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RESPONSE FUNCTIONS FOR ENVIRONMENTAL NOISE IN RESIDENTIAL AREAS

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TNO-Gezondheidsonderzoek stelt zich ten doel bij te dragen aan de verbetering van preventie en behandeling van ziekten en afwijkingen door het toepasbaar maken van kennis op medisch biologisch, psychosociaal en epidemiologisch gebied ten behoeve van de volksgezondheid en de gezondheidszorg.

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CONTENTS

SAMENVATTING

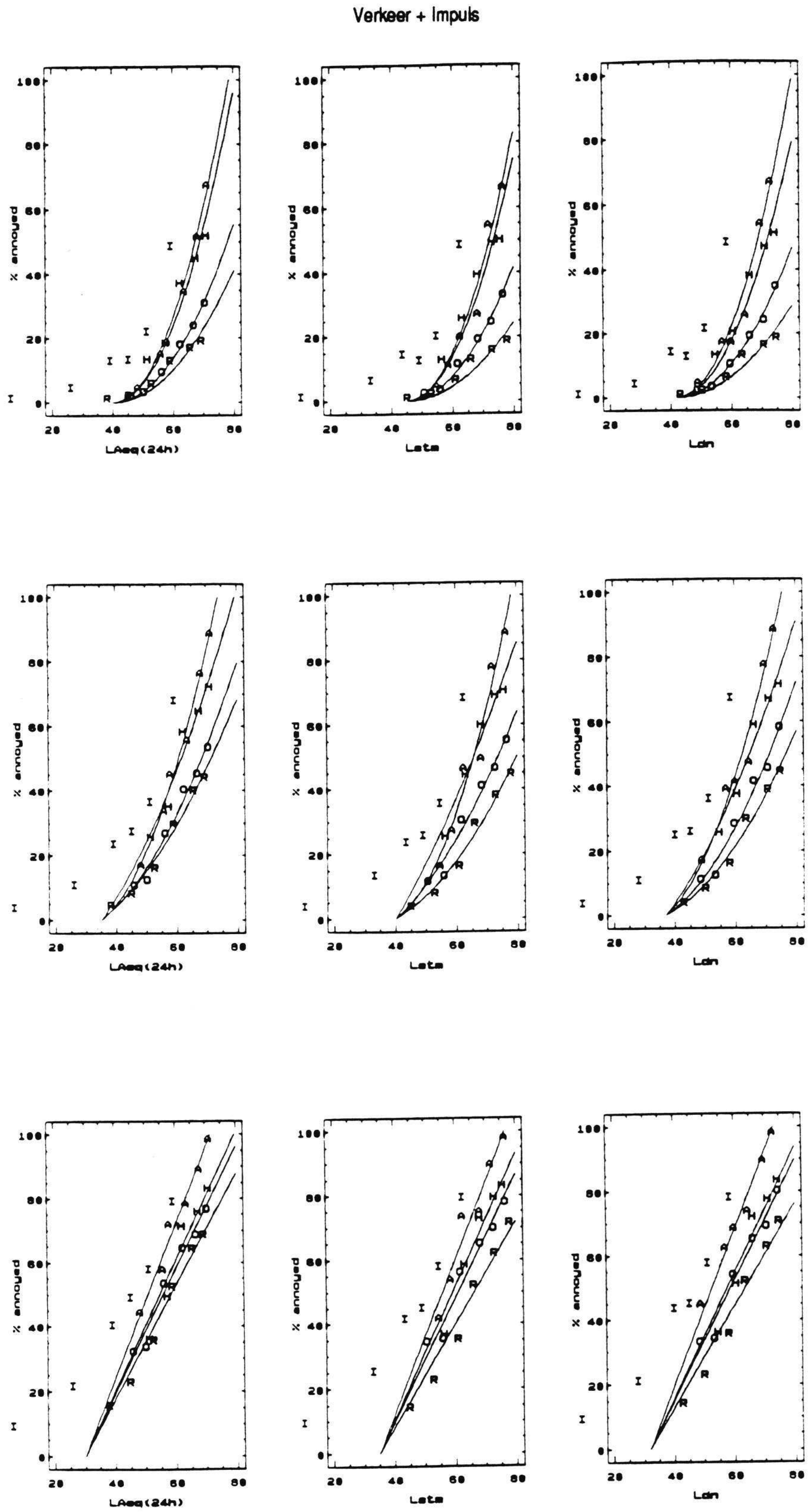
In de onderhavige studie zijn de gegevens uit geluidhinderonderzoeken uit diverse Europese landen integraal geanalyseerd. Het betreft onderzoeken met betrekking tot verschillende vormen van verkeer (vliegtuigen, snelwegen, overige wegen, railverkeer) en verschillende typen stationaire bronnen (industrie, rangeerterreinen, schietterreinen).

Doel van het onderzoek is het vaststellen van responsfuncties, die het verband beschrijven tussen effecten en de blootstellingsmaten L_{Aeq}(24h), L_{etm} en L_{dn}. Voor het realiseren van deze doelstelling is het van belang een geschikte classificatie van geluidbronnen te vinden. Een classificatie voldoet als binnen een klasse één responsfunctie voldoende is om het verband tussen een effect en een blootstellingsmaat te beschrijven.

De responsfuncties of hun curven kunnen gebruikt worden om blootstellingen aan individuele bronnen te evalueren. Deze evaluatie begint met het vergelijken van de desbetreffende bron met de klassen waarvoor curven zijn vastgesteld. Er moet een beslissing genomen worden over de klasse waar de bron het best inpast en daarmee over de curve die het meest geschikt is voor de beoordeling van die bron. In veel gevallen zal duidelijk zijn welke klasse en curve genomen moeten worden. Deze studie werd speciaal gemotiveerd door de behoefte aan curven en aan inzicht in de meest geschikte keuze daaruit voor industriële bronnen.

Voor de vaststelling van de responsfuncties zijn de originele data heranalyseerd. Er is veel aandacht besteed aan het voor de verschillende studies op vergelijkbare wijze vaststellen van blootstellings- en effectmaten. De blootstelling is, in aanvulling op de karakterisering door L_{Aeq}(24h), L_{etm} en L_{dn}, geclassificeerd aan de hand van diverse andere akoestische variabelen. De effecten, die aan L_{Aeq}(24h) L_{etm} en L_{dn} zijn gerelateerd, zijn (niet-specifieke) geluidhinder, communicatieverstoring, slaapverstoring, schrikken en hinder door trillingen.

Figuur 4.27 Percentage ernstig gehinderden (bovenste rij), gehinderden (middelste rij) respectievelijk matig of sterker gehinderden (onderste rij) als functie van L_{Aeq}(24h), L_{etm} en L_{dn} (A=vliegtuigen, H=snelweg, O=ander wegverkeer, R=railverkeer, I=impulse bronnen)



Voor (niet-specifieke) hinder zijn zowel de scores voor de hindercategorieën als hinderpercentages aan L_{Aeq}(24h), L_{etm} en L_{dn} gerelateerd. De verbanden bleken voor *verschillende typen verkeer* met eenvoudige functies beschreven te kunnen worden. In figuur 4.27 zijn de curven voor het percentage ernstig gehinderden (bovenste rij), gehinderden (middelste rij) respectievelijk matig of sterker gehinderden (onderste rij) weergegeven. Er zijn curven afgebeeld voor vliegtuigen, snelwegverkeer, overig wegverkeer en railverkeer.

De hinder is voor *impulsbronnen* bij gelijk expositieniveau hoger dan voor elk van de verkeerstypen. De resultaten voor impulsbronnen zijn eveneens in figuur 4.27 weergegeven. De trend is dat het verschil met vliegverkeer afneemt bij hogere niveaus. Deze trend is het duidelijkst waarneembaar als gekeken wordt naar de analyses waarin de hinderscores zijn gebruikt als effectmaat (zie hoofdstuk 4). Aan de hand van die analyses is ook duidelijk dat het verschil met overig wegverkeer minder variabel is. Door een straffactor van 15 dB(A) toe te passen wordt het even hinderlijke (overig) wegverkeersniveau redelijk benaderd.

Voor *(niet-impuls) industriële bronnen* wordt eenzelfde patroon gevonden als voor impulsbronnen. Bij lage niveaus zijn deze bronnen hinderlijker dan elk van de verkeersbronnen met gelijk niveau. En dit verschil neemt af bij hogere niveaus. Voor deze industriële bronnen zijn de verschillen met verkeer minder groot dan voor impulsbronnen. Verder is het beeld minder duidelijk omdat er uitbijters voorkomen die naar beide kanten aanzienlijk van de trend voor industriële bronnen afwijken.

Het probleem met industriële bronnen is dat ze een aanzienlijk heterogenere groep vormen dan elk van de verkeerstypen. Bovendien kan er bij één fabriek sprake zijn van verschillende typen geluiden, die met verschillende aspecten van het produktieproces verband houden. Voor de voorspelling van de hinder is het in ieder geval belangrijk onderscheid te maken tussen impulsgeluid (laden en lossen van containers of kratten, hameren, sorteren van metaal, etc.) en andere geluiden (kranen voor het laden en lossen, verkeer op het fabrieksterrein, raffinage-installaties, generatoren, ventilatoren, etc.).

Maar ook met dit onderscheid zal naar verwachting de hinder niet geheel te voorspellen zijn. Het feit dat de hinder voor impuls- en industriële bronnen bij lage niveaus relatief hoog blijft ten opzichte van verkeer lijkt (deels) te wijten aan het voorkomen van incidentele geluiden. Deze dragen naar verwachting meer bij aan de hinder dan vermoed zou worden op basis van hun bijdrage aan het geluidniveau, vooropgesteld dat ze gemeten worden. Het gaat hierbij bijvoorbeeld om het herstarten van het produktieproces bij een chemische installatie, na een defect of onderhoud, waarbij het affakkelen van gassen een luid geraas veroorzaakt. Of een stoomfluit bij een voedingsmiddelenfabriek die tweemaal per dag gaat. Of een telefoonbel bij een werkplaats die zo afgesteld is dat hij ook buiten wordt gehoord. Enzovoorts. De hinder van dit soort geluiden wordt niet in kaart gebracht als alleen naar geluidniveaus wordt gekeken.

Op basis van de resultaten uit dit onderzoek wordt voor de beoordeling van geluidsituaties een procedure voorgesteld, waarin vier stappen onderscheiden kunnen worden.

Stap 1 is het maken van een inventarisatie van de geluidbronnen die bijdragen aan het geluidniveau in de woonomgeving. Per geluidbron wordt voor de dag, avond en nacht het L_{Aeq} bepaald. De diverse verkeers- en stationaire bronnen worden onderscheiden. Voor industriegeluid wordt onderscheid gemaakt tussen impuls- en niet-impulsbronnen. Per bron wordt het L_{etm} bepaald en wordt vastgesteld in welke klasse, waarvoor responscurven beschikbaar zijn, de bron het best kan worden ondergebracht.

Stap 2 is het maken van een inventarisatie van de atypische aspecten van de geluidsituatie. Dit zijn de aspecten die tot gevolg hebben dat een bron meer hinder veroorzaakt dan wordt afgelezen uit de meest geschikte curve voor die bron, bij zijn L_{etm} waarde. Het gaat hierbij bijvoorbeeld om de eerder genoemde incidentele geluiden bij industriële bronnen. Maar ook voor verkeer spelen bijzondere aspecten een rol. Voor wegverkeer mag van optrekkend verkeer, en van brommers en motoren extra hinder verwacht worden. Voor vliegverkeer van reclamevliegtuigen. Voor trams van punten waar stoten of bonken optreedt door het passeren van wissels, of waar piepen optreedt door een korte boog. Enzovoorts.

Dus deze tweede stap is een aanvulling op de eerste, die nodig is omdat nooit voor alle specifieke situaties responscurven vastgesteld zullen kunnen worden. In de toekomst kan de set beschikbare curven wellicht uitgebreid worden, en kan gewerkt worden aan het verhelderen van de keuze van een curve daaruit voor een te beoordelen bron, maar er blijven in veel gevallen atypische aspecten. Met een alleen op het L_{etm} of andere maat gerichte benadering zouden deze aspecten buiten beschouwing blijven, terwijl soms juist door aanpak van de bijzondere geluidaspecten het eenvoudigst en voordeligst een reductie van de hinder te bereiken is.

