee on Standardisation (CEN) and will subsequently become Dutch Standards (NEN).

1.3 Procedure

1.3.1 Literature review

The 'Noise and health' project was included in the Work Program of the Health Council, after consultation with the Ministry of Welfare, Health and Cultural Affairs, the Ministry of Housing, Spatial Planning and Environment and the Ministry of Social Affairs and Employment. After discussions with these ministries about the outlines of a request for advice concerning noise and health, the project started with the President of the Health Council commissioning a literature review to mrs W Passchier-Vermeer (Netherlands Institute of Preventive Health Care, TNO*). A draft of this review became available in April 1993 and the review was finalised in December 1993 (Pas93a,b).

1.3.2 The Committee on Noise and Health

In order to prepare an advisory report, the President of the Health Council invited experts from the Netherlands and from abroad to participate in a Committee on Noise and Health. The committee was asked to evaluate the conclusions from the literature review and to answer the questions from the ministers.

The members of the committee were first interviewed by the scientific secretaries of the committee (May 1993). A draft report , based on these interviews, was then the subject of a meeting of the full committee in Leyden (The Netherlands) on June 30 and July 1, 1993. The text of the report was completed and approved by the committee-members by correspondence.

The membership of the committee is given in annex B.

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* at present: TNO Prevention and Health

1.3.3 *Request for advice*

In a letter, dated May 17, 1994 the Minister for Welfare, Health and Culture, also on behalf of the Minister of Housing, Spatial Planning and Environment and of the Minister of Social Affairs and Employment, asked the President of the Health Council to prepare an advisory report on the subject noise and health. The Minister specifically put forward the following questions:

1 Which health effects are to be expected from exposure to noise at different sound levels?
2 To which extent is the population of the Netherlands affected by these effects?
3 Which health based exposure limits can be derived from these data?
4 To which extent does international agreement exist about these aspects and in how far is this expressed in standards?

Annex A gives the full English translation of the request for advice.

1.4 Structure of the report

The report is structured as follows. In chapter 3 the committee reviews the relevant research data on the effects of noise exposure on health. There is special emphasis on results from epidemiological studies. Where appropriate exposure-effect relations and the levels above which an effect starts to occur for an average population are given and the sensitive groups are identified. The aforementioned literature review (Pas93a,b) was taken as the basis of this chapter. However, explicit references to the review are omitted. Only those publications which are considered of crucial importance are quoted in the text. Readers interested in other related publications are referred to the list of publications in the literature review (Pas93a,b).

Chapter 3 on health effects of noise is preceded by a discussion on the concept of health and by an overview on the noise measures used to associate noise-induced health effects with noise exposure.

Chapter 4 gives trends in the Netherlands for the extent of noise exposures and estimates of the effects in the population of the Netherlands in 1993.

In chapter 5 answers to questions put forward in the request for advice are given.

Annex A gives the text of the request for advice. Annex B lists the members of the Health Council Committee on Noise and Health. Annex C defines several technical terms.

Chapter 2

Health and noise exposure

2.1 Health

Definition

According to the World Health Organisation, health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. Since this definition cannot be applied 'as it is' to set norms and to take measures with respect to individual and public health, the Health Council Committee on 'Air quality standards' defined health as a dynamic condition of the organism which functions properly both physically and mentally according to the individual itself and according to physicians, taking into account both the individual's age and sex and general condition of the population to which the individual belongs, and the current state of science and technology and the related objectives of health care and public health, the beliefs and the cultural patterns of society (GR77). This definition implies that health is not an objective concept. Individual and social attitudes influence what is considered to be a state of good or bad health. The definition also implies that it are not only clinical symptoms that are an indication of a deteriorating state of health, but that annoyance is also relevant in this respect.

Factors

Several models have been developed to describe health status. Figure 2.1 gives an example (RIV93c). According to the Canadian minister Lalonde (Lal74), exogenous factors, endogenous factors and public health policy determine the health status of an individual and of a population. These factors are not mutually independent. Lifestyle, e.g., may modify exposure to physical environmental factors and will depend on the social environment. The health effects of exposure to physical factors depend on susceptibility, and thus on inherited and acquired traits.

The present report discusses the effect on health of exposure to noise. In figure 2.1 exposure to noise is one of the physical factors. Figure 2.2 (modified from Bie89a, 89b) presents a model in which health is more specifically related to exposure to noise. The cause-effect chain is divided into three phases: exposure to noise, appraisal by the organism and health effect. Exposure to noise is determined by so-called determining factors. Examples of these are double glazing for indoor exposure and the number of nightflights in the case of aircraft noise. The organism evaluates the exposure and will try to defend itself. Several factors may modify and determine this appraisal by the organism, e.g. familiarity with the noise, the relation of the individual or his community to the noise source and the extent to which the noise interferes with personal activities. The last phase is the effect on the state of health. Endogenous factors will influence the probability and the severity of the effect.

This model suggests that exposure to noise in itself is a determining factor for health. However, if the exposure to noise is strongly coupled to other external factors, it is the combination of exposure to noise and the stressors associated with the other factors that is relevant. Annoyance from highway traffic is an example. Vibrations and light exposure (at night) may be contributing factors in addition to the noise. It is difficult to separate the effects of these three factors.

2.2 Characterisation of noise exposure

A variety of noise exposure measures can be found in national and international regulations and standards and in the scientific literature. The present report presents the measures that are most relevant for the effects of noise on health, including those used in the Netherlands legislation (Noise Nuisance Act and Aviation Act). Formal definitions are given in annex C.

Sound can be characterised by frequency and level . The frequency is expressed in hertz (Hz) and a subjective characteristic of sound related to frequency is pitch.

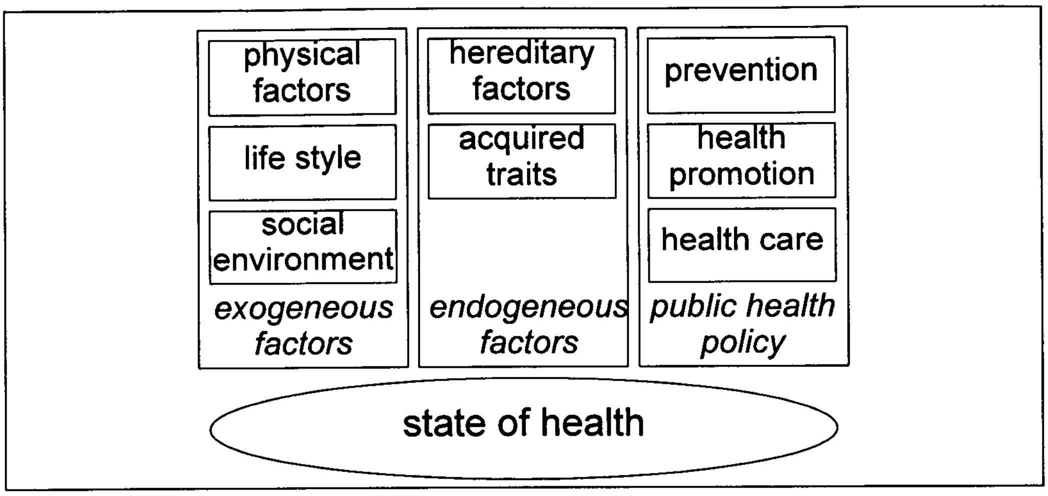

Figure 2.1 Model with factors which determine the state of health

The *sound pressure level* of a sound is expressed in decibels (dB). The commonly used symbol is L. Sound pressure level is related to the subjective characteristic loudness.

The *A-weighted sound pressure level* (expressed in dB(A)), often simply denoted as *sound level*, is used in a number of noise regulations. The A indicates that the sensitivity of the human ear with respect to frequency was taken into account. The A-weighted sound pressure level can be measured directly by a sound level meter using the A-weighting network.

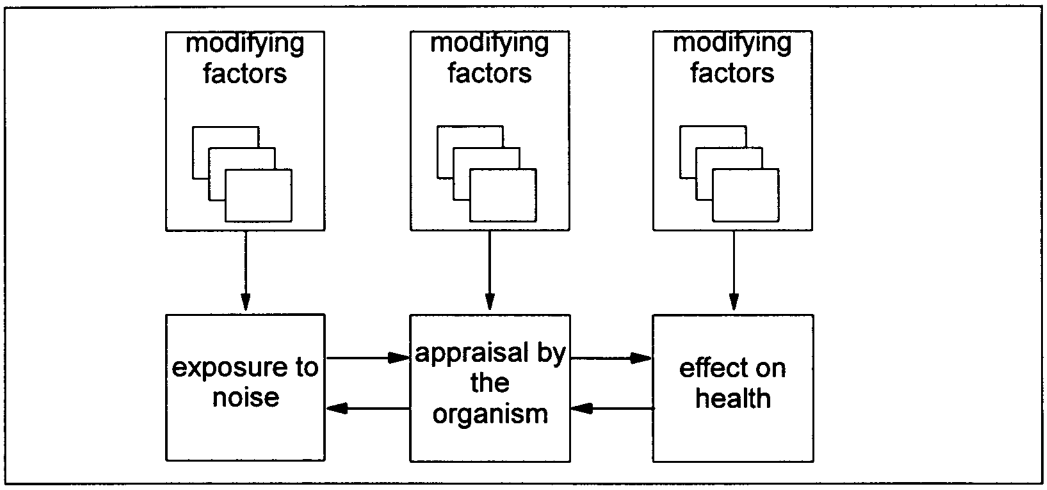

Figure 2.2 Model of the relation between noise exposure and effects on health.

To characterise noise of a more or less isolated event, noise measures such as the *maximum sound level* ($L_{A,max}$), the *peak level* (L_{peak}) and the *sound exposure level* (SEL or L_{Ax}) are in use.

For most purposes, values representative of longer exposure times are used. The *equivalent sound level* during a period T, $L_{Aeq,T}$, is such a value, which takes into account all sound levels during period T*.

For occupational and environmental noise exposure, equivalent sound levels are determined over several hours. $L_{EX,occ}$ is used for occupational noise exposure. It is derived from the equivalent sound level during a representative workday, with the duration of the workday set at 8 hours.

A weighted combination for environmental noise exposure can be computed from L_{Aeq} values during specific portions of the 24-h day, applying penalties to evening and/or to night-time values. In the Netherlands, the Noise Nuisance Act specifies noise exposure by its L_{etm} value**. L_{etm} is the maximum of the following three values: $L_{Aeq,07\text{-}19h}$, $L_{Aeq,19\text{-}23h}$ +5 and $L_{Aeq,23\text{-}07h}$ +10. In other countries L_{dn}*** is used to describe traffic noise exposure.

In the Netherlands, exposure to air traffic noise is usually expressed by the quantity B in the Kosten Unit (Kosteneenheid, Ke). B is determined from the maximum sound levels during overflights, the number of overflights and varying penalties for evening and night-time flights. Noise exposure from small airplanes is expressed in BKL-values**** in the Netherlands. With respect to night-time aircraft noise around main airports, in the Netherlands legal requirements are in preparation. In these requirements night-time exposure to aircraft noise is expressed in the equivalent sound level during a seven hour period of the night (23-07h) measured indoors, and taken on a yearly basis (WNN93).

Usually noise measures representative of noise exposure over a longer period of time are not mutually independent. Their relationship depends, however, on the circumstances (Mie92). For instance, for road traffic noise, the difference between L_{dn} and L_{etm} is often about 3 dB(A) ($L_{etm} \approx L_{dn} + 3$). The difference between the equivalent sound

* The equivalent sound level is by definition not a simple average of the sound levels during period T, since the higher levels are more taken into account than the lower ones; see annex C.

** 'etm' is the abbreviation of 'etmaal', the period of the 24-hour-day. The observation period in the determination of the various equivalent sound levels is one year.

*** 'dn' is the abbreviation of day-night; 07-22h and 22-07h, respectivily.

**** 'BKL' is the abbreviation of 'Belasting Kleine Luchtvaart' (Exposure caused by Small Aircrafts).

level over the 24 hour period and L_{etm} for road traffic noise is usually about 5 dB(A) ($L_{etm} \approx L_{Aeq,24h} + 5$).

For situations around civil airports the relation between B and L_{etm} depends primarily upon the distribution of the aircraft noise events during the day, evening and night. For a distribution* of aircraft noise of 80% during the daytime, 15% during the eveking and 5% during the night, $L_{etm} \approx 0.5$ B + 45 for B-values above 30 Ke.

2.3 Evaluating health effects from noise exposure

Data on effects of environmental factors on health are obtained from epidemiological studies and from experimental research with human subjects and with animals. In the case of noise exposure, animal studies are scarce and their results cannot be easily extrapolated to humans. In this report, with a single exception related to the susceptibility of children to noise-induced hearing loss, the results of animal studies do not play a role. The committee recognises, however, that animal studies have provided important indications about the underlying biological mechanisms.