Stap 3 is een beoordeling per geluidbron van de consequenties voor de kwaliteit van de woonomgeving. Hiervoor wordt uitgegaan van het bij de eerste stap vastgestelde L_{etm} en de keuze van de broncategorie waar de desbetreffende bron het best kan worden ondergebracht. Op basis van de resultaten uit de onderhavige studie wordt het volgende beoordelingssysteem verkregen:

L_{etm}

beoordeling	overig wegverk.	snelweg verkeer	vlieg verkeer	rail verkeer	impuls	niet-imp. industrie
goed	< 40	< 40	< 40	< 40	< 20	< 40
tamelijk goed	40-45	40-44	40-44	40-46	20-26	40-44
redelijk	45-50	44-48	44-48	46-52	26-32	44-48
matig	50-55	48-52	48-51	52-58	32-38	48-52
tamelijk slecht	55-60	52-57	51-55	58-64	38-44	52-57
slecht	60-65	57-61	55-59	64-70	44-50	57-61
zeer slecht	65-70	61-65	59-63	70-77	50-56	61-65
extreem slecht	≥ 70	≥ 65	≥ 63	≥ 77	≥ 56	≥ 65

Stap 4, tenslotte, is een beoordeling van de consequenties van het totale geluid voor de kwaliteit van de woonomgeving. Een fabriek waar zowel impuls als ander geluid wordt veroorzaakt, is een voorbeeld van een cumulatiesituatie. Voor de beoordeling van het totale geluid kan een elders beschreven methode (Miedema, 1992b) voor de beoordeling van cumulatiesituaties worden gebruikt. Daarmee kan de L_{etm} waarde voor (overig) wegverkeer worden vastgesteld, die evenveel hinder zou veroorzaken als de te beoordelen combinatie van geluidbronnen. In bovenstaande tabel kan bij deze waarde een kwaliteitsoordeel worden afgelezen.

PREFACE

The present study is the first of three related studies about environmental noise and odour. They are reported under the titles:

I. Response functions for environmental noise in residential areas;

II. Response functions for environmental odour in residential areas;

III. Quantification of environmental quality.

In the first and second study the original data from a number of investigations are analysed together to find functional relations between annoyance and exposure. These relations can be used to find for *individual* sources the exposure levels which correspond to limits with respect to annoyance. These relations make it also possible to find for various noise and odour sources the levels which have equally adverse effects.
The third is a study into the foundations of the description of environmental quality. An environmental quality measure is described. It can be used to find for *combinations* of noise and odour sources the levels which correspond to limits with respect to annoyance. Moreover, the measure can be used to find the (combinations of) exposure levels for noise and odour sources which are equally adverse.

The present study was especially motivated by the question how to evaluate noise from stationary sources. Since the amount of useful data for stationary sources is limited, we also used data for a variety of transportation noises and tried to find general features which explain the degree of annoyance caused. When these features have sufficient generality, they also can be used for the evaluation of stationary sources. Since so much data about transportation sources are analysed, the results are also relevant for the evaluation of transportation noise itself.

This study, as well as the two others, have been carried out under contract for the Ministry of Housing, Physical Planning and Environment.
Several people have contributed to this study. Jim Groeneveld of our institute succeeded with skill and patience in organizing the vast amount of data from different hardware and software systems into one database. Ruurt van den Berg of our institute advised with respect to several acoustical issuess. Collegues from several countries were so kind as to provide us with their original research data and communicated with us about the many details that needed to be understood for a correct use of these data. We would like to express our gratitude to all of them. We are especially grateful to James Fields (USA) for his assistance with obtaining information, also about studies of others.

1. INTRODUCTION

In numerous studies data have been collected about the effects of environmental noise. For the evaluation of environmental noise exposures little can be gained from collecting more data, except perhaps with respect to some specific problems. Unfortunately this does not mean that a clear picture exists about these effects. There have been relatively few integrative attempts to summarize the studies.

This may partly be explained by the lack of standardization in research methods, which makes such an integration a difficult task. The present state is that knowledge is scattered over many reports and articles plus a few books. New data would add a piece to the puzzle but the main question of how the pieces fit together would still persist.

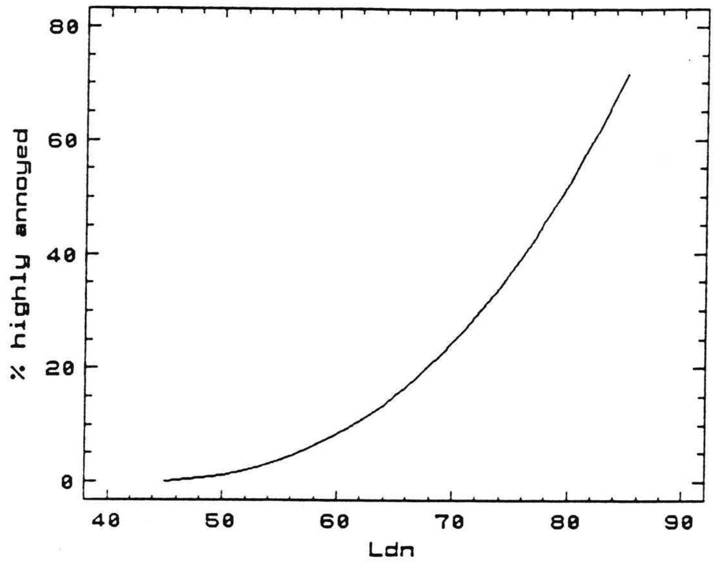
In the present study integral analyses are performed on the data of a number of investigations. These studies concerned transportation (aircraft, highway, other road traffic, railways) and stationary sources (industry, shunting yards, shooting ranges). The purpose is to establish response functions, which describe the relation between effects and the exposure measures $L_{Aeq}(24h)$, L_{etm} and L_{dn}. An important aspect is a proper classification of sources. Within a class one response function per effect and exposure measure has to be sufficient.

Response functions or their curves can be used to evaluate exposures due to individual noise sources. To evaluate a source, it has to be compared with the classes of sources for which curves are drawn. The most appropriate class has to be chosen and thereby the most appropriate curve for the evaluation of that source. In many cases the best choice clear. This study is especially motivated by the need of curves and the need of clarification of the most appropriate choice from them for industrial sources.

To find the response functions, the original data of the investigations are re-analyzed at the individual level. Much effort has been put into a comparable determination of the exposure and effect measures for different studies. The exposures are, in addition to the characterization by $L_{Aeq}(24h)$, L_{etm} and L_{dn}, classified with several other acoustical measures. The effects, which are related to $L_{Aeq}(24h)$, L_{etm} and L_{dn}, are (nonspecific) noise annoyance, communication disturbance, sleep disturbance, startle and vibration.

In the remainder of this introduction results from previous integrative studies are described. We do not attempt to be complete: there are more results in the studies mentioned and there are more studies than mentioned. We merely provide the results that seem most relevant in the present context.

Figure 1.1 Schultz' synthesis curve for transportation noise



The most comprehensive work on the effects of noise on man is a book by Kryter (1985). This book is more general than our present interest, which is focused on environmental noise. As argued in our chapter 3, the most important type of effect for the evaluation of environmental noise is annoyance. For a summary of data on the relation between exposure and annoyance from environmental noise, a paper by Schultz and the subsequent discussion between Schultz and Kryter are particulary informative (Schultz, 1978, 1982; Kryter, 1982a, b). In his 1978 article Schultz discussed a large number of noise annoyance investigations carried out in several countries. These investigations concerned aircraft, railway traffic and various types of road traffic. In order to make the investigations comparable Schultz used the available data to determine L_{dn}. He also attempted to define annoyance in a similar way.

For each of the investigations he drew up a curve showing the percentage highly annoyed persons as a function of L_{dn} (Schultz, 1978, figures 1 and 2). On the basis of the individual curves he synthesized a single curve as the 'best currently available estimate of public annoyance due to transportation noise of all kinds'. He also remarked: 'It may also be applicable to community noise of other kinds.' (Schultz, 1978, figure 3). Supporting the statement that the synthesized curve was a good representation of the research results, he showed that the majority of the data points from the investigation involved lay within the 90% confidence interval of the synthesized curves (Shultz, 1978, reproduced in figure 1.1).

Kryter (1982a) cast doubt on the adequacy of the synthesized curve. He did this on three main grounds:

1. the manner by which the percentage of highly annoyed persons was defined for the different investigations;
2. the methods used by Schultz to establish L_{dn} from the available data;
3. the criteria used by Schultz for excluding a number investigations when drawing up the synthesized curve.

Kryter argued that for ground traffic (i.e. road and rail traffic) and air traffic separate and non-identical curves give a significantly better representation of the data considered by Schultz (Kryter, 1982a, figure 11). According to Kryter, for a given L_{dn} the annoyance due to aircraft lies above the value given by the synthesized curve, whereas the annoyance due to ground transportation noise lies below. Kryter indicated that although the nonspecific annoyance due to the different sources can indeed be compared, the annoyance caused by different sources is of a different kind. This is shown when the specific annoyance is compared (Kryter, 1982a: figure 13).
The argument between Kryter and Schultz regarding the adequacy of a single curve for transportation noise has not led to agreement between them. However, sufficient data are available to show significant differences between the dose response relations for different types of source. This is also demonstrated in section 4.6 by comparing Schultz' summary curve (figure 1.1) with the results of the present compilation.
Recently, Fidell, Barber and Schultz (1991) extended the original compilation of Schultz and arrived at the same curve. Although their additional data appear to support Kryter's point that at the same exposure level aircraft noise is more annoying than ground transportation noise, the authors ignore the discussion with Kryter in which this point was brought forward.
Three more specific questions have been subjected to a summarizing analysis by Fields (1984, 1986, 1990). A first question concerns the relative effect of noise at different times of the day. For the curves drawn by Schultz and Kryter, L_{dn} is used as the exposure measure. In this measure a 10 dB penalty is applied to the nighttime level. Whether this or some other practice can be supported by annoyance studies was the question addressed by Fields (1986). He re-analyzed the data from aircraft, road and railway traffic with a total number of 22.000 respondents. In the most straightforward analysis different time-of-day weighting models were related to annoyance for the 24 hour period. For each model the parameters giving an optimal relation were estimated. One tested model would give the L_{dn} with the appropriate parameter substitution. The results were disappointing in the sense that it did not became clear which model and parameter values were most adequate. The

most important explanation was the high correlation among the levels for different periods within 24 hours in the studies examined. As a consequence the error of the estimation for parameters, which determine the time-of-day weights, was too high to draw a conclusion.
Here L_{etm} and L_{dn} are the measures with time of day penalties which are compared with the unpenalized $L_{Aeq}(24h)$. L_{dn} mostly because its widespread application and L_{etm} because its application in the Netherlands. L_{dn} is also included because there are theoretical and empirical reasons to prefer it above L_{etm} (see section 2.4 and Miedema, 1992b).
A second question concerns the effect of the number of events on annoyance. When all noise events are similar, $L_{Aeq}(T)$ equals the sum of the L_{AX} for a single event and 10 times the log of the number of events (minus ten times logT). Fields (1984) analyzed a number of studies to find the effect on annoyance of the number of events in combination with the average peak level of the events. He studied whether, for optimal annoyance prediction, the number of events has to be transformed logarithmically and whether this (transformed) number of events is additively combined with the average peak level expressed in PNdB. He found no evidence to reject these conventional hypotheses of logarithmic transformation and additive combination. Furthermore, using these hypotheses, the coefficient for the log of the number of events is estimated to be half or less than the coefficient for the average peak level. Fields does not compare the combination of averaged peaks and number of events with $L_{Aeq}(24h)$ or L_{dn}.
In the present analyses the number of events is used in addition to L_{Aeq} based measures. The number of events is used to give an indication for the prevalence of pauses (see section 2.5), which was suggested by Finke (1980) as a factor influencing annoyance.
Another issue recently studied by Fields (1990) concerns the effect of non-acoustical variables on the relation between noise exposure and annoyance. He analyzed 280 relevant English publications on the intervening effect of three types of variables: demographic, attitudinal and situational.
Table 1.1 gives a summary of his findings. None of the demographic variables has an effect. As a consequence, the demographic composition of the sample in different studies is not very relevant.
As a category, attitudinal variables have the strongest effect. It has to be kept in mind, however, that for this category common response tendencies may explain a relation between those attitudes and annoyance. Of the three variables that have a clear influence, fear and preventability are associated with the type of source. It is known that fear influences the annoyance from aircraft noise and that people do not in general feel that the noise from e.g. road or rail traffic could be avoided. These factors may therefore explain some of the differences between sources. In this study the working assumption for idiosyncratic factors such as noise sensitivity is that their distribution is independent of the noise exposure and other acoustical factors.

Table 1.1 Influences on the relation between noise exposure and annoyance: + and - mean consistent evidence in favour of respectively against influence, whereas ± indicates that results are inconsistent (source: compilation study by Fields, 1990).

Demographic factors		
	1. age	-
	2. sex	-
	3. socio-economic status	-
	4. renting versus owning a house	-
	5. single versus multiple unit dwelling	-
	6. length of residence in neighbourhood	-
	7. dependence on noise source for employment or transportation	-
Attitudinal factors		
	8. fear with respect to source	+
	9. belief that noise could be reduced if authorities took the appropriate actions	+
	10. awareness that non-noise problems are associated with the source	±
	11. general noise sensitivity	+
	12. belief that source of the noise is an important economic activity	±
Situational factors		
	13. amount of time spent at home	-
	14. ambient noise level	-
	15. visibility of the source, distance to flight path, etc.	±
	16. newness of noise	±

Before we turn to the analysis of the compiled data, the noise measures used are described in chapter 2 and noise annoyance measures in chapter 3. Then, in chapter 4, non-specific annoyance is analyzed as a function of different noise measures. The same is done for communication disturbance, sleep disturbance, startle and for reports of vibration. The results are discussed and conclusions are drawn in chapter 5. In the appendix the incorporated studies are described, thereby focusing on the determination of the noise and annoyance measures needed in this study.

2. EXPOSURE

In our perception environmental noise is structured by distinguishing contributions which are attributed to different sources. Sources are distinguished at different levels of abstraction. We may e.g. refer to traffic noise or, more specifically, to the squealing of bus brakes. It appears that there is a limited range of natural levels of abstraction for discriminating sources.
It is hard for a person to evaluate contributions from sources, whose definition do not fit in their natural scheme. Presumably this is because experiences with sounds are processed and remembered in relation with their source. To question noises at too specific or too general a level would ask for more than a person knows.
For example, most persons do not distinguish the noise from different types of civil aircraft. Therefore, they cannot give an evaluation of annoyance caused by each type separately. On the other hand, for answering a question about annoyance from road plus air traffic information for each source separately can be retrieved from memory. However, to combine this information would require mental calculations. Which calculations are performed seems to be determined by the phrasing of the questions (Miedema, 1987b) and the validity of the result is questionable (Miedema, 1987a).
The following sources appear to constitute natural entities for discussing noise annoyance: large aircraft, small aircraft, helicopters, jet fighters, local road, highway, trains, trams, subway, shooting ranges, many different kinds of industrial sources and different kinds of recreational activities such as motor crossing or speed boat racing.
These sources are used to spatially structure the origins of sounds and to organize memories of annoying events. For the prediction of its adverse effect, a source has to be rated with respect to loudness and other aspects.
Acoustical aspects, known to be relevant for annoyance, can be divided in characteristics of the frequency spectrum, of the time pattern and spatial characteristics. Each of these aspects is discussed in a separate section. See Schultz (1982) for a general, unsurpassed overview of noise measures, proposed to characterize acoustical aspects relevant for annoyance.

Table 2.1 Acoustical variables which influence annoyance, besides the (average) level expressed e.g. as L_{Aeq}(24h)

Frequency	
1.	tonality: relative concentration in small frequency bands.
2.	height: position of the centre of gravity of the frequency spectrum.
Time	
3.	onset: level increase per second.
4.	period: distribution over periods as day, evening and night.
5.	pauses: prevalence of relative quiet periods.
Spatial	
6.	quiet side: level differences between sides of the dwelling.

2.1 Tonality

Measures for tonality have been proposed by Kryter & Pearsons (1965) and by Little (1961). They were developed for the aircraft certification. Determination of these measures requires rather detailed knowledge about the frequency spectrum of the noise and is not feasible in the noise abatement practise. Tonality can also be caused by interferences in the form of amplification at some frequencies and suppression at others. This phenomenon can occur with coherent sources or reflections of a single source.

A distinction of a few types of tonal sounds from non-tonal sounds appears to be the most that can be accomplished. For the present compilation study tonal sounds from railways and from stationary sources are the only two categories which are distinguished from non-tonal sounds.

2.2 Height

What we mean by height is for pure tones usually called pitch and depends on the frequency of the tone. For a single peaked A-weighted frequency spectrum the location of the peak could be used as a generalization of this. In general, the centre of gravity of the spectrum could be used. This position could be categorized as low, intermediate or high.

For the studies in the compilation the directly available information about frequency spectra, however, is not sufficient to study the effect of height on adverseness. After having prepared our data set for the analyses, we became aware of the possibility to use the percentage of heavy vehicles for rail and road traffic as an indication of the amount of low frequency noise. (Of course, it has to be studied whether low frequency or other features are responsible for any effect of the percentage heavy vehicles on annoyance.) At that point, however, we had to postpone the inclusion of these data to a later occasion.

Part of a necessity to consider height may derive from the failure of the commonly used A-weighted measures to take the effect of low frequency components on loudness sufficiently into account. The A-weighting procedure does not take into account the spread of excitation in the basilar membrane to regions corresponding to higher frequency. A measure that does, as Zwickers sone, would eliminate this part of the frequency effect. For application of this measure to environmental noises in field studies see Schumer et al. (1983) and Miedema (1985) and for application in laboratory studies e.g. Fastl (1981).

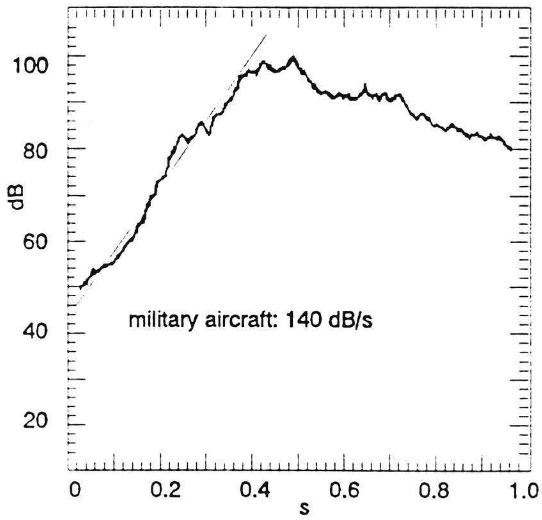
2.3 Onset

Extensive EEC laboratory studies on measures for the impulsiveness of sound, reported by Rice (1989), did not provide clear evidence that one measure was better than others. One measure that has intuitive appeal is (average) rise velocity. Since the studies in the present compilation do not contain rise velocity data, indirect information is used to derive rise velocities. This information is only sufficient to discriminate between a few wide classes of rise velocities. Most of this section is concerned with the definition of these classes.

A first, tentative distinction is between *impulses* (hammer strokes, shooting), *passages* (of cars, trains, aircraft) and *no detectable fluctuation* (refinery noise). These three classes are in decreasing order with respect to rise velocity. Passages constitute a rather broad class, with at one extreme the fused sound of cars on a highway at some distance and, at the other extreme, a low overflight of a jet fighter. In between are other overflights (at greater height with lower speed), passages from rail vehicles and cars on a road at shorter distance or with lower traffic intensity. It appears that the minimum rise velocity that may cause startle lies somewhere in the range covered by passages. We therefore take a closer look at this category. Subsequently, it is discussed whether further differentiation of the category of impulses in needed.

Suppose that vehicles (road, rail, air) follow a straight path with constant speed and emission. Then the main variables determining the rise velocity are speed and shortest distance from the observer to the path. It increases with emission and speed, but decreases with distance. Since (considering all types of passages) low overflying jet fighters have a high emission and speed and are medium with respect to distance, it is to be expected that they cause the highest rise velocities. Figure 2.1 shows a recorded overflight. The average rise velocity is 140 dB/s. Mostly rise velocities for overflying jet fighters are lower, in the order of 50 dB/s.

Figure 2.1 Overflight of a jet fighter (Curio, 1986). The average rise velocity is 140 dB/s, the rise velocity at the steepest part is 200 dB/s



Which type of passage has the next highest rise velocity is not immediately clear since the trade off between the variables relevant for rise velocity (speed, emission and distance) is not simple.

Figure 2.2 shows records of passages for aircraft, trains, trams and cars. The rise velocities of this large class of passages can be seen to be of another order of magnitude than for low flying jet fighters.

We estimate that the effect of the rise velocity is negligible for this class of passages. It therefore appears reasonable to distinguish for passages only between low flying jet fighters and other passages, and to combine those other passages with the class of no detectable fluctuation. The planned extension of the lines for high speed trains in Europe appears a proper cause for studying refinements of the dichotomization of rise velocities for passages. For these trains, with velocities up to 300 km/h, rise velocities are expected to have magnitudes in the order of double of those of the present intercity trains. Therefore they may constitute a separate category in the sense that the adverseness of such onset cannot be equated with either passages of jet fighter or the other types of passages.

For impulses a distinction with respect to rise velocity can be made between shots and other impulses. Figure 2.3 shows recordings of artillery and rifle shots with rise velocities in the order of 32.000 and 320.000 dB/s respectively and figure 2.4 an impulse from pile driving with a rise velocity in the order of 8000 dB/s.

Figure 2.2 Average rise velocities for passages of aircraft, trains, trams and cars. Upper row left: aircraft near Glasgow airport (left) (Walker, 1986) and recording at 330 m from take off Boeing 737 (Myncke, 1978). Bottom row left: trains recorded at 125 m from the railway (Hermelink, 1976) and freight train at 30 meter. Upper and bottom row right: trams and cars in busy city traffic (TNO measurements).

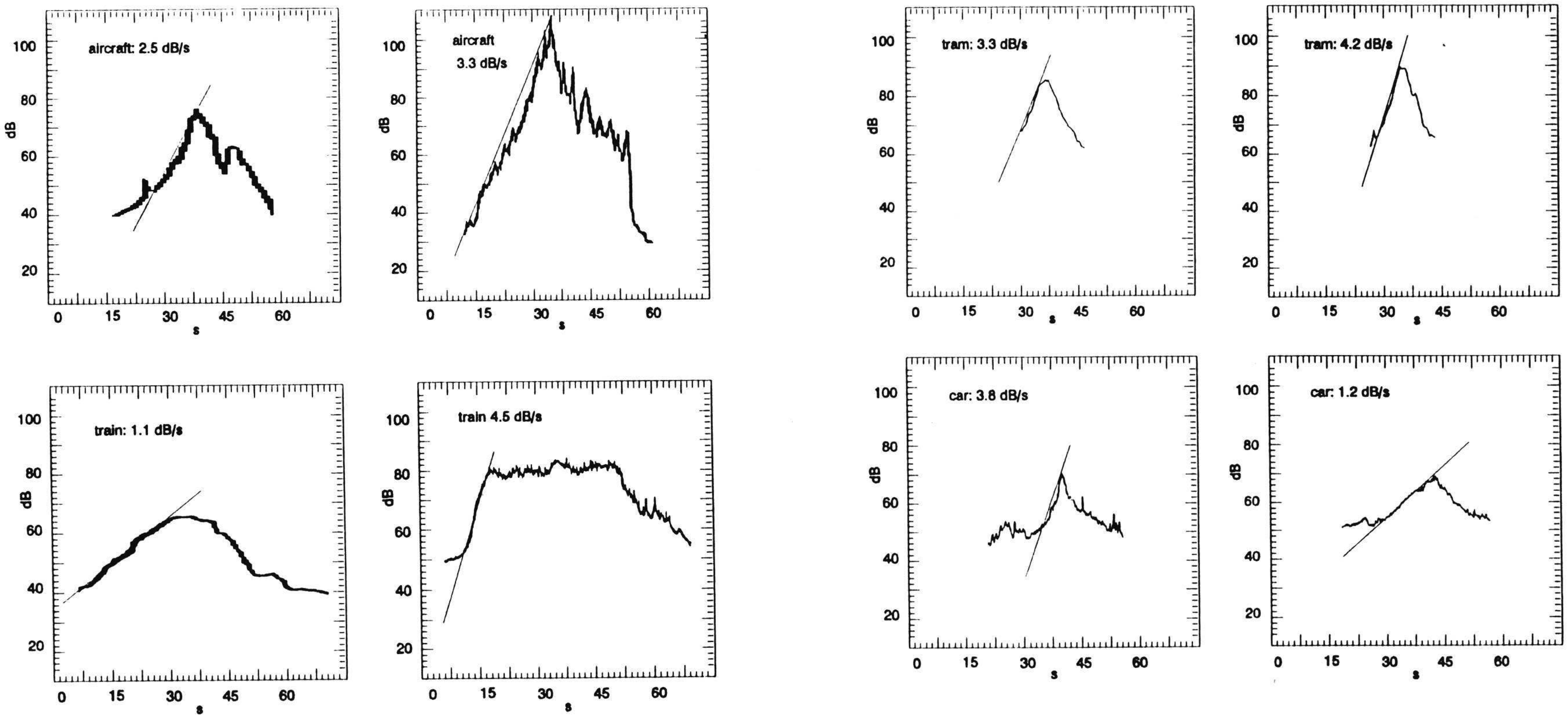


Figure 2.3 Impulses from gunshots. Left 105 L 53 gun mounted on an AMX tank recorded at 25 m distance. The peak level is 161 dB. Right a FAL rifle shot recorded at 4 m distance. The peak level is 155 dB. Rise times are less than 5 respectively 0.5 ms (Smoorenburg, 1979).