Evidence of causal relationship

The International Agency for Research on Cancer (IARC87) rates the evidence that an agent is carcinogenic in humans according to four categories. The present committee used the same scheme in its evaluation of the scientific data on the health effects of noise exposure. The four categories are:

- *Sufficient evidence of causal relationship* indicates that such a relationship has been established. It implies that a relationship has been observed between noise exposure and a specific health effect in studies in which chance, bias and confounding factors could be ruled out with reasonable confidence.
- *Limited evidence of causal relationship*: an association was found between noise exposure and a health effect for which a causal interpretation is considered by the committee to be plausible, but for which chance, bias and confounding factors could not be ruled out with reasonable confidence.
- *Inadequate evidence of causal relationship*: the available studies are of insufficient quality, lack the consistency or statistical power to permit a conclusion regarding the presence of absence of a causal relationship.
- *Evidence suggesting lack of causality*: several adequate studies covering the full range of exposure, are available which are mutually consistent in not showing a

* This distribution was applicable to Schiphol Airport in 1992.

positive association between exposure and effect at any observed level of exposure.

In chapter 3, the committee will state, for each health effect described, whether it rates the available evidence as sufficient, limited or inadequate to support a causal relationship or as suggesting lack of causality.

Hill (Hil65) and Doll (Dol85) have published a set of criteria for evaluating the results of epidemiological research and assessing the evidence of causation, the most important of which are:

- *Consistency of association.* The association should be found in all or in most studies.
- *Magnitude of association.* The stronger the effect of the environmental factor appears to be, the more probable a causal relationship becomes.
- *Exposure-response relationship.* If causality exists, a change in exposure should be reflected by a change in response.
- *Supporting biological data.* The effect should be confirmed by experimental research.
- *Time pattern of exposure and response:* considered over time, exposure should precede and/or accompany response.
- *Plausibility.* The mechanism of action should be understandable on the basis of biophysical and biochemical theory.

The committee took into consideration these criteria for rating the evidence for a causal relationship between noise exposure and an effect on health. There are, however, in the report no specific references to these criteria.

Exposure-effect relationship

If specific health effects can be linked causally to noise exposure, the nature of the relationship between exposure and response becomes of interest. This relationship will depend on a number of factors, e.g. the biological mechanism of action, the individual susceptibility and modifying factors (see figure 2.1 and 2.2). The committee will express its evaluation of the data on exposure-effect relationships in the following way:

- *Exposure-effect functions.* If extensive and reliable data from epidemiological research are available, the exposure-response relationship can be expressed in quantitative terms. Should this be the case, the committee will provide references to the data describing the exposure-effect function.

- *Observation threshold.* The committee defines the observation threshold as the lowest exposure value at which on average an effect from exposure to noise has been observed in epidemiological studies. If an exposure-effect function was established for a given effect, e.g. noise-induced hearing loss, the observation threshold is derived from this function. To determine observation thresholds for the various noise-induced health effects, the committee used the information presented in the background study (Pas93a,b).
- *Susceptible groups.* Specific (groups of) individuals of the population may be more susceptible to an effect of noise exposure than are "average" individuals. The committee will indicate whether there is evidence of groups with high susceptibility and, where possible, indicate the consequences of this susceptibility.

In this report observation thresholds are used in the evaluation of the effects of noise on health. For other environmental factors usually other terms, such as health based exposure limits are in use. The conclusion section of this report will touch upon this subject. To show in which way an observation threshold was derived in this report, the following may serve as an example. In table 4.7 of the background study (Pas93a,b) the results from epidemiological studies on the effect of traffic noise on the prevalence of ischaemic heart disease in 19 populations have been presented in terms of relative risk. Averages of the relative risks of the various subpopulations, splitted up according to exposure level, are - relative to exposures with equivalent sound levels (06-22 h) below 60 dB(A) - 1.02, 1.01, 1.5 at exposures of 60-65 dB(A), 65-70 dB(A), > 70 dB(A), respectively. The average relative risk for ischaemic heart disease appeared to be 1.5 for traffic noise exposures with equivalent sound levels (06-22h) larger than 70 dB(A). Therefore, the committee concluded the observation threshold for ischaemic heart disease to be 70 dB(A) in the case of traffic noise.

Chapter **3**

Effects of noise on health

3.1 Noise-induced hearing loss

3.1.1 Occupational noise exposure

Relations between noise exposure and noise-induced hearing loss

The second edition of ISO 1999 'Acoustics - Determination of occupational noise exposure and estimation of noise-induced hearing impairment' (ISO90) gives a calculation method for the determination of hearing threshold levels of populations exposed to all types of noise (steady-state, intermittent and impulse) during working hours. The noise exposure is characterised by the noise exposure level, L_{EX}. In this report L_{EX} is denoted by $L_{EX,occ}$, indicating the exposure concerns an occupational one. Relations are given between $L_{EX,,occ}$ and noise-induced permanent threshold shift (NIPTS) for frequencies in the range from 500 to 6000 Hz, and for exposure times up to 40 years. These relations are expressed in statistical terms (median values of NIPTS as well as values from the 0.05 to the 0.95 fractile). The relations show that NIPTS is a phenomenon which occurs predominantly in the higher frequency range from 3000 to 6000 Hz; the effect is largest at a frequency of 4000 Hz. With increasing equivalent sound level and increasing exposure time, hearing loss also occurs at the lower frequencies, more specifically at 2000 Hz. For prolonged occupational noise exposure, ISO 1999 shows that permanent threshold shift is not induced by noise with $L_{EX,occ}$ values at and below 75 dB(A).

The value of 75 dB(A) below which there occurs no noise-induced permanent threshold shift from occupational noise exposure had already been given by the World Health Organisation in 1980 (WHO80). Also the draft Physical Agents Directive of the European Union specifies this level at 75 dB(A).

Exposure to impulse noise

There is evidence that temporary effects on hearing from exposure to impulse or impact noise are different from those of exposure to more or less steady-state noise. However, epidemiological studies could not show any systematic difference between permanent threshold shifts from occupational exposure to impulse or impact noise and from steady-state noise (Pas89a) with the same equivalent sound level. Regarding shooting noise this seems to hold only for equivalent sound levels up to 85 dB(A) over a period of 8 hours; for higher equivalent sound levels shooting noise may be more damaging than should have been expected from its equivalent sound level (Smo82).

At very high levels mechanical damage of the hearing organ may occur. To avoid this, adults should not be exposed to peak levels exceeding 140 dB. Possibly, for children a lower value is appropriate. This value is, as yet, unknown.

Identifying sensitive persons

ISO 1999 shows that variation in human sensitivity to noise-induced permanent threshold shift increases with noise exposure level; variation is considerable at high equivalent sound levels. However, there are as yet no tests for identifying individuals that may be susceptible to noise-induced hearing loss before the hearing damage occurs. ISO 1999 presumes females and males to be equally susceptible.

3.1.2 Non-occupational noise exposure

Non-occupational noise exposure can be divided into four categories:

- exposure to environmental noise in the living environment such as: traffic, industrial and residential noise
- exposure to noise from home-based activities
- exposure to noise from traffic during travel between home and work/school
- exposure to noise* during leisure.

* noise includes music

The committee is of the opinion that extrapolation of the calculation scheme in ISO 1999 to (a combination of) the daily non-occupational noise exposures as specified above is justified. This implies that, for adult populations, a permanent threshold shift is not induced by noise with $L_{Aeq,24h}$ values at and below 70 dB(A), whether noise exposure is prolonged or not.

The committee regrets the lack of information on the patterns of exposure of populations to non-occupational noise. Due to this lack of information, only global estimates can be made and general conclusions be drawn concerning noise-induced hearing loss from non-occupational noise exposure.

3.1.3 *Susceptible groups*

A pregnant woman's exposure to noise may affect the hearing of the unborn child. The two epidemiological studies that examined the hearing acuity of young children with mothers who had been exposed to occupational noise during pregnancy, both showed an increase in percentages of children with high-frequency hearing loss. On the basis of these results, the committee concludes that equivalent sound levels of 85 dB(A) or higher during an 8-hour working day appear to be detrimental to the hearing of the unborn child. It recommends that further research should be undertaken to verify whether, at equivalent sound levels lower than 85 dB(A), increased hearing loss in young children occurs, especially when it concerns exposure to low frequency noise and vibrations.

Data from animal experiments indicate that young children may be more susceptible to noise-induced permanent threshold shift than adults. Such an increased susceptibility has not been confirmed by epidemiological studies in human populations. Spreng (Spr90) considers a difference of 5 dB(A) applicable for certain types of exposures.*.

Males exposed to occupational noise, who have high plasma cholesterol levels in blood, have an increased risk of noise-induced hearing loss in comparison to occupational noise exposed male populations with normal cholesterol levels (Axe85a).

3.1.4 *Social consequences of hearing loss*

The main social consequence of hearing damage concerns the inability to understand speech under day to day living conditions. Since speech is the most common means of

* This concerns exposures with rapid increases of the sound level, such as in the case of low-flying fighter-jets. The middle ear of children may then react differently from that of adults.

communication between people, a decreased understanding of speech should be considered a severe social handicap.

In the case of the combination of age-related hearing loss (presbyacusis) and occupational noise-induced hearing loss, decrease in speech intelligibility is a process which may proceed over years. Understanding speech first starts to become difficult in noisy surroundings (cafeterias, parties, noisy meetings). Next, difficulties occur during church services, theatrical performances and public meetings, even when people with hearing damage place themselves close to the speaker. Once the hearing impaired start compensating for their handicap, others will recognise the decreased hearing capacity. In the next stage, telephone calls start to present problems and conversations in fairly quiet surroundings become difficult, the more so when they involve strangers. Eventually, understanding the speech of close friends and family starts to become critical. A decreased hearing capacity can be partially compensated by lip reading, even without the hearing-handicapped listener being aware of it.

Even small values of hearing damage may have an effect on understanding speech in normal live. In investigations of groups of people with noise-induced hearing loss, a decrease in speech understanding has been observed at hearing threshold levels from 10 dB, averaged over 2000 and 4000 Hz and averaged over both ears (Smo86, Pas85). When the hearing threshold level exceeds 30 dB, again averaged over 2000 and 4000 Hz and over both ears, the hearing damage becomes a noticeable social handicap (Smo86, Pas87a,b).

3.1.5 Classification of health effects

The committee is of the opinion that there is sufficient evidence for a causal relationship between noise and hearing loss. Exposure-effect functions are specified in ISO 1999. For occupational noise exposure $L_{EX,occ}$ is taken as noise measure and for non-occupational noise exposure $L_{Aeq,24h}$ is the measure to be used. Observation thresholds correspond to a value of $L_{EX,occ}$ of 75 dB(A) and a value of $L_{Aeq,24h}$ of 70 dB(A).

Although there is sufficient evidence for a causal relationship between occupational noise exposure during pregnancy and hearing loss in babies, the available data do not allow it to be specified whether and to what extent hearing loss occurs below a value of $L_{EX,occ}$ of 85 dB(A).

3.2 Noise-induced stress-related health effects

3.2.1 Stress

The reactions to a stressor can be of a psychological, behavioural and somatic nature. Psychological effects concern feelings of fear, depression, frustration, irritation, anger, helplessness, sorrow and disappointment. Examples of behavioural reactions to a stressor are social isolation, agression and resort to excessive use of alcohol, tobacco, drugs or food. Psychological and behavioural stress may have a direct or indirect effect on physiological processes within the body.* A great number of laboratory experiments have demonstrated changes in various somatic, physiological and biochemical factors in humans due to acute noise exposure. These experimental studies show that noise should be considered as an unspecific stressor that stimulates central nervous system and hormonal activity (Isi93, Mar88, Mar90).

Research into long-term noise-induced stress-related health effects has been limited mainly to cardiovascular disorders. To a far lesser extent, epidemiological research has been carried out regarding changes in biochemical parameters and parameters of the immune system. There is a complicated interaction between the hormonal and immune system. Hormones produced by the pituitary gland interact with immune factors, whereas both hormones and immune factors have an impact on the brain. The connections with parts of the limbic system, the system which largely determines emotional activity, are also of importance.

Research into the chronic effects of long-term exposure to noise involves inherent difficulties:

- Cardiovascular and biochemical changes are non-specific; a number of other factors may cause these changes, some of the factors possibly not yet being identified. A major problem in epidemiological research is to control these factors.

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* In this respect, it is not always obvious in the analysis of the results of an epidemiological study whether observed differences in behaviour of a noise-exposed group and of a group of people not exposed to noise should be considered as a direct or indirect result of exposure to noise or as a confounding factor. Take as an example effects of traffic noise on the prevalence of ischaemic heart disease and on smoking, presuming that smoking is a risk factor for this heart disease. It could be argued that smoking is associated with stress and that due to stress from daily exposure to high levels of road traffic noise, the relative number of people smoking and the cigarettes smoked increase. Smoking should then not be considered as a confounding factor and corrections should not be applied on the test results with respect to this factor. On the other hand, should smoking be considered as a confounder, corrections should be applied, when exposure to noise is associated with ischaemic heart disease in the analysis of the test results.

- In epidemiological research it is time-consuming and difficult to obtain good quantitative data about the noise exposure, especially about past exposure. For example, noise maps of cities may be used in road traffic noise studies. Using these maps could give a non-systematic misclassification of the noise exposure of some inhabitants. Such a misclassification will obscure a noise-induced effect.
- People intervene to a certain extent in their own living and working situation, e.g. by moving to more quiet surroundings or by changing their job. This may result in a selection in which people who are 'noise-proof' will remain in noisy situations and those who are not will leave the situation.
- There are great differences in individual susceptibility.