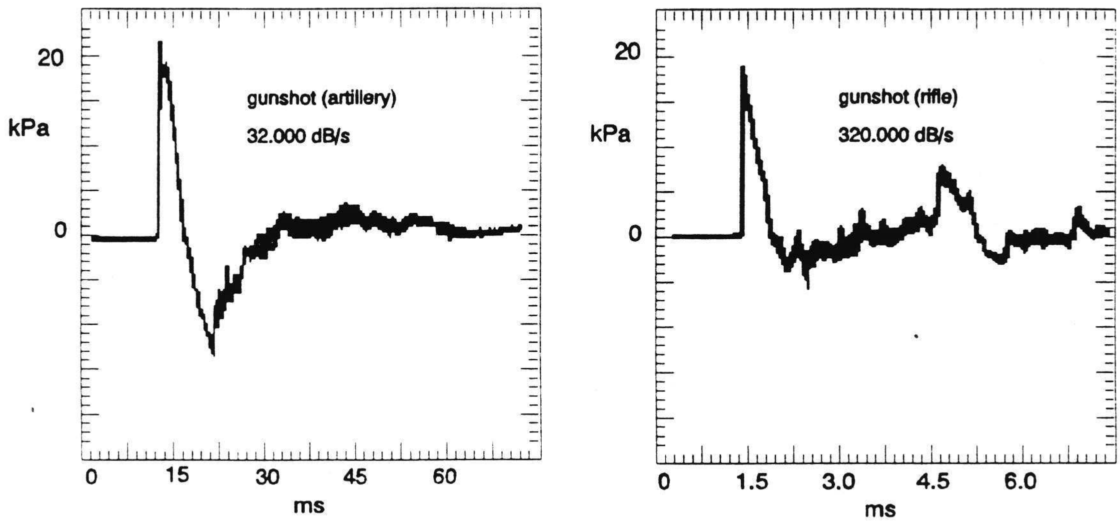
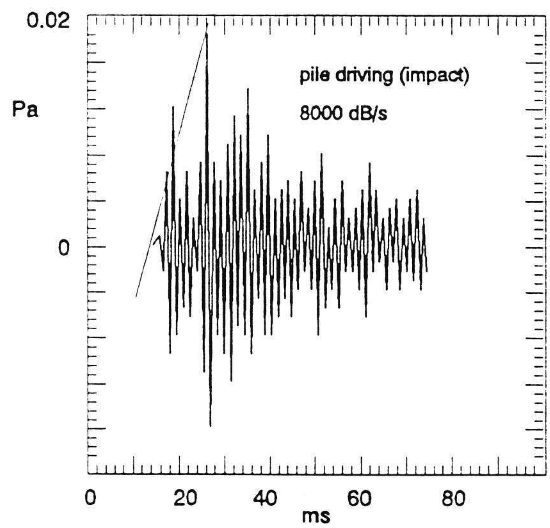


Figure 2.4 Impulse from pile driving (TNO measurement)



However, the loudness integration time of the hearing system is somewhere between 20 and 200 ms, and the (loudness) excitation does not vanish instantaneously. This imposes restrictions on the rise velocities that can be discriminated. Since for all types of impulses rise times are much less than the duration of the loudness integration period and the extinction period, rise velocities of impulses will hardly influence the perceived velocity of their loudness increment. For impulses the maximum level and possibly the duration are more important for the loudness increment velocity. Thus, a distinction between different kinds of impulses is not needed.

Summarizing the above considerations, our proposal is to use three categories for rise velocities: ≥ 1000, circa 50, and < 10 dB/s.

These categories correspond to impulsive sounds, low flying jet fighters, and other passages together with steady noises. The partition is not exhaustive. And it is not known where to place exactly the boundaries. (New) environmental sounds as from high speed trains may require refinement of the categorization.

Apart from pure impulse sounds from stationary sources, stationary sources and traffic may cause impulses in combination with other sound. Impulses from traffic can e.g. be caused by irregularities in the road or in the track, due to shunts or transition to a viaduct. A special case is the noise of a helicopter, whose bladeslaps produce very regular and highly predictable impulses.

2.4 Time of day

Effects of environmental noise not only depend on the noise but also on the activity the exposed person is engaged in. Some activities are more sensitive to noise than others. Since most activities are not performed synchronously, it is hard to connect noise in different time intervals to activities. The most important exception is the cycle of being awake and sleeping, which approximately coincides with day + evening versus night period.

Two measures which take into account that sleeping is more sensitive to noise than most activities carried out when awake are L_{etm} and L_{dn}. Both are calculated from the L_{Aeq} levels for different day periods. Of course there is a large individual variation in sleeping periods and the optimal division of a day in periods should be further studied. But here L_{etm} is used because it is used in the Netherlands' legislation and L_{dn} because it is used in many other countries.

There are two differences between these measures. For L_{etm} three periods are distinguished: 7 - 19, 19 - 23 and 23 - 7h. For L_{dn} the periods 7 - 22 and 22 -7h are used. The penalties applied to the L_{Aeq} for the day and night period are 0 respectively 10 dB for both measures. Disregarding an

exception made for the application to road traffic, for L_{etm} a penalty of 5 dB is used for the evening. The second difference is the way of combining the contributions from different periods. For L_{etm} the maximum is taken over the three (penalized) levels, while for L_{dn} the two (penalized) levels are combined according to the common (energetic) sound averaging procedure.
Whether the evening period has to be considered separately and the night period should be taken to start at 22 or 23h could be the subject of discussion. But with respect to the way of combining contributions from different periods the procedure for L_{dn} is to be preferred above that for L_{etm}. The reason for this is as follows. For L_{etm} a maximum is taken with the consequence that it is insensitive to the level within a period as long as the penalized level is not the maximum. But, as a matter of fact, a situation with an L_{Aeq} of 70 dB(A) in the day and 60 dB(A) in the night is more detrimental than with 70 dB(A) in the day and 45 dB(A) in the night.
In the compilation study both L_{etm} and L_{dn} are used in addition to L_{Aeq}(24h). Sufficient data about levels for the different periods are available.

2.5 Pauses

As mentioned in the previous section when comparing L_{etm} and L_{dn}, the sound averaging procedures do not disregard the non-maximal contributions, which is qualitatively correct. However, this leaves open the quantitative question about the trade off between contributions from different moments. The sound average, for unpenalized levels denoted by L_{Aeq}, is largely determined by the loudest events. This is in accordance with the knowledge that these events do have a great influence on annoyance. But there is a less desirable second consequence, similar to the neglect of the non-maximal contributions in the L_{etm}. Changes of sound levels which are and remain at least 10 dB(A) below the maximum have hardly any influence on the L_{Aeq}. And this too is contrary to the facts. Exposures with substantial quiet pauses are less detrimental than ever present noise. For the same reason, an 'escape room' and quiet nearby outdoor places are valuable, even though their use may hardly lower the personal L_{Aeq}.
Finke et al. (1980) proposed a measure to capture these phenomena. The information it adds to e.g. L_{etm} or L_{dn} is for traffic strongly related to the number of passages or events. Since this information is more easily obtained and available in most of the studies in the compilation we use this. Specifically we use as a measure a count of the number of quiet minutes. A rough approximation is to subtract one minute from 1440 for each passage. This procedure does not take into account

multiple passages in the same minute. When information about the distribution of passages is available, it is used to get a more precise estimate.

For sources other than traffic, specifically industrial sources, each minute of operation time is subtracted.

2.6 Quiet side

Relative quietness may occur because of a pause in the emission, but also because one goes to a relatively quiet place. Spatial distinctions between noise levels can be made in different ways. Within a house some rooms may be relatively quiet, when only one side of the house is exposed to noise. The difference between the sound level outside, in the garden or on the balcony, and inside may vary for houses, due to construction and noise insulation differences. And in the neighbourhood of some houses there are quiet places, but for others this is not the case. Finally, for houses in densely populated areas a quiet place for a walk or bicycle tour often can only be found at large distance, while persons in other dwellings do not have to travel that far.

In the present compilation we only have data to study the effect of a quiet side of the house. We use the L_{Aeq} difference between the most and least exposed side of the house as indicator. It is classified in the classes <5, 5-15 and ≥ 15 dB (A). E.g. for connected houses with road traffic at close distance a difference of ≥ 15 dB is to be expected. For a house under a flight path or with two equally busy close roads at similar distance of opposite sides of the house a difference <5 dB is to be expected.

2.7 Summary

The table below gives a summary of the sound measures which are used in this study.

Table 2.2 Summary of sound measures used in addition to $L_{Aeq}(24h)$

Frequency		
1.	tonality:	absent or present
2.	height:	-
Time		
3.	onset:	rise velocity is < 10, about 50 or ≥ 1000 dB/s
4.	period:	L_{etm} or L_{dn}
5.	pauses:	MAX (0, [1440 - N] /14.4), where N is number of passages or minutes of operation time.
Spatial		
6.	quiet side:	L_{Aeq} difference between most and least exposed side of house is < 5, 5-15 or ≥ 15 dB(A)

3. EFFECT

3.1 A general taxonomy of noise effects

The effects of environmental noise can be divided in three categories: *somatic effects*, *functional effects* and *annoyance*. There are no sharp boundaries between these categories and an effect in one category can have a correlate in another. Prototypical examples for the categories are raised blood pressure (somatic), speech disturbance (functional) and nonspecific annoyance attributed to noise (annoyance). Sleep disturbance (functional) is an example of an effect that has correlates in other categories: α-rhythm changes in the EEG pattern (somatic) and annoyance caused by not having slept well (annoyance).

Apart from the already mentioned nonspecific annoyance, there are reports of annoyance related to specific functional effects or other specific causes. Most important specific annoyance effects are due to *sleep* disturbance, *communication* disturbance, concentration disturbance with *startle* as extreme and *vibration* of the house. In this compilation study nonspecific annoyance and these four specific annoyance effects are considered.

Social consequences could be added as fourth general category. Phenomena as aggression to others and decreased willingness to help, which are related to the concept of alienation, have been studied. The study on these effects started at about the same time as systematic studies on annoyance. An example of an early study is that of Stemerding-Bartens (1960, 1965) on the effect of noise on group interaction. But, altogether, the amount of data collected is far less than for the other three categories. For an overview, see De Boer (1986).

3.2 Effects and the evaluation of noise situations

An important question is which effects have to be considered for the evaluation of environmental noise exposures.

An effect can be taken into account only if there exist reliable and valid measures for it. Reliability has to do with measuring something other than random factors. A measure is more reliable when the influence of random factors is less. Validity means that the right, intended effect is measured. Reliability is a prerequisite for validity. In addition, validity requires low bias.

For *somatic effects* it has been proven difficult, if not impossible, to isolate the part due to noise from the part with random or confounding systematic causes. Presumably this is due to the complex etiology of the phenomena studied, such as hypertension and reduced birth weight. Even at extreme noise levels adverse somatic effects other than hearing damage are hard to demonstrate, presumably because of random and confounding factors. The problems with separating the effect of noise means that either they are absent or not very substantial, or there are at present no reliable and valid measures. Most promising appears to be laboratory research where somatic effects are the cost of sustained performance in noise.

Functional effects are abundantly demonstrated in the laboratory. The insight into speech disturbance is most developed and led to specialized measures to predict it (AI, SIL, STI). One factor that contributed to this high level of development is the availability of simple, reliable and valid tests for speech disturbance.

For other functional effects simple tests are lacking. For sleep disturbance measures in terms of the EEG pattern have often been used. Apart from being far from simply established, their validity is questioned. Probably the most straight forward measure available at the moment is the probability of involuntary awakening. A disadvantage is that the sleep quality may deteriorate without a single awakening. Other measures used, such as self reported sleep quality and performance tests, may turn out to be the most useful indicators of the adverse effects on sleep.

For noise during task performance it has become clear that effects can occur although accuracy and speed of performance in simple tasks are often sustained. Noise in relatively complex tasks, as double tasks, induces shifts in priorities and strategies. But the demonstration of effects still requires levels higher than found in residential areas. More sensitive tests are still lacking. Often a person can sustain his performance as measured, but with costs in the form of detrimental effects that easily remain unnoticed since they are of another type. See Veltman (1988) for demonstrations of 'displaced' effects even in the relatively short period of laboratory tests.

Annoyance is measured with questionnaires, either used in a face-to-face or telephone interview or sent by mail. In the introduction it was already mentioned that annoyance can only be determined for sources that fit in the respondents conceptualization of the noise environment. When source definitions are used that deviate from this, the reports are not valid. For individual noise sources, defined at the level of abstraction of the list in chapter 1, the reliability and validity has been studied by several researchers.

A high correlation between repeated measures of annoyance, either within the same questionnaire or at different times, is a indication for reliability. Groeneveld and De Jong (1985) found correlations from .85 - .95 for four European studies on impulse noise between annoyance determined with a four and ten point scale. Questions on impulse noise and on traffic noise were involved. A correlation of .61 has been found by Griffith and Delauzin (1977) for annoyance responses determined with a time interval in which no significant change in exposure occurred. These results support the view that annoyance measures are at least moderately reliable.

It may be noted that a high correlation at the individual level may be considered to be a too strong requirement. Momentary factors may influence the annoyance responses and reduces the correlation between responses at different times. But this does not make annoyance a less useful measure, as long as the distributions of responses at given noise conditions is stable. So it may be more relevant to look, e.g., at the stability of distribution means, than to determine correlation coefficients for individual responses at different times.

Validity follows from a relatively high correlation with conceptually related measures (for nonspecific annoyance e.g. with communication disturbance by the same source) as compared with correlations with conceptually unrelated measures (for nonspecific annoyance e.g. with nonspecific annoyance from another source). Hall and Taylor (1982) found correlations from .7 to .8 for questions on different annoyance aspects for the *same source* in the same interview. The correlation between annoyance from *different* sources, which has to be comparatively low for validity, is found to be in the order of .10 to .35 by Van Kamp (1990). These correlations are low but not all negligible. The correlations may be due to correlations between exposure levels for different sources. They may also be caused by tendencies to respond in a certain direction or use a certain part of the scale. For an elaborate view on response criteria see Berglund et al. (1987).

Table 3.1 Rating of the evidence on effects at realistic environmental levels. The rating is more positive when effects are demonstrated and relations with exposure characteristics are known.

adverse somatic effects	-	trends at high levels or no effects found
functional effects		
speech disturbance	+++	detailed knowledge about relations
sleep disturbance	+	knowledge about relations
performance deterioration	o	effects found, mainly at high levels
annoyance	++	substantial knowledge about relations

The state of affairs, summarized in table 3.1, suggests that noise situations can be evaluated on the basis of systematically collected noise annoyance reports. An advantage of noise annoyance reports is that they constitute a measure for deterioration of the quality of life, with an implicit weighting by the exposed person of specific effects.

Since adverse somatic effects, when found at all, are only found in situations where annoyance reports already demonstrate severe detrimental effects on the quality of life, their relevance for evaluating environmental noise is questionable. Documentation of functional effects, such as communication, sleep and performance disturbance, is more likely to give valuable information about the acceptability of noise exposures.

3.3 Translation of differently measured annoyance

Unfortunately, researchers have been very creative in the design of questionnaires, and the annoyance items in particular. Arguments could be presented for any particular approach. By now there is probably consensus on the desirability of some features (e.g. no bipolar category systems; more than two categories; no extreme verbal labels; do not skip annoyance questions when little is heard of the source). But the gain of these insights comes at high costs in terms of difficulties for comparing results. Variation with respect to the following two aspects may be important when comparing results from different surveys.

Focus on annoyance. There are differences in the degree of focusing on noise annoyance, both prior to the noise annoyance question and in the formulation of this question itself. Three relevant aspects are the introduction of the topic of the questionnaire (e.g. noise annoyance versus evaluation of neighbourhood), the position of the noise annoyance question in the list (e.g. are there prior noise annoyance questions or not) and the phrasing of the question (e.g. is there a reference to prior self-reported noise effects).

Answer categories from which the respondent can choose for reporting his degree of annoyance. Important are the number of categories and their verbal labels, if any.

We estimate that the second type of difference, with respect to answer categories, is the more important. In the remainder of this section it is described how we coped with these differences. With respect to variation in focus on annoyance little can be done to adjust results, if this would be necessary. The relevant features can only be reported, which is done in the appendix for the surveys in the present compilation.

Dose-response data can be analyzed in several ways. One possibility is to describe the *percentages* of respondents reporting at least a certain level of annoyance as a function of the dose. Using the percentage approach the problem is to determine for different category systems a category boundary that dichotomizes the annoyance continuum at approximately the same point. Another possibility is to describe the annoyance *scores* as a function of the dose, after having assigned scores to the categories. Using this scoring approach the problem is to assign to categories from different systems scores that represent the category midpoints on the annoyance continuum. Finding a cut-off point as well as assigning scores is simplest when the following two assumptions can be made:

- Equal intervals: each category from a single system occupies an equal portion of the annoyance continuum;
- Equal extremes: the lower and upper outer category boundaries from different category systems coincide.

If these assumptions are met, the cut-off points and scoring given in table 3.2 can be used. They depend only on the number of categories. The cut off scores are determined as follows: (score for inner category boundary i) = 100i/m, where m is the number of categories and i = 1,...,m-1 is the rank number of the category, starting at low annoyance. The category midpoint scores are determined as follows: (score for category i) = 100 (i - ½) /m, where m is the number of categories and i = 1,...,m is the rank number.

Table 3.2 Cut off points and category scores for different category systems. The numbers of categories which effectively occur in this compilation study are starred.

number of categories	cut off points	category scores
3	33 - 67	17 - 50 - 83
4*	25 - 50 - 75	13 - 37 - 63 - 87
5*	20 - 40 - 60 - 80	10 - 30 - 50 - 70 - 90
6	17 - 33 - 50 - 67 - 83	8 - 25 - 42 - 58 - 75 - 92
7	14 - 28 - 43 - 57 - 72 - 86	7 - 21 - 36 - 50 - 64 - 79 - 93
10*	10 - 20 - .. - 80 - 90	5 - 15 - .. - 85 - 95

Since Schultz used the cut-off at 72, this is also used here. He called this percentage the percentage 'highly annoyed'. Kryter argued for a lower cut-off point. We use the cut off points (10) - 20 - 28 - 40 - 50 - 60 - 72 - 80 - (90). In order to get these percentages annoyed for different category systems, the cumulative percentages at the nearest cut-off points on either side are linearly interpolated.

Since we did not extrapolate, we sometimes could not determine percentage for 10 and 90.

For clarity and to stress the often neglected fact that annoyance percentages are rather meaningless without references to the cut-off boundary, we write A_{10}, A_{20}, A_{28}, ..., A_{90} for the annoyance percentages.

Unfortunately, verbal labels may lead to violation of the 'equal intervals' and 'equal extremes' assumptions. Especially bothering are bipolar category systems and extreme verbal labels.

Adjustments to account for the effect of labels, as well as miscellaneous consideration are, when applied, described in the appendix. The number of categories after such adjustments are referred to as the effective number of categories.

The approach to obtain comparable cut-off points and category scores is based on a priori considerations. These considerations are checked with a procedure known as optimal scaling. Results are reported in chapter 4.

4. RESPONSE FUNCTIONS

In this chapter the analyses of the relation between annoyance and exposure measures are reported. Nonspecific annoyance is related to $L_{Aeq}(24h)$, L_{etm} and L_{dn}, which we call overall exposure measures. Effects of additional acoustical variables, such as the percentage of quiet minutes or the difference between most and least exposed side, are analyzed with L_{dn} as overall measure. Communication disturbance, startle and vibration are related to $L_{Aeq}(7\text{-}19)$ and sleep disturbance to $L_{Aeq}(23\text{-}7)$.

For both nonspecific and specific annoyance the individual *scores* are related to the overall levels by the best fitting continuous, piecewise linear function. In general the overall levels are divided in five intervals with, as far as possible, an equal number of observations. On each interval the fitted function consists of a linear piece. They are connected at the boundaries between the intervals. Because there is no restriction on how the pieces are connected, these functions have considerable freedom to follow variations in the data. It should be noted that this type of function fitting is different from linear interpolation between a few points, which also leads to curves with linear pieces.

The goodness of fit is characterized by the correlation coefficient r. As with linear or other polynomial regression, r^2 is the proportion of variance of the dependent variable accounted for by the fitted function, in this case a piecewise linear function.

Variations of a piecewise linear function may be due to random factors. Therefore, a more restricted function, such as a linear function, is to be preferred when this gives only a small drop in correlation coefficient. A large drop, however, indicates that the restriction causes significant features of the relation to be lost. Thus, by comparing the fit we know when a piecewise linear functions hardly improves the simpler linear solution.

For nonspecific annoyance we also present *percentages* annoyed as a function of the overall levels. Different percentages are obtained with different bisections of the annoyance range: A_{10}, A_{20}, A_{28}, A_{40}, A_{50}, A_{60}, A_{72}, A_{80} and A_{90}. The two extreme percentages, however, could not always be determined. To some percentages verbal labels are attached. A_{28} is called the percentage of those (at least) moderately annoyed, A_{50} the percentage annoyed and A_{72} the percentage highly annoyed. In figures that follow, the curves for these three percentages are drawn with a solid line, whereas for the other percentages a dotted line is used.

To determine a percentage curve, the overall exposure levels are divided in, generally five, intervals, in the same way as described above. A simple procedure would be to determine per interval the percentage annoyed. Who is counted as annoyed depends on the particular annoyance curve that is determined (A_{10} or A_{20} etc.).

The procedure used here is an elaboration of above procedure, which gives a result that is less sensitive to random errors. Corresponding to each interval boundary, a tent shaped weight function is defined. Using these (six) functions, weighted averages are determined for exposure levels and for annoyance coded as 100 or 0, depending on whether the particular cut off point is exceeded or not. In this way we obtain for six exposure levels the percentage annoyed. The curves in the percentage figures are obtained by linear interpolation between these points.

First, the results for three types of transportation sources are presented in separate sections (aircraft, railway traffic, road traffic). In a fourth section the results for stationary sources are reported. The curves for different types of sources are compared in the fifth section. In the sixth section our results are compared with Schultz' synthesis curve and a study involving several types of sources, carried out in Hamburg.

For the relations between nonspecific annoyance and L_{Aeq}(24h), L_{etm} or L_{dn} correlation coefficients are presented in triples, with at the first place the coefficient for L_{Aeq}(24h), etc.

4.1 Aircraft

The results for aircraft are based on the EC study with 1758 respondents, carried out in the vicinity of Paris-Orly, Glasgow Airport and Amsterdam-Schiphol (see section A.1).

In figure 4.1 the piecewise linear (r = .53 .56 .54) as well as linear (r = .53 .54 .53) relations between annoyance scores and each of the overall noise measures are shown (N = 1756). The correlation coefficients are very high. For the simple linear relations they are about the same for the three exposure measures. The simple linear relation can be used to describe the relation, without significant loss of accuracy.

It should be noted that the highest and lowest annoyance that can be attained are not 0 and 100, but 9 and 91 (see section A.1.2). The actual minimum and maximum depend on the annoyance categories used in the studies involved and are in general around 10 respectively 90.

Figure 4.2 shows that the percentage highly annoyed vanishes at 45 50 45 dB(A). But at higher levels it increases rapidly. At 70 75 72 dB(A), the upper end of the range, it approaches 70%. Moreover, at that level the entire population is at least moderately annoyed, i.e. A_{28} approximates 100%. In fact, at that point even A_{40} comes close to 100%.

Figure 4.2 contains cues that the scoring procedure for category boundaries (and midpoints) is indeed correct.

Figure 4.1 Annoyance score as a piecewise linear and linear function of the overall exposure level.

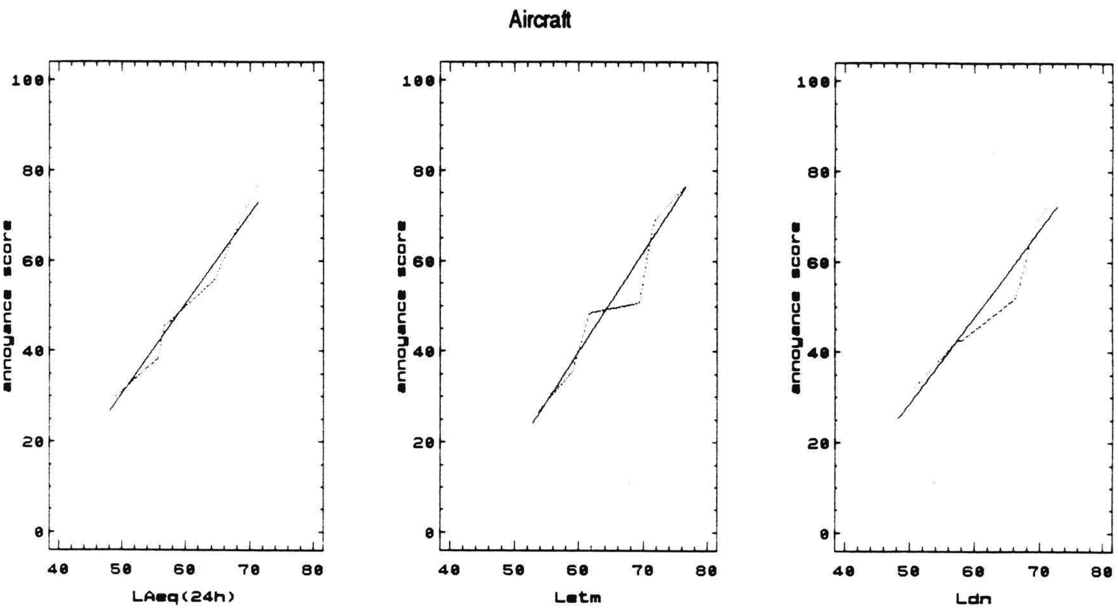


Figure 4.2 Differently determined percentages annoyed as a function of the overall exposure level (beginning with the highest curve: A_{10}, A_{20}, A_{28} = % at least moderately annoyed, A_{40}, A_{50} = % annoyed, A_{60}, A_{72} = % highly annoyed, A_{80}, A_{90}).