3.2.2 *Cardiovascular effects in the working environment*

Epidemiological research into the long-term stress-related health effects has been focused on changes in the blood pressure of workers exposed to occupational noise and on the prevalence of hypertension among these workers (Dij84, Isi80a, Isi93; for other references see Pas93a,b). Hypertension has been defined, according to the World Health Organisation, as a systolic blood pressure of at least 160 mmHg* and/or a diastolic blood pressure of at least 95 mmHg.

The committee concludes that prolonged exposure to occupational noise may contribute to increased blood pressure and hypertension. These effects have been shown to occur at equivalent sound levels during the working day of at least 85 dB(A). Effects of chronic exposure at lower noise levels such as in offices have hardly been studied.

Other noise-induced effects on the cardiovascular system have been observed in workers exposed to high or extremely high equivalent sound levels during the working day, such as an increase in abnormalities in the electrocardiogram, more heart beat irregularities, faster pulse rate, faster increase in heart rate during a physical test and slower recovery of vascular constriction during a noise exposure test. Apart from abnormalities in the electrocardiogram, the other noise-induced effects seem not be detrimental to health, taken into account the extent of the effects in so far they were due to noise exposure.

3.2.3 *Cardiovascular effects in the living environment*

Long-term effects of exposure to noise in the living environment have only been investigated in relation to road and air traffic noise to which people are exposed in their own homes (Alt87, Alt89, Bab88, Bab90, Bab92, Bab93a,b, Bie89a,b, Isi80b, Isi93,

* 1 mmHg corresponds to approximately 0.13 kPa.

Jon92b, Kni76; for other references see Pas93a,b). These exposures are usually much lower than those to occupational noise, but the exposed population is much greater. A complicating factor in the determination of noise exposure in homes is that people are not only exposed to traffic noise, but also to various, often even louder, noises from other sources. Furthermore, housing features (e.g. single or double glazing) and personal habits (e.g. closing windows, moving to quieter sides of the house, staying indoors during the summer) affect the actual noise exposure.

Several studies on the effects of traffic noise have had the occurrence of changes in blood pressure and hypertension, and the risk of ischaemic heart disease as their subject. Epidemiological studies show that, in general, there are no obvious effects from exposure to traffic noise on the mean systolic and diastolic blood pressure, except in children. However, the committee considers the observed increase of, at most, 10 to 15 mmHg (Coh80, Kar68) in the average systolic and diastolic blood pressure in children to be of a temporary nature and not relevant for permanent health damage.

The committee draws the following conclusions from the results of epidemiological research:

- there is little evidence for an increased risk of hypertension and of ischaemic heart disease in people living in areas with traffic noise at outdoor equivalent sound levels (from 06 to 22 hours) below 70 dB(A)*
- the relative risk of ischaemic heart disease and of hypertension starts to increase for persons living in areas with road or air traffic noise at equivalent sound levels above 70 dB(A) (from 06 to 22 hours).

3.2.4 *Biochemical effects*

Epidemiological studies on the effects of high to very high environmental and occupational noise exposures on the biochemical** composition of the blood of exposed people mostly show noise-induced changes which should be expected if noise acts as stressor. Several studies also show changes which indicate an increased risk of ischaemic heart disease (Bab88, Bab90, Bab92, Bab93, Isi80b,c). However, there are only limited data available. Therefore the committee is unable to establish to what extent changes in blood composition occur under which particular environmental and occupational circumstances. However, laboratory studies with volunteers show that such effects may occur.

* There are some indications that this value might have to be lowered to 65 dB(A) once the results of additional studies become available.

** This concerns specific hormones and metal-ions (Mg^{2+}).

3.2.5 *Effects on the immune system*

No epidemiological investigations except for the Caerphilly and Speedwell Collaborative Heart Disease Studies (Bab92, Bab93) have been carried out into the effects of noise on the immune system. This study has revealed an increased concentration of leucocytes in blood in the case of exposure to high levels of road traffic noise.

Effects on the immune system might ultimately lead to an increased prevalence of infectious diseases, such as influenza and inflammations, and possibly cancer. No epidemiological studies concerning such effects of noise exposure have been reported.

3.2.6 *Effects on the unborn child*

In view of the available research data, it cannot be excluded that noise exposure of pregnant women to air traffic noise in the *living* environment may affect the birthweight of the baby. Should a reduced weight at birth occur, this is only at noise exposures with L_{dn} values greater than 62 dB(A) (more than 40 Ke). The available data virtually exclude an aircraft noise-induced risk of the occurrence of congenital defects.

The studies on the health of babies whose mothers were exposed to *occupational* noise during pregnancy suggest that there does not seem to be a higher risk of lower birthweight and of premature birth; the results with regard to congenital defects are contradictory, whereas those related to increased risk of spontaneous or imminent abortion and death at birth are questionable.

3.2.7 *Susceptible groups*

People highly annoyed by low levels of road traffic noise have an increased risk of hypertension. Men exposed to high levels of road traffic noise in the living environment and also exposed to occupational noise have an increased risk of ischaemic heart disease compared to men exposed to road traffic noise only (Bab90). Pregnant women exposed to occupational noise show an increased risk of hypertension during pregnancy, compared to pregnant women not exposed to occupational noise. People with noise-induced sleep disturbance have an increased risk of hypertension and ischaemic heart disease compared with people in the same living environment without sleep disturbance (Isi93). Exposure of hospitalised patients to relatively high levels of noise from sources inside or outside the hospital delays recovery and wound healing.

3.2.8 *Classification of health effects*

The committee is of the opinion that the following classificatios are applicable:

- biochemical effects: limited evidence
- hypertension: sufficient evidence
- ischaemic heart disease: sufficient evidence
- effects on immune system: limited evidence
- birthweight: limited evidence
- congenital defects: evidence suggesting lack of a causal relationship.

For occupational industrial noise-induced hypertension, the observation threshold probably has a value of $L_{EX,occ}$ below 85 dB(A). For groups exposed to values of $L_{EX,occ}$ of 90 dB(A) and above the relative risk is 1.7.

For environmental road- and air traffic noise-induced hypertension the observation threshold has a value of $L_{Aeq,06-22h}$ of 70 dB(A) (measured outdoors). For ischaemic heart disease the same value is applicable. Groups exposed to higher values (70 to 80 dB(A)) will have a relative risk of hypertension and of ischaemic heart disease of about 1.5.

3.3 Psycho-social effects

Subjects studied in epidemiological research with respect to psycho-social effects from noise in the living environment include noise annoyance, effects on psycho-social well-being and the question of whether noise-induced feelings of irritation have such an impact that they increase the number of admissions to psychiatric hospitals. Effects studied in the working environment concern annoyance and increased absenteeism from the worksite.

Noise annoyance is a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with someone's thoughts, feelings or actual activities. The capacity of a given sound to annoy depends on its physical characteristics including sound level, spectral characteristics and variations with time. These variables are characterised by onset times, durations and repetition rates. However, annoyance also depends on non-acoustical, cognitive factors, such as fear with regard to the noise source, the conviction that the noise exposure could be reduced by third parties, individual noise sensitivity, the degree to which an individual feels able to control the noise, whether the noise stems from a new situation or technology, and, to a lesser extent, the recognition that the noise source gives rise to problems other than mere noise exposure or that it results from an important economic activity.

Demographic variables - age, sex, socio-economic status - are almost unrelated to annoyance from a given noise source.

Noise annoyance and psycho-social well-being can both be evaluated using questionnaires. Psycho-social well-being concerns depression, relaxation, activity, passivity, aggression, general well-being and social aspects, such as group interaction and willingness to help.

3.3.1 *Annoyance in the living environment*

Noise from road traffic, trains and airplanes

Recently defined exposure-effect functions relate annoyance to exposure to various types of traffic noise in the living environment (Mie92). Severe* annoyance by noise from several types of traffic (aircraft, highway traffic, other road traffic, railroad traffic) starts to occur at L_{dn} values of 42 dB(A), annoyance starts at L_{dn} values of 37 dB(A) and some annoyance at 32 dB(A). These L_{dn} values were measured outdoors, in front of the dwellings. Annoyance increases most with L_{dn} for aircraft noise, followed by highway traffic noise, other road traffic noise and railroad noise. For the traffic noise exposures that were considered, there is a close relationship between $L_{Aeq,24h}$, L_{etm} and L_{dn}, due to a high correlation between the equivalent sound levels during the day and those during the night.

Noise from high-speed trains

Noise from high-speed trains is of special importance these days, in view of the plans for a high-speed train network in Europe, including the Netherlands. Based on measurements made abroad, on the acoustical characteristics of this type of train noise and on the projected future use of highspeed trains, De Jong (Jon93) concludes that annoyance from noise produced by high-speed trains in the Netherlands will not exceed annoyance caused by conventional trains with equal L_{etm} values.

Noise from helicopters and small aircraft

Noise from helicopters differs from that of conventional airplanes due both to the characteristic sound of the rotating blades (blade slap) and to the helicopter's lower speed, which make helicopters audible during a longer period. Furthermore, helicopters do

* Miedema defines severe annoyance as annoyance of at least 72 (on a scale with a lower boundary of 0, corresponding to being not at all annoyed, and an upper boundary of 100, corresponding to being extremely annoyed) (Mie92).

not only pass an area, but often also circle above it for some time. This last comment is also applicable to some types of small aircraft.

Annoyance from passing helicopters and small aircraft has been found to be comparable to annoyance from conventional aircraft only when the duration of the noise is taken into account. Expressing exposure to helicopter noise in Ke is therefore not advisable, as this measure does not take the duration of noise events into account.

Noise of low-flying fighter jets

Noise of low-flying fighter jets, with flight paths with a minimum height of 75 meter, contrasts with that of civil aviation in several aspects:

- under the low-flying corridor, the maximum sound level of an overflight is relatively high
- this very high level is not restricted to the surroundings of the airport, since low-flying corridors can be situated elsewhere
- the onset time of the noise from a low-flying fighter jet is relatively short.

It is estimated that noise from low-flying fighter jets is as annoying as noise from conventional aircraft with a 10 dB(A) higher equivalent sound level (Pas93a,b). Other effects in addition to annoyance, are to be expected. These include psychological effects such as fear and panic in adults and children.

Other noise sources in the living environment

Noise from stationary sources, such as industry, shunting-yards and artillery-ranges is more annoying than traffic noise, especially when the noise contains impulse or impact components (Vos85a, Vos85b). Annoyance from shunting-yards is comparable to that from passing trains for L_{dn} values up to about 60 dB(A), but is much more annoying at higher levels (Mie92).

There exists a relation between annoyance from indoor noises from neighbouring dwellings and the sound insulation between dwellings: low values of sound insulation resulting in high percentages of people annoyed. Due to the large variability in the levels of outdoor noises from neighbours and noises in the neighbourhood of private homes, e.g., people shouting, slamming car doors, the sound of car horns and lawnmowers, and the variety of non-acoustical factors that also determine annoyance, it is difficult if not impossible to determine exposure-effect relations for these types of noises.

Accumulation of noise exposures

When people are exposed to more than one environmental noise source, annoyance is cumulated. Weighted summation of the annoyance effects provides a fair description of the accumulation (Mie93, Vos92). The resulting annoyance from two noise sources is sometimes much larger than the annoyance expected from the most disturbing source alone (Mie93).

3.3.2 *Psycho-social well-being*

The limited research carried out with respect to effects from exposure to road traffic noise on psycho-social well-being does not permit a definite conclusion. Two investigations showed psycho-social well-being to be decreased in people living in very noisy areas (equivalent sound levels during the daytime over 70 dB(A)) compared to that of people living in quiet surroundings. This concerned social orientation, activity and depression. The third investigation showed psycho-social well-being of people not to be related to the noise level as determined in front of their dwelling, but to their noise sensitivity and to the extent to which noise penetrates into their bedroom and disturbs sleep (Ohr89, Ohr91).

3.3.3 *Effects on admission to psychiatric hospitals*

For some people psychological stress may lead to admission to psychiatric hospitals. A number of factors other than noise exposure in the living environment are involved in such admissions. The effect of aircraft noise in this respect has been studied in the vicinity of Heathrow Airport in the past twenty years. Taking into account several intervening factors, the most recent analysis showed a statistically significant increase in the percentage of admissions to psychiatric hospitals with exposure to aircraft noise. In areas with L_{dn} levels of more than 70 dB(A) (B more than 55 Ke) due to air traffic noise, admission to psychiatric hospitals was higher than in areas with L_{dn} values of less than 65 dB(A) (B less than 45 Ke); the prevalence ratio found was 1.1 (Kry90). However, since a causal relationship was shown in only one investigation and in only one analysis, the committee is of the opinion that care should be taken to generalise this relation to other situations and other populations.

3.3.4 *Annoyance in the work environment*

No relations have been established between noise annoyance experienced during working hours and noise level (Mie85). Only a very small part of the variance in annoyance in the workplace is attributable to variations in noise exposure. The following non-acoustic variables have a much greater effect than noise level on annoyance during working hours:

- meaningfulness and information content of the noise (discussions by colleagues in the surroundings of the workplace score high in this respect)
- predictability, avoidability and controllability of the noise
- attitude of the workers towards the noise source
- task demand
- individual susceptibility.

Annoyance in offices is already considerable at equivalent sound levels above 55 dB(A) during working hours. The few available results of epidemiological investigations show that 35% to 40% of the office workers exposed to an equivalent sound level of 55 to 60 dB(A) are severely annoyed. In industrial situations similar percentages of annoyed workers occur at equivalent sound levels over 85 dB(A). These results do not allow the determination of observation thresholds for annoyance in office and industrial workers.