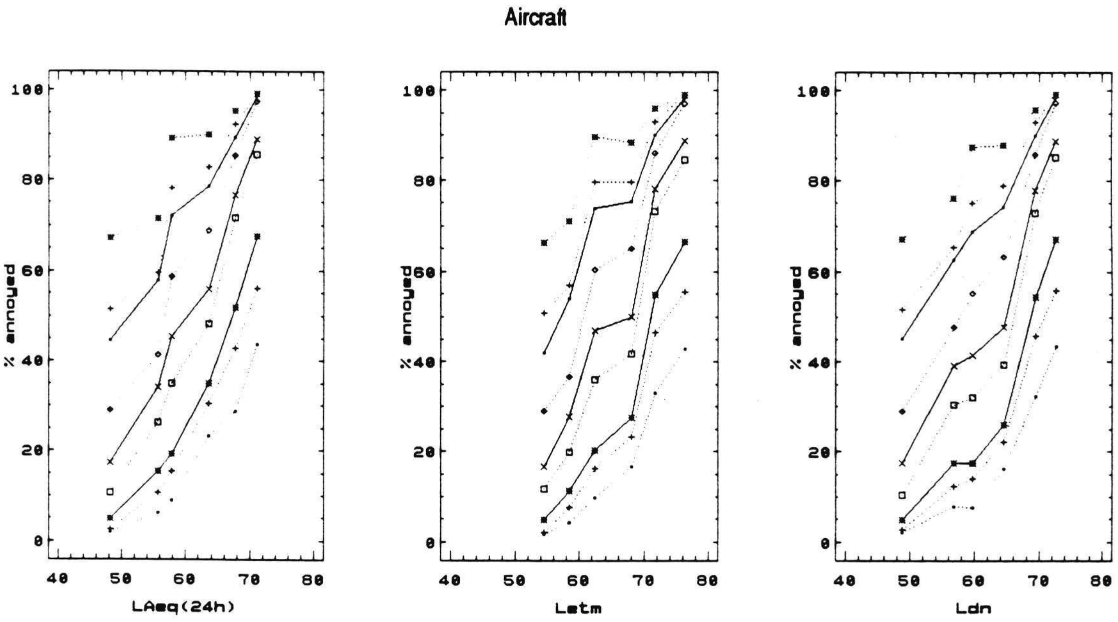
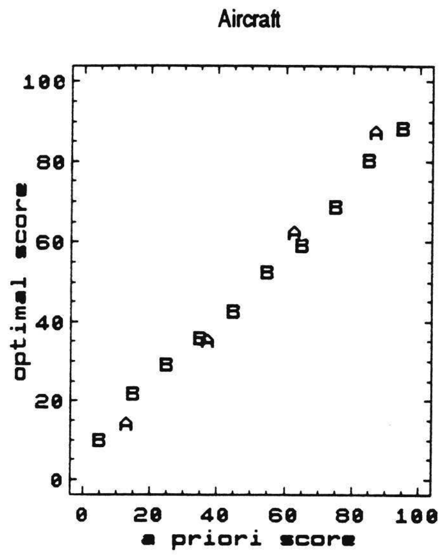


Figure 4.3 Optimal score of annoyance categories versus the a priori score (A=four, B=ten point annoyance scale).



The curves for A_{28}, A_{50} and A_{72} are based on responses to two questions, one with four and the other with ten response alternatives. The other curves are based only on the latter question. If persons did not respond consistently or the scoring of the category boundaries was wrong, this could lead to deviations from the expected ordering of the curves with A_{90} at the bottom, A_{80} next, etc. and finally A_{10} at the top. Apart from reversals of entire curves, crossing could occur.

That none of this happens supports the idea that (persons respond consistently and) the scoring of the category boundaries is correct.

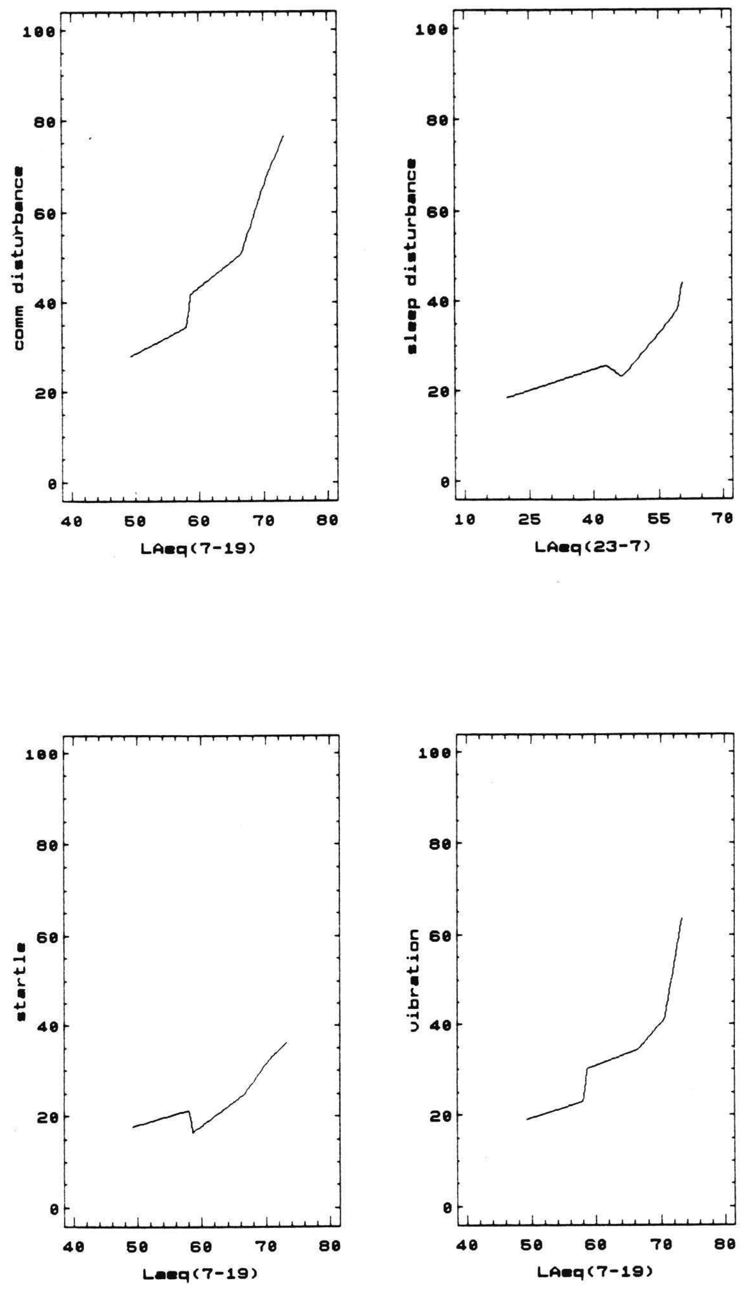
Figure 4.3 is directly pertaining to the question just raised. With a method known as correspondence analysis (Greenacre, 1984) or optimal scaling (Gifi, 1990), the relation between the two annoyance questions is analyzed.

This method finds the category scores for either of both questions which maximize their correlation. Since the maximal correlation is equal to .86, it can be concluded that persons responded consistently. The optimal scores that produce this maximal correlation are shown for both questions in figure 4.3. Thus, if the questions are scored in this optimal way, then each person has as much as possible, in a statistical sense, the same score on both questions. That is, one annoyance level is scored in the same way for both questions. Most importantly, the figure shows that these optimal scores are a linear transformation of our a priori scores. Moreover, the optimal scores are nearly equal to the a priori scores. This strongly supports the a priori scoring procedure.

Curves for specific annoyance are shown in figure 4.4 (N = 1755 - 1758).

Figure 4.4 Specific annoyance score as a piecewise linear function of L_{Aeq} for the day or night.

Aircraft



The correlation for communication is r = .50, for sleep r = .28, for startle r = .28 and for vibration r = .44. It appears that communication disturbance and vibration play a greater role than startle. There is some indication that at high night respectively day levels the increase of sleep disturbance respectively vibration accelerates.

4.2 Rail traffic

The results for railway traffic are based on four studies with 4573 respondents. Three were carried out at locations all over Great-Britain (trains), the Netherlands (trains) respectively (West-)Germany (mostly trains, two locations with trams). One is a study in three cities in the Netherlands (trams) (see section A.2 - A.5).
It was found that there is no distinction between tonal and nontonal situations for trains with respect to the relation between annoyance scores and the overall noise measures. Furthermore, the relation for tram locations without tonality or impulses, which were mostly locations with straight tracks, could not be distinguished from that for trains. Therefore all train locations and tram locations without tonality or impulses are analyzed together. In figure 4.5 the piecewise linear (r = .39 .40 .40) as well as linear (r = .38 .39 .39) response functions are shown (N = 4099). The correlation coefficients are lower than for aircraft. They are about the same for the three exposure measures. The simple linear relation can be used to describe the relation.
If a threshold exists such that below it there is no annoyance and above it annoyance increases linearly, then a single straight line, fitted with cases below the threshold, would have a too small gradient above that threshold. As can be seen in figure 4.5, for railways very low exposure levels are included. Moreover, because four or five annoyance categories were used in the studies involved (see section A.R.2), the lowest annoyance scores that can be attained are 10 - 13. But the straight lines extend to lower annoyance values. Therefore the straight lines in this figure may involve this type of distortion.
The distortion should be less or possibly eliminated in figure 4.6. There the linear response functions (r = .38 .39 .39) for cases with $L_{Aeq}(24h) \geq 35$ dB(A) are shown (N = 4044). Due to the relatively few cases which are dropped there is not much difference of the latter lines with the previous straight lines.
Figure 4.7 shows that trams which produced impulse or tonal sounds cause more annoyance. The linear relation from figure 4.6 is shown again, together with the two piecewise linear functions (r = .17 .17 .16) for trams with special sound characteristics (N = 305). For these sounds the

annoyance is poorly related to the overall noise measures. The correlation coefficients mentioned describe the overall fit for the two lines.

In the remainder of this section we concentrate on trains and trams without impulse or tonal components, for which annoyance curves are shown in figure 4.5.

In addition to the overall noise exposure, measured by L_{Aeq}(24h), L_{etm} or L_{dn}, the difference between the most and least exposed side of the house influences annoyance. For both Netherlands' studies (a train and the tram study) the difference between most and least exposed side could be assigned to one of the classes < 5, 5 - 15, ≥ 15 dB(A). It was found that distinguishing the two lower classes had no effect. Therefore they were combined.

Figure 4.8 ($r = .30$) shows that having a quiet side can reduce annoyance ($N = 1065$). The effect appears to increase when L_{dn} increases. When the difference between sides of the house is disregarded, then $r = .28$.

When pauses are also taken into account and the two categories for difference between sides are crossed with three pause categories, the correlation increases to .36. However, because we could not confirm the effect of pause with the entire railway data set (for cases without tonality or impulse) ($N = 4099$), no figures are shown.

In the case of railway noise, prevalence of pauses is directly related to the number of passages. It may, however, be necessary to differentiate between types of passages. Fields and Walker (1980) showed that the percentage of freight versus passenger trains and diesel versus overhead electrified (versus third rail) has an effect on annoyance, additional to that of the overall noise level L_{Aeq}(24h).

Figure 4.5 Annoyance score as a piecewise linear and linear function of the overall exposure level, all cases.