3.3.5 *Effect on absenteeism in the work environment*

Epidemiological studies suggest that the absentee rate increases if workers are exposed to higher equivalent sound levels during work. This was demonstrated for various industrial situations at equivalent sound levels higher than 75 dB(A) in one study (Mel92; CORDIS-study: Cardiovascular Occupational Risk Factor Detection in Israel*) and in another study in the coal and steel industry (Sch91) at equivalent sound levels higher than 90 dB(A)**. On a small scale, a statistically significantly higher*** absentee rate was shown in office workers who were (very) frequently exposed to clearly audible noise events, compared to those seldom exposed to such events (Sch82). However, some of these studies have insufficiently taken into account confounding variables and others are flawed in other aspects. Therefore, the committee concludes that no causal relationships between absentee rate and industrial occupational noise exposure or exposure to noise in offices has yet been demonstrated conclusively.

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* In this study the prevalence ratio was 1.2 for equivalent sound levels from 75 to 85 dB(A) and 1.7 for higher sound levels.

** In this study the prevalence ratio was 1.1.

*** In this study the prevalence ratio was 1.3.

3.3.6 *Sensitive groups*

People annoyed by noise in the workplace show an increased post-work irritability which might affect their general well-being. Noise-sensitive people, people with fear of certain noise sources and people feeling they have no control over a noise situation (i.e. feel an abuse of power) have an increased risk of severe annoyance.

3.3.7 *Classification of health effects*

The committee is of the opinion that the following classifications are applicable:

- annoyance in the living and work environment: sufficient evidence
- psycho-social well-being: limited evidence
- admission to psychiatric hospitals: limited evidence
- absenteeism from work: limited evidence.

Exposure-effect functions have been specified (Mie93) for annoyance from environmental exposure to traffic and industrial noise . The observation threshold for severe annoyance corresponds to a value of L_{dn} of 42 dB(A).

Exposure-effect functions for annoyance from occupational noise exposure in offices as well as in industrial situations are lacking. Observation thresholds for office noise and for industrial noise exposure are well below $L_{EX,occ}$ values of 55 respectively 85 dB(A). At these values, the fraction of workers severely annoyed amounts to 35% to 40%.

3.4 Sleep disturbance

3.4.1 *Effect of noise on sleep*

Night-time noises can disturb sleep (Gri76, Gri90a,b, Hof91, Hof92b, Jur83, Luk75, Mie93, Ohr83, Ohr88, Oll92, Pea89, WNN93). According to the advisory report of the Health Council on airplane noise and sleep (GR91), external factors such as noise may affect sleep in different ways, resulting in:

- degradation of sleep quality
- disturbance of functioning or performance the next day
- disturbance of mood the next day.

Since many of the underlying experimental and epidemiological studies concern exposure to a wide range of types of noise sources, the conclusions about the influence of aircraft noise on sleep in the former Health Council report are also largely applicable to exposure to other types of intermittent traffic noises.

3.4.2 *Effects on sleep quality*

Sleep quality may be affected in various ways:

- by changes in sleep pattern
- by changes in sleep stages from deeper to less deep sleep
- by awakening during the sleeping period
- by changes in subjective assessment of sleep quality
- by changes in cardiovascular and hormonal parameters
- by changes in the immune system.

Sleep pattern

Night-time noise of sufficient intensity changes the sleep pattern in such a way that it increases the time awake during the sleep period and increases sleep latency (the time between lights out and falling asleep). According to the committee the results of experimental and epidemiological research do not permit the assessment of a level above which the sleep pattern starts to worsen. It is recognised, however, that at high levels of traffic noise a significantly greater percentage of the exposed population reports difficulties falling asleep than at lower levels.

Changes in sleep stages and awakening

The sleep stages can be determined from electro-encephalograms (EEGs), measured while the subject is falling asleep and during sleep. The EEG is a continuous recording of the electrical activity of the cerebral cortex. The EEG, together with the electro-oculogram (EOG), indicate the sleep stages: W (waking), 1, 2, 3, 4, REM (Rapid Eye Movements).

For intermittent noise exposures such as produced by aircraft, trains and road traffic, various exposure-effect relations between the characteristics of night-time noise exposure and awakening and sleep stage changes have been derived. Figures 3.1 and 3.2 show these exposure-effect relations. The curves proposed by Griefahn (Gri76) and by Lukas (Luk75) are mainly derived from laboratory experiments. The curves of Pearsons (Pea89) distinguish between laboratory and epidemiological studies. The curve derived from the research by Ollerhead (Oll92) concerns epidemiological research. Comparison of the exposure-effect relations from field and laboratory studies supports the hypothesis that habituation results in fewer awakening reactions. This,

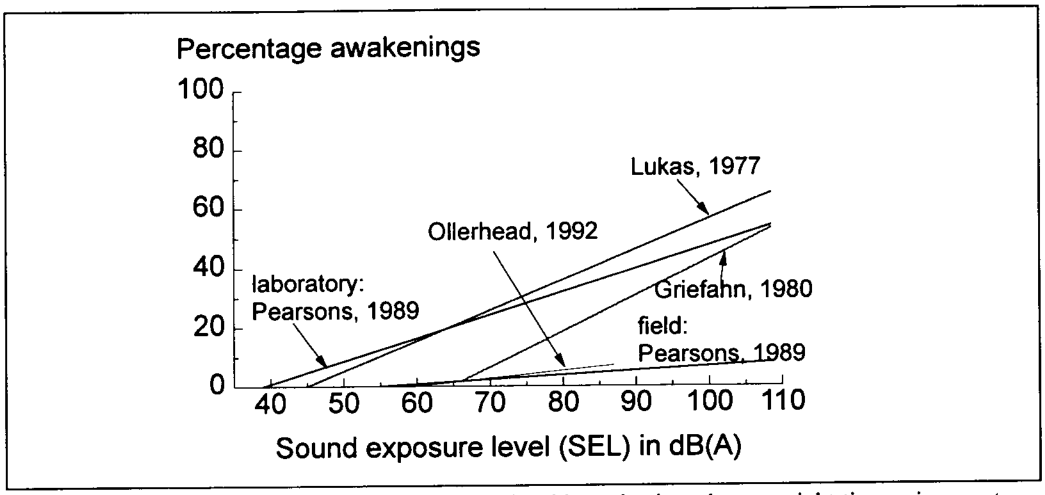

Figure 3.1 Relations between the percentage of people with awakenings due to a night-time noise event and the indoor sound exposure level of such an event.

however, seems less correct for changes between different stages of sleep, a statement which is supported by the results of the joint European field investigation (Jur83) into sleep disturbance. In the two field studies (Pea89, Oll92), the onset of noise-induced awakenings is found to be at a SEL of about 60 dB(A), measured indoors. The onset of noise-induced changes between sleep stages is found at a SEL value of about 35 dB(A). Based on the preliminary exposure-effect relation derived from the two field studies, the total number of awakenings and sleep stage changes during all nights of the year have been estimated as a function of the equivalent sound level indoors during the night (23-07h) due to aircraft noise, where this equivalent sound level during the

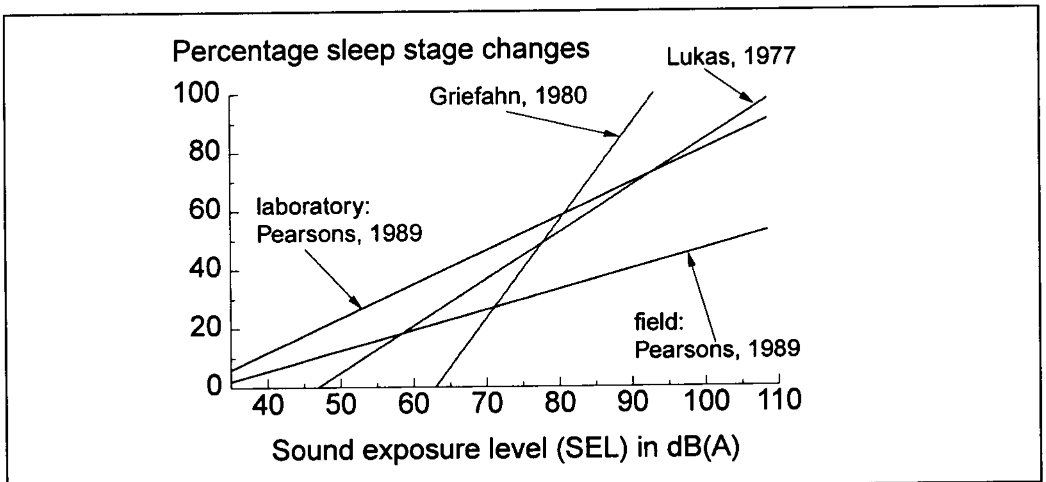

Figure 3.2 Relations between the percentage of people with sleep stage changes due to a night-time noise

night has been taken on a yearly basis (Pas94). This equivalent sound level has been taken as the noise exposure measure in the preparation of legal requirements concerning night-time flights around main airports in the Netherlands (WNN93).

Subjective sleep quality

The subjectively experienced quality of sleep of people exposed to high levels of night-time noise is lower than that for non-exposed people, even for persons who have lived for years in noisy surroundings (Jur83, Ohr89, Ohr90, Ohr91, Sch90, Mie93). In one investigation (Mie93) data on self-reported sleep disturbances due to traffic noise were gathered from questionnaires on noise annoyance. Analysis of these data indicated that at outdoor equivalent sound levels during the night (23-07h) from 40 dB(A) subjective sleep quality started to decrease. The committee is of the opinion that there is yet insufficient information to permit determination of the exact exposure-effect relation between subjective sleep quality and night-time noise, especially not at the lower noise exposure values, but that it is justified to take an equivalent sound level of 40 dB(A) during the night as observation threshold.

Cardiovascular and hormonal parameters during sleep

Night-time noise exposure may increase heart rate during the night; habituation to this effect does not seem to occur. The observation threshold is equal to a SEL value of 40 dB(A), measured indoors.

The effect of night-time noise on the endocrine system has so far not been investigated in epidemiological studies, but only in a laboratory study (Gru92, Mas92). The latter study concerned changes in epinephrine* and norepinephrine* excretion in urine as a function of aircraft noise exposure. Statistically significant effects could be observed at indoor equivalent sound levels of 35 dB(A) (64 overflights). The study has been reported (Isi93) to show a high correlation between epinephrine levels and sleep stage changes. The committee is of the opinion that further research is necessary before conclusions can be drawn for hormonal effects.

The immune system during sleep

Only in a Japanese laboratory study by Osada (Osa68, Osa69, Osa72, Osa74) in the period from 1968 to 1974 were changes in the percentages of leucocytes and granulocytes in blood measured. The committee does not consider the results of the Osada

* The hormones epinephrine and norepinephrine are also denoted by adrenaline and noradrenaline. They are hormones related to stress.

research as proof of an effect of noise exposure during sleep on immune system function. Although noise exposure at night may affect the immune system, as daytime noise exposure may do, experimental confirmation of such an effect is still lacking.

3.4.3 After-effects

The performance during the day, in relation to noise exposure during the previous night, is usually measured by testing reaction time. Epidemiological research showed that the reaction time of residents exposed to night-time noise for years was longer when they had been exposed to more noise during the previous night (Jur83). The committee is, however, of the opinion that the available data do not allow levels to be specified at which these noise-induced effects on performance the next day start to occur. Most studies into the effect of night-time noise on mood the succeeding day showed a decrease in mood of persons exposed to high levels of night-time noise. An outdoors equivalent sound level of 60 dB(A) during the night is the observation threshold.

3.4.4 Sensitive groups

The ill people, older people and people with sleeping difficulties show more noise-induced sleep disturbance, especially with respect to inability to fall asleep (after being awakened), than do other adults. Older people also have an increased risk of being awakened by night-time noise (WNN93).

3.4.5 Classification of health effects

According to the committee the following classifications apply:

- changes in sleep pattern: sufficient evidence
- changes in sleep stages and awakening: sufficient evidence
- subjective sleep quality: sufficient evidence
- heart rate frequency: sufficient evidence
- hormonal system: limited evidence
- immune system: inadequate evidence
- mood next day: sufficient evidence
- performance next day: limited evidence

Although the committee has concluded that there is sufficient evidence for a causal relationship between night-time noise exposure and various effects on sleep, exposure-effect functions are lacking for some of these effects. Exposure-effect functions have been specified for awakening and for sleep stage changes with exposure specified as SEL-values (Pea89). Observation thresholds for the various noise-induced effects are with exposure specified as SEL-values:

- awakening: a SEL value (measured indoors) of 60 dB(A)
- sleep stage changes: a SEL value (measured indoors) of 35 dB(A)
- changes in heart rate: a SEL value (measured indoors) of 40 dB(A).

The number of awakenings and sleep stage changes have been related to the equivalent sound level during the night due to aircraft noise (near main airports) with the noise exposure taken on a yearly basis (Pas94).*

The observation threshold for subjectively experienced deterioration of sleep quality is found at a value of $L_{Aeq,night}$ of 40 dB(A), measured outdoors. After-effects, the day following night-time noise exposure, on mood and, presumably performance, have observation thresholds at night-time equivalent sound levels of 60 dB(A) measured outdoors.