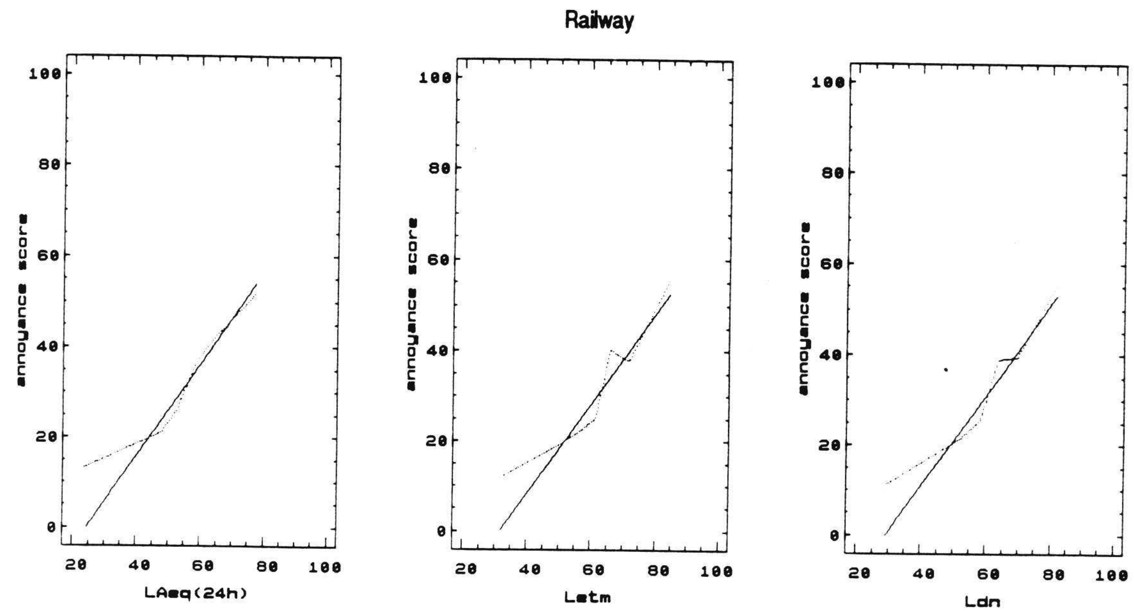


Figure 4.6 Annoyance score as a linear function of the overall exposure level for cases with $L_{Aeq}(24h) \geq 35$ dB(A).

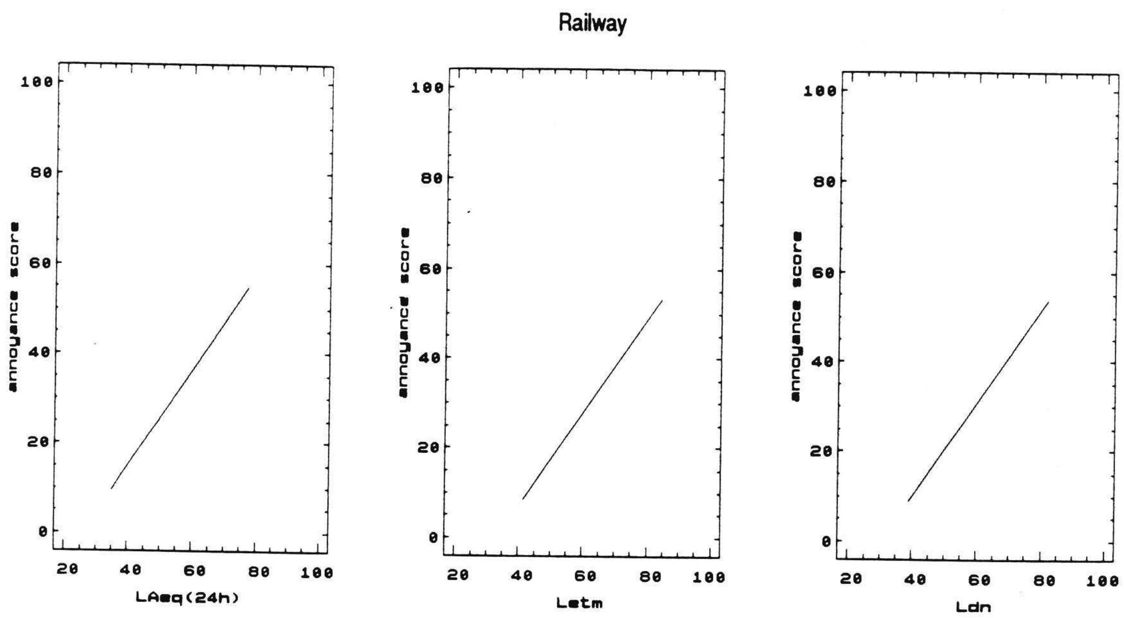


Figure 4.7 Annoyance score as a function of the overall exposure level. The straight lines from figure 4.6 are reproduced. In addition the curves for tram noise with impulses (highest) and with tonal components (middle) are shown.

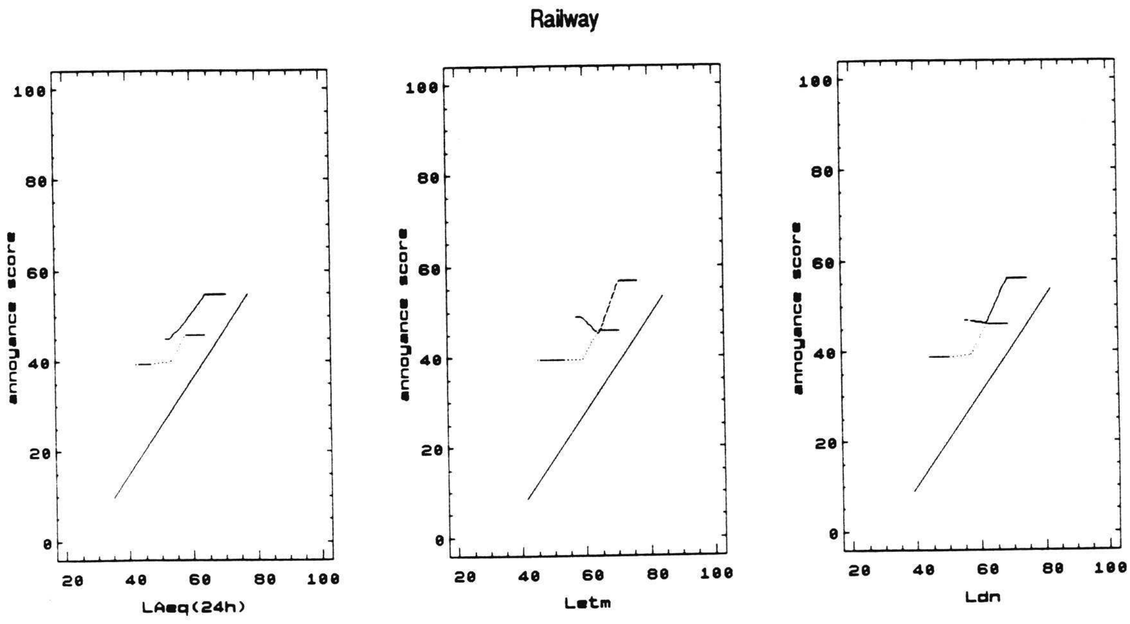


Figure 4.8 Annoyance score as a linear function of L_{dn}, controlling for the difference between the most and least exposed side of the dwelling. For the highest line this is < 15, for the lowest ≥ 15 dB(A).

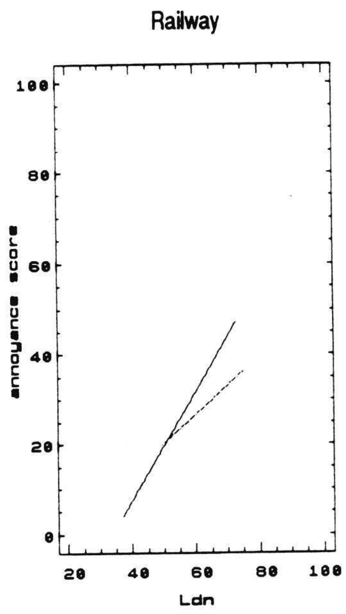
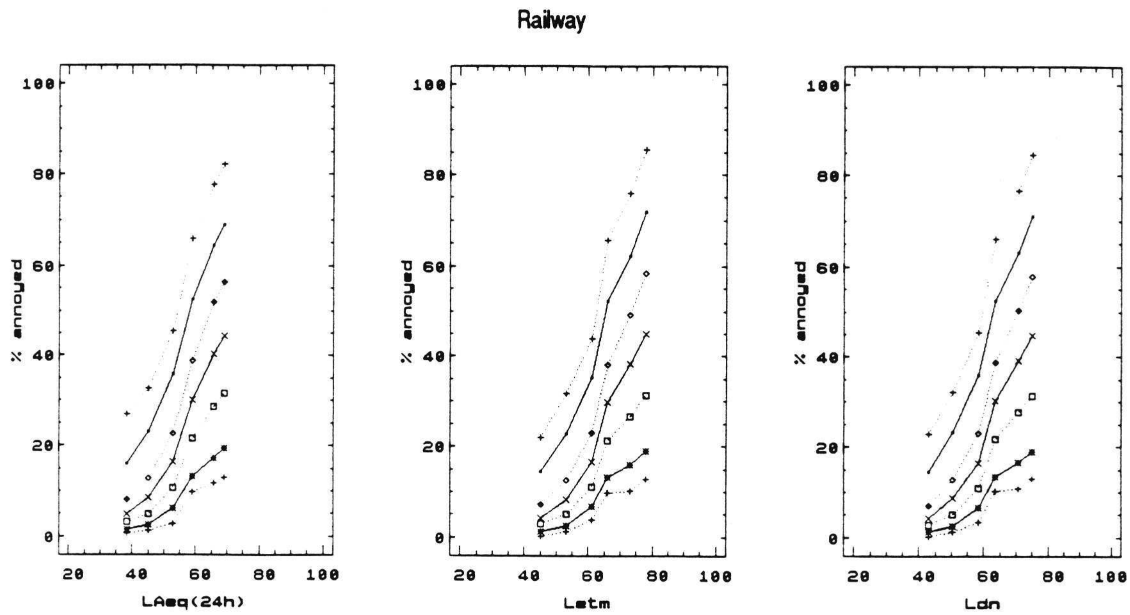


Figure 4.9 Differently determined percentages annoyed as a function of the overall exposure level (beginning with the highest curve: A_{20}, A_{28} = % at least moderately annoyed, A_{40}, A_{50} = % annoyed, A_{60}, A_{72} = % highly annoyed, A_{80}).



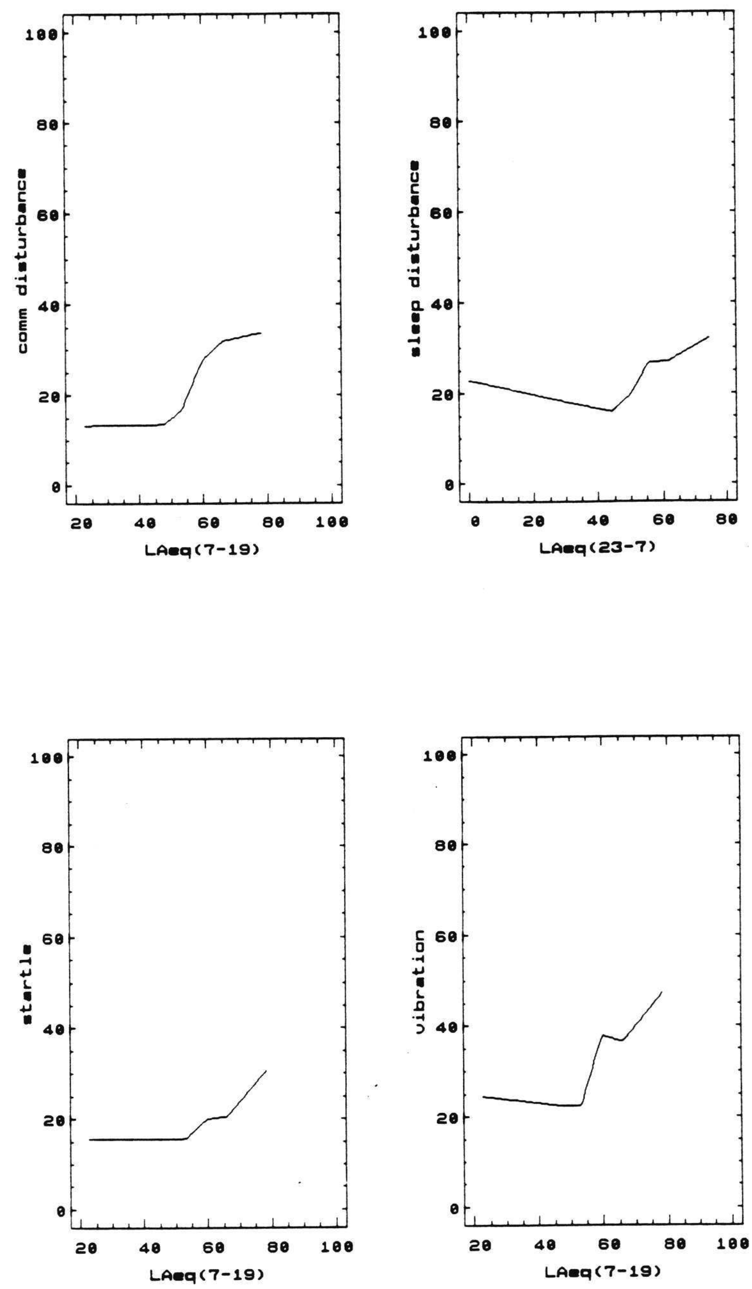
In figure 4.9 the percentage curves are shown. Because for the large, British and German studies we had no information about the difference between sides of the house, this factor is taken into account in figure 4.9. The previous analysis, however, showed that the percentage curves would be sensitive to this difference.