3.5 Effects on performance

Laboratory studies with test subjects have shown that noise exposures may have a significant effect on performance. While a task is being performed, noise may in test subjects increase arousal, alter the choice of task strategy, and decrease attention to the task. Noise may also affect social performance, mask speech and impair communication and it may distract attention from relevant social cues. When a task involves auditory cues, and these auditory signals are masked by noise, this will have an effect on task performance.

Even relatively low noise levels may have acute adverse effects. It is obvious from laboratory experiments that to a large extent habituation occurs. Performance of a task involving motor and monotonous activities is not always disturbed by noise; noise (music) can also enhance performance in these situations.

Due to the complex character of noise-induced effects on task performance and the many non-acoustical factors involved, no exposure-effect relations were drawn up.

People whose performance strategies are already limited for other reasons and people who are faced with multiple tasks, putting requirements on short-term memory, may be more vulnerable to the distracting effects of noise.

Epidemiological research into effects on performance of schoolchildren has shown that these children, when exposed to very high levels of aircraft or road traffic noise

* For this specific situation the observation threshold might be an equivalent sound level of 16 dB(A) taken over 7 hours during the night and measured indoors.

(equivalent sound levels during schooltime over 70 dB(A), measured outside the school) do show an impaired performance in cognitive tasks. They are distracted more easily and make more mistakes when they are exposed daily to high noise levels, while at school (Coh80, Kar68).

The committee is of the opinion that there is limited evidence for a causal relationship between noise exposure as experienced under normal living conditions and decreased performance in adults. There is sufficient evidence in the case of schoolchildren.

3.6 Combinations of noise exposures

People may be exposed to different noise sources in the same situation, e.g. to a combination of road traffic and train noise in the living environment. People may also be exposed to different noise sources, acting on them in different situations at different times, such as a combination of occupational noise during working hours and road traffic noise while at home.

3.6.1 Accumulated effects from different sources in the same situation

Miedema and Vos studied annoyance from two or more environmental noise sources; their work resulted in models for these accumulated noise effects (Vos92, Mie93). Further research may show whether these models are also appropriate for stress-related environmental noise-induced health effects and for sleep disturbance. The combined effect of different noise sources on hearing levels is related to the equivalent sound level of the combined exposure.

3.6.2 Accumulated effects from different sources at different locations

Concerning noise-induced hearing loss, the committee considers it appropriate to estimate the accumulated effect of combined exposures based on the equivalent sound level over the total relevant exposure period.

The only epidemiological research into the combination of noise exposure in the living and in the working environment on stress-related effects (cardiovascular and biochemical parameters) showed that effects of road traffic noise in the living environment are more pronounced in men who were also working in high noise levels (equivalent sound levels over 90 dB(A)) than in men without occupational noise exposure (Bab90). In this respect, occupational noise exposure may be considered a risk factor for ischaemic heart disease for people exposed to high levels of environmental noise.

Concerning annoyance, the preliminary conclusion from the scarce epidemiological research is that, irrespective of the extent of the noise exposure at work, only those persons annoyed by noise during working hours show an increase in post-work irritability from noise sources at home (Mel92).

Whether noise exposure during the daytime affects sleep quality the night after the exposure was only tested in laboratory research ((Fru88a,b, Fru90). The results were contradictory. One investigation showed noise exposure during the daytime to stimulate recovery processes of neural- and endocrine functions during sleep and another investigation showed no such effect.

3.7 Interaction of noise with other agents

3.7.1 Effects on hearing

Noise may interact with drugs and industrial agents to produce additive or even synergistic effects on hearing. The ototoxic properties of certain drugs, such as aminoglycoside antibiotics (the mycine drugs) are heightened by exposure to noise. Although high doses of salicylates (aspirin) accompanied by noise exposure can produce temporary hearing loss, increased permanent hearing loss does not seem to occur.

Several case reports have been published on acute and chronic effects of carbon monoxide on hearing. The hearing loss resulting from carbon monoxide exposure appears to be reversible in most cases and is associated with toxic effects in the central nervous system. In one epidemiological study, noise-induced hearing loss in welders and plant assembly workers appeared to be influenced by exposure to carbon monoxide.

Epidemiological studies on workers suggest that carbon disulfide, carbon tetrachloride, trichlorethylene and n-butanol induce sensorineural hearing loss. However, the number of studies and the size of the populations studied seem too small to allow a decision about a possible interaction between noise and solvents on hearing.

Heavy metals have also been mentioned as possible industrial ototoxic agents, but very few studies have tested this suggestion.

Noise and vibrations may have a combined effect on hearing. Several epidemiological studies showed that groups of workers exposed to noise and hand-arm vibrations had a noise-induced hearing loss that was more frequent and greater than that in groups of workers exposed only to noise or only to hand-arm-vibrations. The effects were more pronounced in workers suffering from vibration-induced white finger syndrome. All epidemiological studies concerned exposures to very high noise levels and very intense hand-arm-vibrations. For whole-body vibrations (rather than hand-arm) a smaller effect on hearing levels was observed in groups of workers exposed to a combination of noise and vibrations than in groups of workers exposed to noise only.

3.7.2 *Other health effects*

Epidemiological research into the effect of combined exposure to noise and other environmental agents on health other than on hearing is scarce. Investigations are usually carried out in the laboratory with test persons or with animals. Forestry workers using vibrating and noisy tools, with several years of daily exposure to noise, vibration and cold, showed bradycardia. In laboratory experiments it could be shown that other stressors, such as heat and whole-body vibration do exert, when combined with noise, a greater effect on pulse rate, blood pressure and catecholamines than does noise exposure alone. Notwithstanding the data from laboratory research, the committee does not deem it possible to draw any quantitative conclusions applicable to real-life

3.8 Summary of noise-induced effects

Table 1 summarises the present data on the effects on health of exposure to noise. The observation thresholds are given in the measures used in the pertinent literature. The use of such a measure in the table does not necessarily imply it to be recommended for use in practical situations or regulations.

With respect to the use of noise exposure measures for the estimation of noise-induced health effects, table 1 shows that for all of these effects, with the exception of some aspects of sleep disturbance, observation thresholds are expressed in the equivalent sound level determined over a selected representative period during the 24 hour day. Usually, also the existing exposure-effect relations characterise noise exposure by an equivalent sound level over a representative period. However, dependent upon the noise effect under consideration, these representative periods are different. Therefore, the committee concludes that there is, as yet, no single noise measure, such as $L_{Aeq,24h}$, from which all noise-induced health effects can be estimated, without a specification of the type of noise source, the situation and the period of the day, during which the exposure occurs. This seems especially appropriate for the estimation of sleep disturbance in real live situations, since a reliable relation between measures of night-time exposure and measures related to the 24 hour period does not exist.

Table 1 (Possible) long term effects of exposure to noise, classification of the evidence for a causal relationship and data on the observation threshold

effect	classification[a] of evidence	situation[b]	observation threshold		
			measure	value in dB(A)	in/out[c]
hearing loss	sufficient	occ	$L_{EX,occ}$	75	in
		env recr	$L_{Aeq,24h}$	70	in
		occ unb	$L_{EX,,occ}$	<85	in
hypertension	sufficient	occ ind	$L_{EX,occ}$	<85	in
		env road	$L_{Aeq,06\text{-}22h}$	70	out
		env air	$L_{Aeq,06\text{-}22h}$	70	out
ischaemic heart disease	sufficient	env road	$L_{Aeq,06\text{-}22h}$	70	out
		env air	$L_{Aeq,06\text{-}22h}$	70	out
biochemical effects	limited	occ			
		env			
immune effects	limited	occ			
		env			
birthweight	limited	occ			
		env air			
congenital effects	lack	occ			
		env			
psychiatric disorders	limited	env air			
annoyance	sufficient	occ off	$L_{EX,occ}$	<55	in
		occ ind	$L_{EX,occ}$	<85	in
		env[d]	L_{dn}	42	out
absentee rate	limited	occ ind			
		occ off			
psycho-social well-being	limited	env			
sleep disturbance, changes in:					
sleep pattern	sufficient	sleep			
awakening	sufficient	sleep	SEL	60	in
sleep stages	sufficient	sleep	SEL	35	in
subjective sleep quality	sufficient	sleep	$L_{Aeq,night}$	40	out
heart rate	sufficient	sleep	SEL	40	in
hormones	limited	sleep			
immune system	inadequate	sleep			
mood next day	sufficient	sleep	$L_{Aeq,night}$	<60	out
performance next day	limited	sleep			
performance	limited	occ env			
	sufficient	school	$L_{Aeq,school}$	70	out

[a] Classification of evidence of causal relationship between noise and health.

[b] occ = occupational situation, ind = industrial, off = office, env = living environment, recr = recreational environment, road = road traffic, air = air traffic, sleep = sleeping time, unb = unborn: exposure of pregnant mother, school = exposure of children at school.

[c] Value relates to indoor or outdoor measurement. In the Netherlands, the difference between the level measured outdoors and that indoors is 15 to 25 dB(A) for dwellings with single glazing.

[d] Observation thresholds for traffic and industrial noise; the observation threshold is lower for environmental impulse noise.

Chapter **4**

Noise exposures in The Netherlands and its effects

4.1 Introduction

This chapter presents estimates of the present exposure to noise in the Netherlands and of the health effects attributable to these exposures. The results are summarised in table 3 at the end of the chapter. The committee wishes to stress the fact that the data allow only rough estimates. Several factors have an impact on the reliability of the estimates. These factors are:

- inaccuracies in the data for the various noise exposures; in several cases noise exposure had to be estimated from values expressed in another noise exposure measure
- unreliability of exposure-effect relations
- differences between the noise exposure distribution in the Netherlands and the distribution for the populations used in the derivation of the exposure-effect relations; bias due to such differences may occur predominantly in the highest noise exposure range, especially when this range has no upper boundary.
- intervening and confounding variables; variables such as age, gender, stressors other than noise, could only be taken into account in a few calculations
- combinations of exposures
- the extent to which an effect occurs in situations without noise exposure
- effects of noise reducing measures, such as personal hearing protection in the working environment and sound insulation in the living environment.

Due to these uncertainties it is impossible to derive the margins of uncertainty of the estimates presented in this chapter. The estimates of the number of people involved in the Netherlands are therefore given in seven classes, although calculations have been performed as accurately as possible.

4.2 Occupational noise exposure

4.2.1 Legal exposure limits

In August 1986 regulations have come into force in The Netherlands to limit occupational noise exposure and noise-induced hearing loss. Three basic exposure limits operate in the workplace:

- $L_{EX,occ}$ of 80 dB(A). Above this value hearing protectors must be made available to the workers.
- $L_{Aeq,activity}$ of 85 dB(A). For situations with equivalent sound levels during an activity of at least 85 dB(A) technical measures should be taken where reasonably feasible.
- $L_{EX,occ}$ of 90 dB(A). Above this value hearing protectors must be used by the workers.

Adaptation in 1991 of the Netherlands legislation to the EC Directive 86/188/EEG did not alter these three basic exposure limits. Within the framework of this adaptation, requirements were added concerning information for workers exposed to $L_{EX,occ}$ values of 80 dB(A) or more and about periodic audiometry of these workers. Requirements with respect to noise measurements have also come into force.

4.2.2 Estimated occupational noise exposure

Estimates are available of the extent of occupational noise exposure for the Netherlands industry* in 1975 and 1985 (Pas91a). The result is given in figure 4.1.

It seems that, even in the period before the legal requirements came into force, the percentage of workers exposed to (very) high equivalent sound levels decreased strongly: in 1975 23% of the industrial workers were exposed to an equivalent sound level of 90 dB(A) and above, whereas this value had diminished to 10% in 1985. On the other hand, no change had occurred during the same 10-year period in the fraction of the industrial workers exposed to equivalent sound levels of 80 dB(A) or more.

* Industry comprises the international SIC classes 20 to 39 (among which the metal, food and textile-industry); building and construction industry is not included.

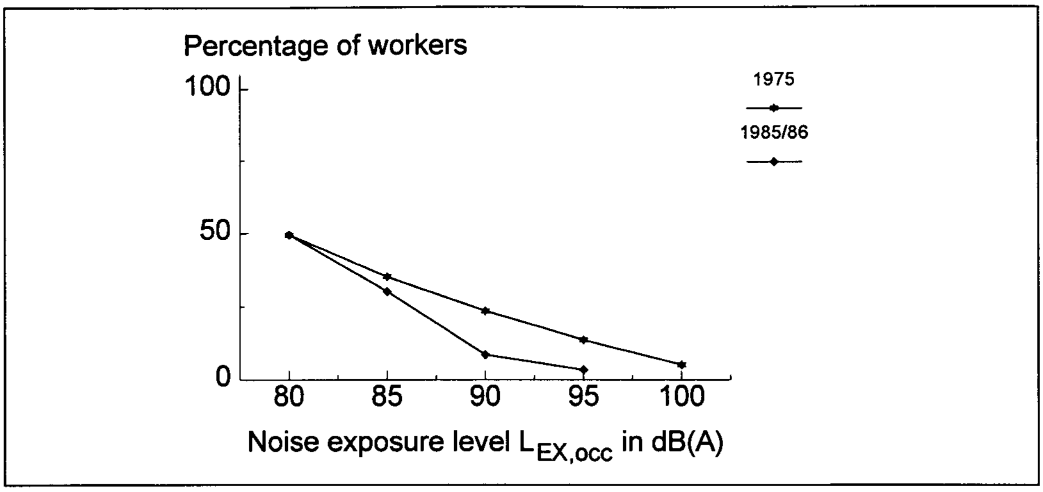

Figure 4.1 Percentage of workers in the Netherlands industry exposed to occupational noise not exceeding a certain $L_{EX,occ}$ value. The estimated percentages pertain to 1975 and 1985/1986.

Many workers are exposed to equivalent sound levels of 80 dB(A) and above in other working environments also, e.g. the building and construction industry, agriculture and mining.

It is not yet known whether the 1986 regulations have resulted in any changes in exposure levels of workers.

In the civil service, trade, and the executive and academic professions the equivalent sound levels during working hours are usually less than 70 dB(A).

4.2.3 *Estimation of noise-induced effects*

Health effects with sufficient evidence for a causal relationship between noise and health are:

- hearing loss of workers
- hypertension
- hearing loss in unborn babies
- hypertension in pregnant women.
- annoyance

The extent of these possible noise-induced health effects from occupational noise exposure will be estimated below.

Noise-induced hearing loss

Taking into account the exposure-effect relations in ISO 1999 and the extent of industrial noise exposure in the Netherlands, noise-induced hearing loss might, in principle, be found in more than 50% of industrial workers. However, the 'real' noise exposure cannot be estimated, since the extent of the use of personal hearing protection is unknown. Also, there is uncertainty about the correct use of these protectors and about their attenuating capacity in real work situations. The extent of hearing loss has been estimated for workers in the construction and building industry. Based on an extensive audiometric investigation (Pas88) it was estimated that about 25% of the workers in the Netherlands construction industry have noise-induced hearing loss of at least 10 dB, averaged over the two frequencies 2000 and 4000 Hz. If it is assumed that noise-induced hearing loss is at least as common in industry*, as it is in the construction industry, the total number of workers with noise-induced hearing loss becomes 360 000 (25% of 1.47 million). This is the result used in table 3.

Hypertension

Taking into account the prevalence of noise-induced hypertension, it is estimated that in the Netherlands industrial situation 6000 of the 0.88 million workers have noise-related hypertension.** Estimates for other professions can not be arrived at.

Hearing loss in unborn babies

It is estimated that only 5% of the workers in industry and trade are females and that only a small fraction is exposed to equivalent sound levels of 85 dB(A) and more (Pas89a). A very rough estimate gives about 1000*** noise-exposed pregnant women in the Netherlands industry, exposed to equivalent sound levels of 85 dB(A) or more.

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* SIC-classes 20-39.

** It is estimated that 88 000 (10% of 0.88 million) industrial workers are exposed to equivalent sound levels over 90 dB(A). Taking a percentage of hypertensives of 10 and a relative risk of 1.7, the increase in number of hypertensive persons amounts to 6000.

*** The number of male and female workers is equal to 1 465 000 (CBS93); 50% is exposed to equivalent sound levels of at least 80 dB(A). This implies 36 000 females. About half of these women are is exposed to equivalent sound levels over 85 dB(A): 18 000 women. The number of births per year for 1000 women aged 15-44 years is equal to 53.2. This implies about 960 pregnant women working in equivalent sound levels over 85 dB(A) in industry.

Therefore, it is estimated that about 250 babies have a hearing loss of more than 10 dB at 4000 Hz due to the occupational noise exposure of their mothers during pregnancy.

Hypertension in pregnant women

Given the estimate of 1000 pregnant women working in high levels of industrial noise, a percentage of 10 for hypertensives among non-noise exposed pregnant women not exposed to occupational noise, and a relative risk of 1.5, the noise-induced increase in number of occupational noise-exposed hypertensive women is about 50.

Annoyance

General surveys have shown that noise annoyance in the Netherlands is a prevalent complaint (CBS78a, CBS78b, Dij81). The result of one CBS study (CBS, Central Bureau of Statistics) showed that 52% of the male and female workers in industry, construction industry, transport and trades have complaints about noise at work; another CBS study resulted in a percentage of 45. Dijkstra found 51% of the industrial workers and 15% of the Dutch office workers to be severely annoyed by noise. Van Dijk (Dij84) analysed the data from CBS78a for the total workforce. He concluded that 31% of the total Dutch workforce had complaints about the noise situation at work. Presuming these percentages to be applicable to the present situation, we find in total 2.1 million persons annoyed, with 0.74 million working in industrial and manual professions, 0.41 million office workers and .95 million workers with other professions.*

4.3 Environmental noise exposure

4.3.1 Legal exposure limits

The Noise Nuisance Act sets limits for traffic and industrial noise. The L_{etm} values for new dwellings should not exceed 50 dB(A) at the front of the building, due to noise from road traffic and industry or 55 dB(A) for train noise. For existing situations L_{etm} values from road traffic noise should be less than 55 dB(A). At values exceeding 60 dB(A) mitigating measures should be taken but, for financial reasons, this is only done at values exceeding 65 dB(A) (RIV88).

The Aviation Act specifies 35 Ke from aircraft noise as the exposure limit for new dwellings. Only in special cases new dwellings with special provisions are allowed to

* The total workforce in the Netherlands consists of 6.85 million persons, including 1.47 million people performing industrial and manual and 2.74 million people with office work (CBS93).

be built in areas with exposures between 35 and 45 Ke. Sound insulation measures are required if exposures exceed 40 Ke in existing situations and, in principle, people living in houses exposed to more than 65 Ke should move. Legal requirements with respect to night-time air traffic are in preparation. It is specified that the equivalent sound level, determined over a period of 7 hours in the 8-hour period from 23.00 - 07.00 hours should not exceed 27 dB(A) on a yearly basis.

4.3.2 *Noise exposure during travelling*

Nowadays noise from traffic during travelling contributes considerably to the daily noise exposure. In large and medium-sized cities travellers are exposed to equivalent sound levels from traffic of 70 to 75 dB(A) when travelling, almost irrespectively of the kind of transport used. In villages and in the countryside exposure to traffic noise during travelling is probably less, except for farmers using machinery and mechanised agricultural vehicles. There is, however, no estimate available of the extent of these noise exposures for the Netherlands population.

4.3.3 *Traffic and industrial noise sources*

A national environmental forecast (Concern for Tomorrow, RIV88) gives an estimate of the noise situation in the Netherlands at the end of the 80s. According to this study, 205 000 dwellings are situated in surroundings with L_{etm} values exceeding 65 dB(A) due to road traffic noise and 30 000 dwellings where this is due to railway noise. Due to industrial noise 150 000 dwellings have an L_{etm} value exceeding 50 dB(A) and 72 000 dwellings have L_{etm} values exceeding 55 dB(A). Due to both civilian and military aircraft 34 000 dwellings (22 000 plus 12 000) have Ke-values exceeding 35.

Data from 1991 (RIV93b) indicate that 35 000 people around Schiphol Airport have a civilian air traffic noise exposure of at least 35 Ke and 15 000 have exposures of at least 40 Ke. The 35 000 persons with an exposure of at least 35 Ke around Schiphol Airport live in roughly 14 000 dwellings, i.e. about 40% of the total number of 34 000 dwellings in the Netherlands with civilian and military aircraft noise exposure over 35 Ke.

4.3.4 *Other environmental noise sources*

There are numerous other noise sources: from neighbouring houses and from outdoor activities of others. A listing includes neighbours toilet and other plumbing, vacuum cleaner, washer, dishwasher, radio, TV, tools, slammed doors, footsteps including on stairs, animals. There can be added loud laughter, shouts and slamming of car doors in the neighbourhood of pubs, cafeterias and recreational sources such as discos, pop concerts, sport halls and various manifestations. Other noises, though not yet quantified, are those escaping from loud walkmans worn on the street or in public transport vehicles and those escaping from cars with audio equipment playing very loudly.

The committee could however, not find estimates of the extent of exposure to these environmental noise sources.

4.3.5 *Estimation of noise-induced effects*

Health effects with sufficient evidence for a causal relationship with environmental noise exposure are

- hearing loss
- annoyance
- hypertension
- ischaemic heart disease
- sleep disturbance

The appropriate demographic data for the Netherlands are (CBS93):

- number of inhabitants, about 15 million
- of these 25.8% are aged under 20 years and 74.2% (11.1 million) are aged 20 years and over
- number of dwellings, 5.8 million
- on average 2.5 inhabitants per dwelling.

Estimates of those health effects of environmental noise exposure, for which sufficient evidence is available for a causal relationship* will be based on these figures.

* With respect to admission to psychiatric hospitals, only limited evidence is available. If nevertheless the exposure-effect relation from one study on aircraft noise exposure is taken (Kry90), then it is estimated (Pas93c) that due to aircraft noise around Schiphol Airport, the increase in number of patients admitted to psychiatric hospitals is 2 per year. For all airports in the Netherlands this value is estimated to be 5 per year. Therefore this effect seems to be practically absent in the Netherlands population. For exposure to aircraft noise there is also only limited evidence for a causal relation between low birthweight and noise exposure. If such an effect occurs, it is estimated in Pas93c that, due to aircraft noise exposure around Schiphol Airport, the increase in the number of babies with a low birthweight is 9 per year. The total effect in the Netherlands is estimated to be limited to 25 babies a year.

Noise-induced hearing loss

In Pas93c and Pas93d it has been specified that noise-induced hearing loss will most likely not result from environmental noise exposure.

Annoyance

Table 2 shows the percentage of people (severely) annoyed due to various environmental noise sources. The table also includes estimates of the situation in 2010 for some noise sources.

According to this table there has been an extensive increase in annoyance in the last decades. An increase in the percentage of people (severely) annoyed by environmental noise has also been observed in other countries. In Germany, the percentage of people annoyed increased from 30% to 40% in 1960/1962 to 60% in 1988. The main cause of annoyance in Germany turned out to be road traffic noise: up to 1980 it was the dominant noise source for 60% of the people in Germany. This percentage decreased in the 80s, whereas the percentage of people annoyed by aircraft noise increased. In 1988, the extent of annoyance from aircraft and from road traffic noise was about equal. Annoyance from other noise sources (railroad, industry, neighbours, loud recreational activities) increased by a factor two in the 80s, from 8% to 15% (UBA93).

Apparently, the situation in the Netherlands has worsened since 1975, in spite of the Noise Nuisance Act coming into force at the beginning of this period. It should be kept in mind, however, that the limits of environmental noise exposures in the Noise Nuisance Act for both new and existing situations are well above the minimum level for severe annoyance (L_{etm} value equal to 45 dB(A)). Therefore, situations without considerable noise exposure and annoyance may develop into situations with (severe) annoyance, while they still are within the requirements of the Noise Nuisance Act.

In a number of situations, people are annoyed by more than one noise source. The main combination of noise sources is that of road and air traffic noise. It is estimated (Ber93) that 16% and 8% of the Netherlands population is annoyed and severely annoyed, respectively, by a combination of these two noise sources.

Again in table 2, it is seen that noise caused by activities of neighbours is nowadays the main source of noise annoyance. Apparently the numerous noise sources from neighbouring houses and from outside add up to the 66% of the people annoyed, of which 26% severely annoyed.

Table 2 Percentage of adult people annoyed and severely annoyed in the Netherlands due to various environmental noise sources in the period 1960 to 2010 (RIV88, RIV93a, Jon90ab, Ber93). Rounded of to whole numbers.

noise source	percentage annoyed					percentage severely annoyed				
	1960	1975	1990	2010[a]	2010[b]	1960	1975	1990	2010[a]	2010[b]
road traffic	22	42	61	44	30	9	13	20	19	16
civil air traffic	2	5	13	14	1	1	2	3	3	0.5
military and other air traffic	-	-	28	-	-	-	-	12	-	-
rail traffic	2	3	5	3	3	1	1	1	1	1
industries	-	9	15	21	13	-	1	4	4	4
other noise sources[c]	-	41	66	-	-	-	16	26	-	-
traffic noise combined[d]	-	-	16	-	-	-	-	8	-	-

[a] With measures as planned in 1990 (RIV88).

[b] With extra measures, not yet planned in 1990 (RIV88).

[c] Other sources, such as associated with recreation and neighbours' activities.

[d] Mainly a combination of road and air traffic; these percentages are also included in the separate categories.

Although the number of noisy household appliances has increased during the last decades, this does not seem the only reason why annoyance from noise of neighbours is increasing. The period of leisure time, spent in- and outdoors is increasing, which corresponds to an increasing number of people involved in noisy activities at home and an increasing number of people aware of these noisy activities. Also, the expectations and demands of people with respect to their living environment may have changed in the last decades.

Hypertension

For road traffic noise, the risk of hypertension starts to increase from a $L_{Aeq,06\text{-}22h}$ value of 70 dB(A). This figure corresponds to a L_{etm} values of about 73 dB(A). The number of dwellings with L_{etm} value over 65 dB(A) due to road traffic noise is 205 000, due to railroad noise 30 000 and due to industrial noise it presumably is 15 000, which adds up to 250 000 dwellings. It is not known which percentage of these dwellings have L_{etm} values over 73 dB(A). Assuming this to be 10%, i.e. 25 000 dwellings, the noise-induced increase in the number of hypertensive persons due to these environmental noise sources is estimated to be about 2300*.

With respect to the effects of aircraft noise around Schiphol Airport, it has been estimated that the increase in the number of hypertensive persons is 1000 due to aircraft noise from this airport (Pas93c). The percentage of dwellings with high civilian and military aircraft noise exposure around Schiphol Airport is about 40% of the total number of such dwellings in the Netherlands. Therefore, it is estimated that the increase in the number of hypertensive persons due to aircraft noise would be about 2500.

The total increase of the number of hypertensive persons due to road and air traffic and industrial noise is thus estimated to be about 5000 in the Netherlands.

It is impossible to estimate the number of persons with hypertension caused by environmental noise sources other than those discussed above.

Ischaemic heart disease

There are no data for the prevalance of ischaemic heart disease in the Netherlands. According to the RIVM, the data given in their report (Kro92) are not suitable for this purpose since they are based on questionnaires and not on medical diagnosis. National data (SIG88) on admissions to hospitals due to ischaemic heart disease (including death) give 5.18 persons per thousand. This is estimated to result in an increase of 160** as a result of exposure to road and rail traffic and industrial noise in the number of hospitalised patients with ischaemic heart disease.

Pas93c specifies that, due to aircraft noise around Schiphol Airport, the increase in the number of persons admitted to hospitals due to ischaemic heart disease is about 67. Again, assuming this to be 40% of the total number and multiplying it by a factor of 2.5 gives an estimate of the results on a national level, i.e a total of 170 persons.

It is estimated that, in total, due to environmental noise exposure, the increase in the number of persons admitted to hospitals with ischaemic heart disease in the Netherlands is 330.

Sleep disturbance

No estimate can be made for the extent of the effects regarding most aspects of sleep disturbance in the Netherlands population, since exposure levels during the night are

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* In 25 000 dwelllings, on average 62 500 persons are living, among them 46 375 adults. The percentage of hypertensives in the general Netherlands population is 10. With a relative risk of 1.5 this results in 2300 persons.

** The number of dwellings to be considered is 25 000 with an average of 62 500 persons. Without noise exposure about 320 of 62 500 persons are admitted to hospital due to ischaemic heart disease. Taking a relative risk of 1.5, this results in 160 extra admissions.

largely unknown. Moreover, observation thresholds and exposure-effect relations for various aspects have not been established in a format that can be used to estimate the extent of the effects on the Netherlands population. Only for subjectively experienced sleep quality the observation threshold has been given in a format allowing a rough estimate. The subjectively experienced sleep quality starts to decrease from 40 dB(A) during the night, i.e. at L_{etm} values of at least 50 dB(A). The number of people at risk is estimated to be a minimum of 1 million, i.e. 150 000 due to industrial noise, at least 600 000 due to road traffic noise, at least 30 000 due to railway noise and an unspecified number due to airtraffic noise.

4.4 Noise exposure during leisure

4.4.1 Legal exposure limits

In general, all legal exposure limits specified in 4.2.1 for environmental noise exposure also apply to leisure, as several leisure activities take place in and around dwellings. There are no regulations in the Netherlands covering noise levels in nature and designated rural areas.

It is specified in a Netherlands Decree that peak sound pressure levels measured at a distance of 2 m of firecrackers should not exceed a certain value if the firecrackers are to be sold in the Netherlands.

No legal requirements exist for other recreational noise sources , apart from local specifications based on the 'Wet Milieubeheer', formerly 'Hinderwet'. This law concerns e.g. permissible outdoor noise levels for discotheques.

4.4.2 Estimated noise exposure during leisure

The numerous sources of environmental noise in and around dwellings also have an impact on people during leisure. However, an estimate of such exposure is lacking. It is also unknown to what extent people are exposed to noise in nature and quiet rural areas and to what extent such exposures cause annoyance. Apart from these unwanted exposures, which may induce effects even at low noise levels, three main sources and situations with high noise exposures can be distinguished:

- pop music
- loud games and sports
- children's toys.

In all three cases people expose themselves to the noises more or less voluntarily.

Pop music

Since the 60s the pop scene has gained considerable importance. Nowadays there appear to be five main situations in which young people especially are exposed to pop music:

- at pop concerts
- in discotheques
- at home
- listening through headphones, usually from portable equipment
- while playing in a band.

In the first three situations exposure to pop music now seems to be levelling off, whereas listening through headphones is a still increasing phenomenon in the Netherlands. It is estimated that about nowadays 50% of young people listen to pop through headphones, compared to about 20% in 1980 (Pas92). Some of the noise exposure characteristics of young Dutch people are known, viz. the time spent listening on a short-term and long-term basis. The levels of their noise exposures, however, are unknown and can only be estimated from levels measured abroad (Ric87a,b).

At present, the two situations in which noise exposure is supposed to be the most extensive are playing in a pop group and listening to pop music through headphones. For amateur musicians playing in pop groups, the equivalent sound level over 24 hours, averaged on an annual basis, is estimated to be 80 to 90 dB(A), taking into account both performances and rehearsals. Listening to pop through headphones gives average equivalent sound levels of 65-70 dB(A) over 24 hours but 10% of the listeners are expected to be exposed to levels higher than 80-85 dB(A) (Pas89b).

Notwithstanding the apparently high sound levels, if one takes into account the habits of young people in the Netherlands, attending pop concerts and going to discotheques are assumed to result in lower long term noise exposures than playing in pop groups or listening through headphones.

Noisy games and sports

Noisy games and sports are shooting, e.g. hunting and target practising, motorsports, such as car racing and riding mopeds/motorcycles. Noisy games are flying model airplanes, arcade games, using fireworks and staying in (football) arenas. For many of these noisy activities acoustical data are available (Axe91a). However, since exposure patterns are largely unknown, the extent of exposures to these noise sources is impossible to estimate.

Exposure of children

Also very young children are sometimes exposed to high noise levels (Axe85b, Axe91a,b, Axe93, Pas89b, Pas91b). Their 'squeaky', moving and stationary toys are reported to produce equivalent sound levels of 78 to 108 dB(A) at a distance of 10 cm. For toy weapons, peak sound pressure levels of up to 150 dB have been measured at a distance of 50 cm. Fire-crackers may produce 160 dB at a distance of 2 meter from the source. Again, the exposure patterns are unknown.

EPA (EPA74) estimated the noise exposure of schoolchildren to reach 77 dB(A) during a 24 hour period. More recently, equivalent sound levels during daytime in day care centres for children have been reported to be 77 dB(A) (Tru88).

4.4.3 Estimation of noise-induced effects

Noise-induced hearing loss is the only sufficiently documented adverse health effect of noise encountered during leisure. Applying the calculating scheme in ISO 1999 to the exposure data for young people and comparing the result with epidemiological data (Isi88, Pas76, Pas81) it is estimated that most people playing in a band will acquire noise-induced hearing losses of 5 to 10 dB, and most people visiting pop concerts and discotheques will have noise-induced hearing losses of maximally 2 to 3 dB. For 10% of the young people listening through headphones noise-induced hearing loss is estimated to be 5 to 10-15 dB and for 1% it is more than 15 dB. Taking into account the various percentages of young people involved in various pop music related activities (Pas93d), these estimated noise-induced hearing losses imply that 5% of the 2.5 million people aged between 15 and 25 years will acquire noise-induced hearing losses of 5 to 10 dB from playing in a group, 15% will have losses up to 2 to 3 dB from attending concerts and discotheques, and 5% losses from 10 to 15 dB due to listening with headphones, and 0.5% will have losses over 15 dB. Information is lacking in how far combinations of these activities occur.

In contrast to the USA, Canada and Scandinavia, in the Netherlands only a small percentage of people hunt or do target practice. It is estimated that fewer than 1% of the Netherlands population uses firearms during leisure. Also, it is common practice in the Netherlands to use personal hearing protection while target shooting. Therefore, exposure to noise in the Netherlands from the use from firearms during leisure seems to be only limited. Since information on patterns for exposure to noise during games and sports are lacking, the extent of noise-induced hearing loss from these sources is unknown.

All investigations into the effect of exposure to noise of firecrackers on hearing have shown an increase of 1 to 2% in the percentage of children with high frequency hearing loss associated with the use of firecrackers (Gja74, Isi88, Gup89, Bro92). The number of Dutch young people suffering from such a loss is unknown, since exposure patterns are not available. The same is applicable to children playing with noisy toys.

4.5 Trends in hearing loss of young populations

Hearing loss has a variety of causes, e.g. infection, illness, ototoxic medicines, hereditary factors, middle-ear inflammation and exposure to noise. Also, hearing deteriorates with increasing age. The results of two quite extensive studies (Bor88, Bor93, Kör92) in Austria and Norway indicate a serious deterioration of the hearing of young men and women in the 1980s. However, the results of a recent Swedish and a German study (Ros93, Ess92) do not support these findings. Due to a lack of research data the committee is unable to give a conclusive opinion regarding the extent of hearing deterioration of people in the Netherlands. Data from research in the Netherlands give no indication of a decrease in hearing of young Dutch people (18 years) in the period up to 1983 (Pas89b, Pas90). However, these data do not permit conclusions about trends in the hearing levels of the 10% of the young people having the highest hearing threshold levels, nor about developments since 1983. The committee recommends that studies be undertaken to determine the present hearing condition of young people in the Netherlands.

4.6 Summary

Table 3 summarises the results of the foregoing paragraphs. The estimates of the number of people involved in the Netherlands are presented in terms of seven classes, consecutive classes differing by one order of magnitude (factor of 10). The classification only relates to the occurrence of effects attributable to noise exposure, and not to the severity of the effects.

Table 3 Estimated numbers of persons in the Netherlands population in 1993 with noise-induced health effects presented in terms of order of magnitude classes.

exposure situation and source[a]	effect		class[b]
work			
	noise-induced hearing loss		6
	annoyance		7
	hypertension		4
	hearing loss unborn babies		3
	hypertension pregnant women		2
living			
	hypertension		4
	ischaemic heart disease[c]		3
	noise-induced hearing loss		-
	decreased sleep quality[d]		7?
road traffic	severe annoyance		7
civil air traffic	severe annoyance		6
military air traffic	severe annoyance		7
rail traffic	severe annoyance		6
industries	severe annoyance		6
combination of traffic	severe annoyance		6
other sources in the neighbourhood	severe annoyance		7
leisure			
pop music:	noise-induced hearing loss		6
• playing in pop group	"	5 - 10 dB	6
• attending pop concerts/discotheques	"	2 - 3 dB	6
• listening through headphones	"	10 - 15 dB	6
	"	> 15 dB	5
loud games and sports			?
childrens toys	"		?

a "Work" concerns the Dutch workplace, "living" the adult populations of the Netherlands (except for low birth weight) and "leisure", young adults and children.

b Classes are specified as:

1 none	5 10 000 - 100 000 persons
2 < 100 persons	6 100 000 - 1 000 000 persons
3 100 - 1000 persons	7 > 1 000 000 persons.
4 1000 - 10 000 persons	

c Number per year.

d Persons at risk; the number of persons with effects could not be estimated.

Chapter 5

Response to the request for advice

The committee has reviewed the results of scientific research into the effects of noise on health. In chapter 3 of this review, it evaluated the evidence for causal relationships between exposure to noise and specific health effects. In chapter 4 this evaluation was used to assess the impact of environmental and occupational noise exposure on the health of the Dutch population. Chapters 3 and 4, together with the extensive literature review published separately by the Health Council, provide answers to questions posed to the committee in the request for advice. This Chapter presents the answers arranged according to the text of the request.

Effects on health

What effects on health are to be expected from exposure to noise at different sound levels?

In chapter 3 of this report noise-induced health effects were specified according to the type of noise source and also a differentiation was made with respect to the living, working and recreational environment. An overview is given in table 1, which specifies possible long-term health effects, together with a classification of the evidence for a causal relationship. If there is sufficient evidence for a causal relationship, observation thresholds have been specified in the table. The observation threshold is the exposure value *from* which, on average, an effect from exposure to noise has been observed in epidemiological studies. The observation thresholds concern an average population of adults or adult workers or average populations otherwise specified, such as babies of women exposed to noise during pregnancy.

For those adverse health effects for which sufficient evidence is available to show a causal relationship between noise exposure and effect, it was examined whether reliable exposure-effect relations do exist. For some of these noise-induced health effects, exposure-effect functions are simply expressed in terms of relative risk above the observation threshold. This holds for ischaemic heart disease and hypertension. With respect to noise-induced hearing loss exposure-effect functions are given in ISO 1999; for occupational noise exposure $L_{EX,occ}$ is taken as noise measure, and for environmental noise exposure and exposure during leisure, $L_{Aeq,24h}$ is the measure to be used.

Also for severe annoyance from traffic and industrial noise in the living environment, exposure-effect functions de exist. However, exposure-effect functions regarding annoyance for occupational noise exposure in offices as well as in industrial situations are lacking.

Although there is sufficient evidence for a causal relationship between night-time noise exposure and various effects on sleep, exposure-effect functions have only been derived from field studies for some effects. For awakening and for sleep stage changes from exposure to intermittent night-time noise, these exposure-effect functions have been derived, with exposure specified in SEL. With these exposure-effect relations as a basis, the number of awakenings and sleep stage changes has been estimated in the special case of night-time aircraft noise around main airports, with the equivalent sound level during the night as exposure measure (Pas94).

With respect to the adverse noise-induced health effects from a cumulation of exposures to different noise sources, information which allows the determination of these effects is available only for the noise-induced effects hearing loss and annoyance. Concerning noise-induced hearing loss, the effect of any exposure to several noise sources can be calculated from the equivalent sound level over the total exposure period. For annoyance from exposure to several environmental noise sources at one location, there is a calculation scheme for determining accumulated annoyance due to these combined exposures (Mie93).

Effects on health from a combination of exposure to noise and that to other physical or chemical agents have rarely been the object of epidemiological research. Since the number of studies and sizes of the populations studied are too small, the data available, do not yet show sufficient evidence of interactions.

Populations whom epidemiological research has shown an increased susceptibility for acquisition of a noise-induced health effect, are:

- children, who are probably more vulnerable to acquire noise-induced hearing loss than adults

- males exposed to occupational noise and having high blood cholesterol levels have an increased risk of noise-induced hearing loss in comparison to occupational noise exposed male populations with normal cholesterol levels
- with respect to stress-related health effects, exposure of hospitalised patients to relatively high levels of noise from inside and outside noise sources delays recovery and wound healing
- pregnant women exposed to high levels of industrial noise show an increased risk of hypertension during pregnancy, relative to pregnant women not exposed to occupational noise
- people highly annoyed by low levels of road traffic noise have an increased risk of hypertension
- men exposed to road traffic noise in the living environment and also exposed to occupational noise have an increased risk of ischaemic heart disease compared to men exposed to road traffic noise only
- people annoyed by noise in the workplace show an increased post-work irritability, which might affect well-being at home
- the sick, people with sleeping difficulties and older people show more noise-induced sleep disturbance, especially with respect to the inability to fall asleep (after being awakened), than other adults. Older people also have an increased risk of being awakened by night-time noise
- people with noise-induced sleep disturbance have an increased risk of hypertension, ischeamic heart disease and negative effects on psycho-social well-being compared to people in the same living environment without sleep disturbance
- noise sentitive people, people with fear of certain noise sources and people feeling they have no control over a noise situation (in this respect, feeling an abuse of power) have an increased risk of severe annoyance.

Effects in the Netherlands population

To what extent is the population of the Netherlands affected by these effects?

This question has been elaborated upon in chapter 4. The results have been summarised in table 3. The extent of a noise-induced effect has been given in classes, since the available information does not allow a more accurate estimation.

Health-based exposure limits

What health-based exposure limits can be derived from the data?

Usually exposure limits are not only based on health considerations, but are a result of political decision processes in which social and economic factors have also been taken into account. Health-based exposure limits depend upon criteria related to the effect considered as an endpoint, to the part of the population to be protected, to the extent of the protection and to the safety margins to be taken into account. If, from a public health point of view, any effect should be prevented in a cross-sectional population, then the observation thresholds are the appropriate health-based exposure limits, if a safety margin is not taken into account. If such a margin and an increased susceptibility of sensitive populations are to be taken into account, health-based exposure limits should be set at lower levels than the observation thresholds, in order to prevent any adverse health effect from exposure to noise.

International standards

To what extent does international agreement exist about these aspects and in how far is this related to standards?

International bodies have produced specifications only for noise-induced hearing loss. In chapter 3 the committee referred to the international standard ISO 1999, in which exposure-effect relations with respect to noise-induced hearing loss are specified. WHO specified in 1981 an equivalent sound level of 75 dB(A) during working hours as the no adverse effect level with respect to noise-induced hearing loss and the same level is mentioned in the draft directive of the European Union on physical agents, proposed in December 1992.

Comparison with the 1971 Health Council Report

Comparing the 1971 Health Council advisory report and the present one the committee notes that, in general, the health effects that now appear to be associated with noise exposure are the same as those identified in the sixties. However, as documented in chapter 3, more detailed and, especially, more quantitative data are available about noise-induced health effects than two to three decades ago. This implies that uncertainties were reduced and that the conclusions about the health impact of noise now rest on a much firmer basis.

Combining the information on health effects of noise with the noise exposure data for the Netherlands, the two most important health effects of noise exposure appear to be:

- annoyance from exposure to occupational and environmental noise
- hearing loss induced by occupational noise.

Sleep disturbance due to noise exposure is also an important effect from a public health point of view. Quantitative data about the extent of the population affected are, however, lacking.

Why are these effects still of such importance, although they have been known about for so many years, and preventive measures have been taken? Two reasons may be mentioned. One is that effects also occur at noise levels that are below the present regulatory limits. The second is that environmental exposures, mainly generated by different forms of traffic, by neighbours and by industry and occupational exposures above these regulatory limits, occur on a wide scale. Noise reduction would thus require extensive financial efforts.

Most other effects of noise, among which ischaemic heart diseases and hypertension, occur at high noise levels: only people carrying out very noisy occupational activities or being in situations with very specific environmental noise exposures may suffer from such effects. This has been documented in chapter 3. Many of these effects might be prevented by strict enforcement of existing regulatory limits.

In summary, the committee concludes that noise exposure has an important effect on public health in industrialised societies such as in the Netherlands. This effect is clearly evidenced by analyses of the quality of life rather than by mortality data.

The Hague, 15 September 1994,
The Committee on Noise and Health

Dr W Passchier-Vermeer,
scientific secretary

Dr GF Smoorenburg,
chairman

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A The request for advice

B Members of the committee

C Terms and definitions

Annexes

Annex **A**

The request for advice

The President of the Health Council received the following letter, dated May 17, 1994, no PAO/GZ 945796, from the Minister for Welfare, Health and Culture.

According to my information the Health Council is planning to report on the present state of scientific knowledge with respect to the effects of noise on health. Also on behalf of the Minister of Housing, Spatial Planning and Environment, and of the Minister of Social Affairs and Employment I would like to put the following before you.

Reports from the Health Council have played an important role in the preparation of the Noise Nuisance Act, especially with regard to the Decree on noise exposure from main airports.

Concerning standards for occupational noise exposure, regulations to protect workers from harmful effects of noise on hearing were most recently updated on December 1, 1991. Annoyance from noise with sound levels below 75 dB(A) at the workplace, however, elicits many complaints. An evaluation of research data on annoyance from noise is relevant. Furthermore, noise seems, in combination with other factors also to act as stressor. Also with respect to other possible health effects of exposure to noise, such as increase in blood pressure and cardiovascular disease, it is desirable to review the available scientific data in order to determine whether, and if appropriate, in which way the results should be incorporated in official standards

Given this, I request you to put emphasis in your advice on the following subjects:

1 What health effects are to be expected from exposure to noise at different sound levels?
2 To what extent is the population of the Netherlands affected by these effects?
3 What health-based exposure limits can be derived from these data?

4 To what extent does international agreement exist about these aspects and in how far is this expressed in standards?

It would be appreciated if also attention was paid in your report to:

a differentiation to the type of noise source;

b differentiation to the living-, working- and recreational environment;

c the reliability of the response-effect relations;

d similarities and differences with exposure limits specified for other agents (toxic substances, air pollution etc);

e cumulation of noise sources and cumulation of noise exposure and other exposures, as far as relevant;

f groups at risk and/or sensitive groups.

Yours Sincerely,

the Minister for Welfare, Health and Culture
(signed)
dr H d'Ancona.

Annex **B**

Members of the committee

- Dr GF Smoorenburg - *chairman*
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Annex **C**

Terms and definitions

1 Sound

Sound is a phenomenon with alternating compression and expansion of air which propagates from a noise source in all directions. These compressions and expansions represent pressure variations around atmospheric pressure. These pressure variations can be described mathematically as the sum of one or more sine functions. The sound pressure variations of a pure tone are described by one sinus as a function of time.

2 Frequency

The number of pressure variations per second is the frequency of a sound and is expressed in hertz (Hz). The frequency determines the pitch of a sound: a high pitched tone (e.g. 4000 Hz) has a squeaking sound, a low pitched tone (e.g. 200 Hz) a humming sound.

3 Sound pressure level

A sound has not only a frequency, but also a level (L). The level is related to the sound pressure (p). In practice, sound pressures range from less than 20 μPa up to more than 200 Pa, a range of 1 to 10 million. Therefore, in acoustics, the logarithm of the sound pressure relative to a reference sound pressure (p_o) is usually taken as a basis for the

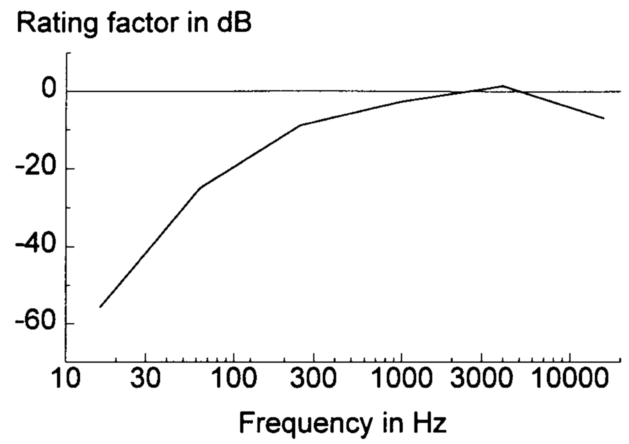

Figure C.1 Frequency weighting of sound.

noise measure. A reference sound pressure of 20 μPa was chosen. It represents the level of a tone just audible at 1000 Hz for someone with normal hearing. The sound pressure level is expressed in decibels (dB) and can be calculated from:

$$L = 10\log\frac{p^2}{p_0^2}\ \text{dB}\ (p_0 = 20\ \mu\text{Pa})$$

4 Sound level

The human hearing organ is not equally sensitive to sounds at different frequencies. Therefore, a spectral filter is used which rates the sound pressure levels at the different frequencies in about the same way as the human hearing organ does. This is a noise filter with the so-called A-characteristic. In figure C.1 this characteristic is plotted as a function of frequency. When the sound pressure levels of a sound are measured, using the A-filter, the result is given as the sound level in dB(A).

5 Equivalent sound level

When the sound level fluctuates with time, the equivalent sound level over a period of time is determined for a number of acoustic applications. This equivalent sound level can be expressed as follows:

$$L_{Aeq,T} = 10\log\frac{1}{T}\int_0^T \frac{p_A^2(t)}{p_0^2}dt\ \text{dB(A)}$$

with:
- $p_A(t)$: the A-weighted sound pressure at time t
- T: duration of the period considered.

6 Noise exposure level ($L_{EX} = L_{EX,occ}$)

The noise exposure level is the equivalent sound level to which a worker or group of workers is exposed on a representative workday. The duration of the workday is normalised to 8 hours.

7 Equivalent sound level over 24 hours ($L_{Aeq, 24h}$)

The equivalent sound level over 24 hours is the equivalent sound level due to an exposure of 24 consecutive hours.

8 Day-night level (L_{dn})

$$L_{dn} = 10\log\left[\tfrac{15}{24}10^{L_{Aeq,d}/10} + \tfrac{9}{24}10^{(10+L_{Aeq,n})/10}\right] \text{ dB(A}$$

in which:
- d (daytime) is the period from 07.00-22.00 h
- n (night-time) is the period from 22.00-07.00 h

The day-night level is the equivalent sound level over 24 hours, with the sound levels during the night increased by 10 dB(A).

9 Etmaalwaarde (24-hour value)

$$L_{etm} = \text{maximum of } L_{Aeq,d}, L_{Aeq,ev} + 5 \text{ and } L_{Aeq,n} + 10 \text{ dB(A)}$$

in which:
- d (daytime) is the period from 07.00-19.00 h
- ev (evening) is the period from 19.00-23.00 h
- n (night-time) is the period from 23.00-07.00 h

The etmaalwaarde ('24-hour value') is the maximum of one of three equivalent sound levels during certain parts of the 24-hour period, with the sound levels during the night increased by 10 dB(A) and those during the evening by 5 dB(A).

10 Aircraft noise exposure measure B

$$B = 20\log\sum_{i=1}^{N}(n_{ti} \times 10^{L_i/15}) - 15 \text{ Ke (Kosten Units)}$$

in which:

- N: number of overflights a year with $L_{A,max}$ at least 65 dB(A)
- L_i: the maximum level during overflight i
- n_{ti}: a weighting factor, dependent upon the part of the 24-hour period (10 during the night, 1 during the day)

11 Sound exposure level of a noise event

$$SEL \equiv L_{Ax} = L_{Aeq,t} + 10 \log t \text{ dB(A)}$$

in which:

- t is the total event time in seconds.

12 Effective duration of a noise event

The effective duration is specified in the following equation:

$$SEL = L_{A,\max} + 10 \log \tau \text{ dB(A)}$$

in which:

- τ is the effective duration in seconds.

13 Relations between measures

$$L_{Aeq,T} = SEL + 10 \log n_T - 35.6 \text{ dB(A)}$$

in which:

- n_T is the average number of noise events during an hour in a period of T hours

For road traffic noise the following emperical relations apply:

$$L_{dn} \approx L_{Aeq,24h} + 2 \text{ dB(A)}$$

$$L_{etm} \approx L_{dn} + 3 \text{ dB(A)}$$

$$L_{etm} \approx L_{Aeq,24h} + 5 \text{ dB(A)}$$

For aircraft noise, the relation between B and L_{etm} depends primarily on the distribution of the aircraft noise events through the day, evening and night. When the distribution of the aircraft noise events is 80 % during the day, 15 % during the evening and 5 % during the night, the relation is

$$L_{etm} \approx \tfrac{1}{2}B + 45 \text{ dB(A)}$$

This approximation holds for B values of at least 30 Ke.