It may be noted that the percentage highly annoyed in figure 4.9 at high exposure levels does not exceed 20 % and thus does not come close to the 50 % and more found for aircraft noise at high exposure levels.

Figure 4.9 contains indications that the scoring procedure for category boundaries (and midpoints) is indeed correct. The curves are based on a question with five categories (the German and both Netherlands' studies) and a question with four categories (British study). The cumulative percentages for the five categories were interpolated to obtain the percentages at our standard cut off points 20 28 40 50 60 72 and 80. This was also done for the answers obtained with four categories, but since we did not extrapolate, this gave only percentages for the standard cut off points 28 40 50 60 72 and not for 20 and 80. Then for each standard cut off point the weighted average was determined for the result with the five and four category questions, weights being equal to the number of cases on which a percentage is based. Because of this weighting, different studies, and hence different category systems, have a different influence on the final percentages. Especially, the

Figure 4.10 Specific annoyance score as a piecewise linear function of L_{Aeq} for the day or night.

Railway



A_{20} and A_{80} curves are determined entirely by questions with five response categories.
If persons did not respond in the same way in different studies or the scoring of the category boundaries was wrong, this could lead the deviations of the ordering of the curves with A_{80} at the bottom, A_{72} next, etc. and, finally, A_{20} at the top. Apart from reversals of entire curves crossing could occur.
That there are no crossings or reversals of curves supports the idea that (persons respond in the same way in different studies and) the scoring of category boundaries is correct.
Curves for specific annoyance are shown in figure 4.10. The correlation for communication is r = .37, for sleep r = .22, for startle r = .18 and for vibration r = .29 (N = 4132). Presumably, the prediction of especially vibration would be considerably improved when the type of rail traffic was taken into account.

4.3 Road traffic

The results for road traffic are based on an EC study carried out near Amsterdam, Glasgow and Paris, a (West-)German study with locations over the whole country and three studies in the Netherlands, one at two locations near highways, one in the three largest cities (Amsterdam, Rotterdam, The Hague) and one in a middle large city (Arnhem) (see section A.6 - A.10).
In figure 4.11 the piecewise linear (r = .46 .46 .46) as well as linear (r = .45 .45 .45) response functions are shown (N = 5144). The correlation coefficient describes the overall fit of the two lines. At higher levels highways cause more annoyance than other road traffic. Indications that this difference extends in fact to lower levels than suggested by the figure are discussed in the sequel of this section. The correlation coefficients are the same for the three exposure measures. The simple linear relation can be used to describe the relations.
In figure 4.12 the linear response functions (r = .45 .45 .46) obtained after deletion of a number of cases with L_{etm} < 55 dB(A) is shown (N = 4782). The exact criterion for deletion and the reason for it are explicated in the sequel of this section.
In addition to the overall noise exposure, measured by L_{Aeq}(24h), L_{etm} or L_{dn} at the most exposed side, the presence of a relatively quiet side influences annoyance. But before studying the effect of differences between sides, we first looked at the influence of pauses. For three studies the percentage of quiet minutes was known: the highway study (no pauses at all), and the German and Arnhem studies.

At first the hypothesis was that the difference between highway and other traffic could be explained by the difference in quiet moments. This is still possible, but within other road traffic we could not find a clear effect of pauses .

We did not take into account the distinction between (heavy) lorries and (lighter) cars. It is comparable to the distinction between (heavy) freight trains versus (lighter) passengers (or post) trains for railway noise. Langdon (1976) has shown that, at a given overall noise level, road traffic causes more annoyance when the percentage of heavy traffic is higher. For road traffic with a given overall noise level, the percentage of minutes without heavy traffic may be a more important factor than the percentage of quiet minutes.

A factor which was found for railway to influence annoyance is the difference between the most and least exposed side of the house. For three Netherlands' studies (highway, three big cities, Arnhem) the difference between most and least exposed side was assigned to one of the classes < 5, 5 - 15, ≥ 15 dB(A). It was found that the difference between the two lower classes had no effect. Therefore they were combined. Figure 4.13 (r = .42) shows an beneficial effect of a quiet side, which increases when L_{dn} increases. Without taking difference between sides of the house into account, r = .40.

In figure 4.14 the percentage curves are shown, separately for highway and other road traffic. For highways the percentage highly annoyed increases more rapidly than for other traffic. It is interesting to note that there is much less difference in the percentage of at least moderately annoyed than in the percentages annoyed or highly annoyed. Hence, the difference between the lines in figure 4.12 is not due to a difference in moderate annoyance but to a difference in the prevalence of more intense annoyance.

Figure 4.14 contains cues that the scoring procedure for category boundaries is indeed correct. The curves are based on a question with five categories (the German and three Netherlands' studies) and a combination of two questions with four and ten categories (EC study).

The cumulative percentages obtained with the five categories were interpolated to get the percentages at our standard cut off points 20 28 40 50 60 72 and 80. This was also done for the answers obtained with four and ten categories in a way described in section A.1.2, giving percentages for all standard cut off points 10 20 28 40 50 60 72 80 90. Then for each standard cut off point the weighted average was determined for the results obtained with the five and the four/ten category questions, weights being equal to the number of cases on which a percentage is based. This implies that curves are determined to a different extent by different studies and hence by different category systems, depending on the number of respondents on which a percentage is based. Especially, the A_{10} and A_{90} curves are determined entirely by answers obtained with (four/)ten response categories.

Figure 4.11 Annoyance score as a piecewise linear and linear function of the overall exposure level. The upper lines are for highways, the lower for other road traffic.

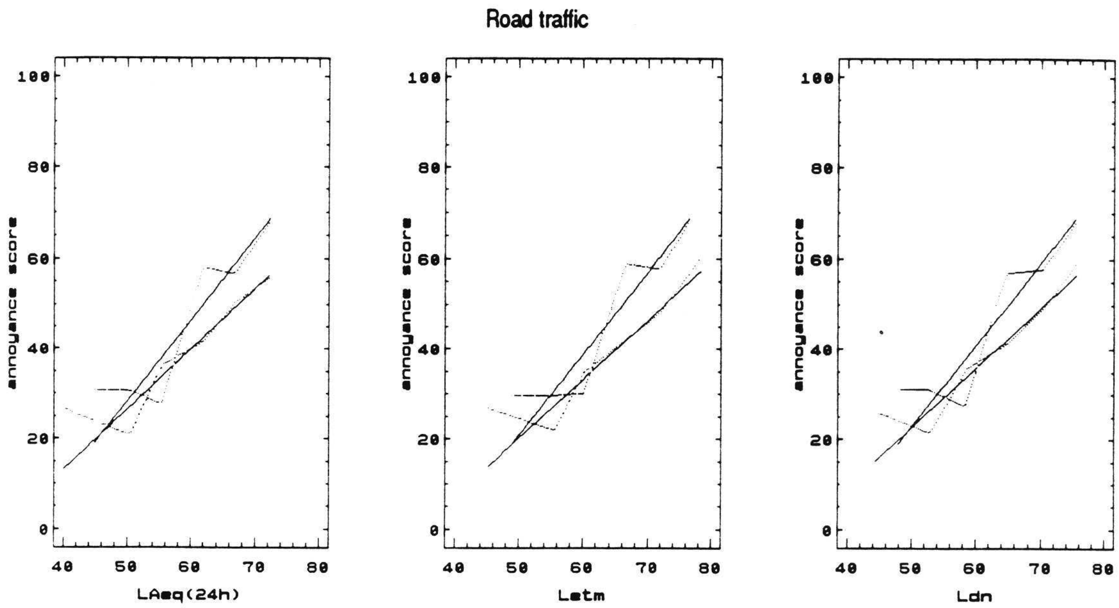


Figure 4.12 Annoyance score as a linear function of the overall exposure level after deletion of several cases with L_{etm} < 55 dB(A) (see text). The upper line is for highways, the lower for other road traffic.

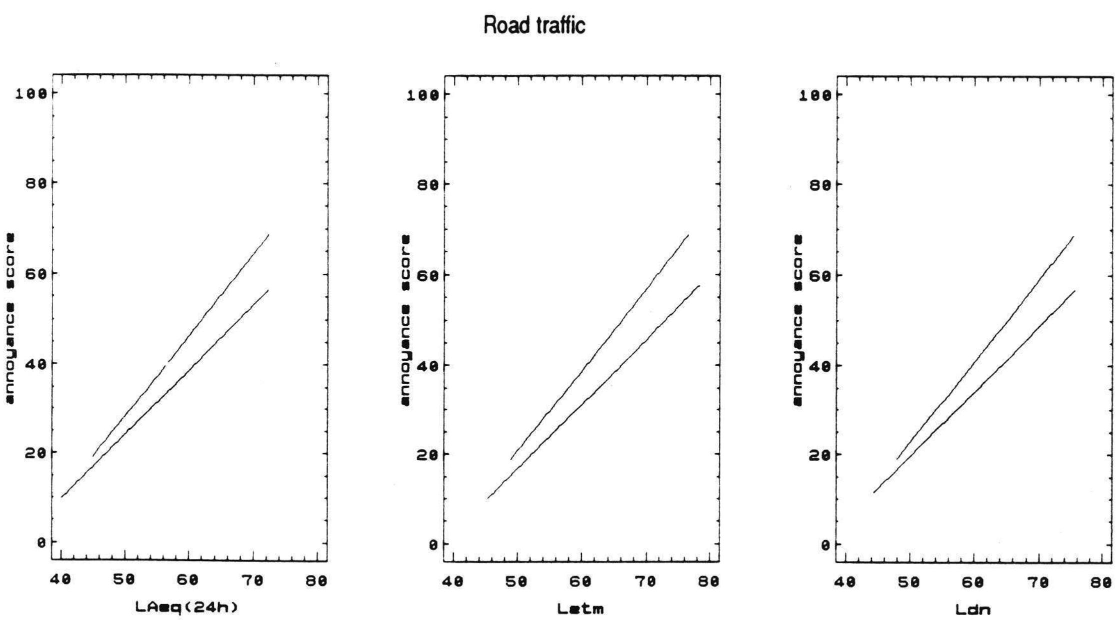
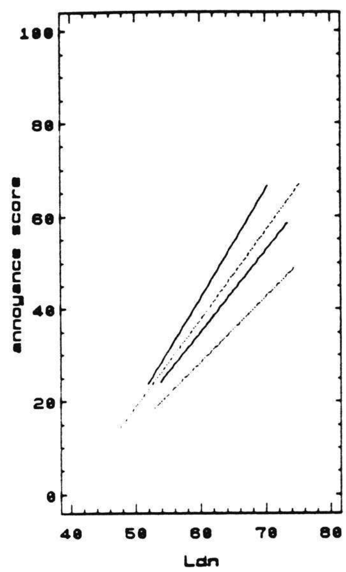


Figure 4.13 Annoyance score as linear function of $L_{dn,}$ controlling for the difference between the most and least exposed side of the dwelling. The upper pair of lines are for highways, the lower pair for other road traffic. The solid line is for differences < 15, the dotted for differences ≥ 15 dB(A).

Road traffic



If persons did not respond in the same way in different studies or the scoring of the category boundaries was wrong, this could lead to deviations of the ordering of the curves with A_{90} at the bottom, A_{80} next, etc. and finally A_{10} at the top. Apart from reversals of entire curves crossing could occur. With one exception there are no crossings or reversals of curves. This supports the idea that (with one exception persons respond in the same way in different studies and) the scoring of category boundaries is correct.

But the exception deserves some attention. It may be noticed that, in addition to the crossing of the A_{10} and A_{20} curve somewhat below 50 55 53 dB(A), the A_{20} and A_{28} curves become flat below these levels and the distance of the latter curve from the A_{40} curve becomes rather large. This crossing combined with the unusual flattening and gap with the adjacent curve suggests that the prevalence of moderate annoyance below 50 55 53 dB(A) is unusually high in the five category studies. We therefore believe that the straight lines for non highway traffic in figure 4.12, obtained after deletion of those cases from the studies with five categories for which L_{etm} ≤ 55 dB(A), give a more generally applicable result than the similar curves obtained without this deletion.

Figure 4.14 Differently determined percentages annoyed as a function of the overall exposure level (beginning with the highest curve): (A_{10}), A_{20}, A_{28} = % at least moderately annoyed, A_{40}, A_{50} = % annoyed, A_{60}, A_{72} = % highly annoyed, A_{80} ,(A_{90})). The upper row is for highways, the lower for other road traffic.

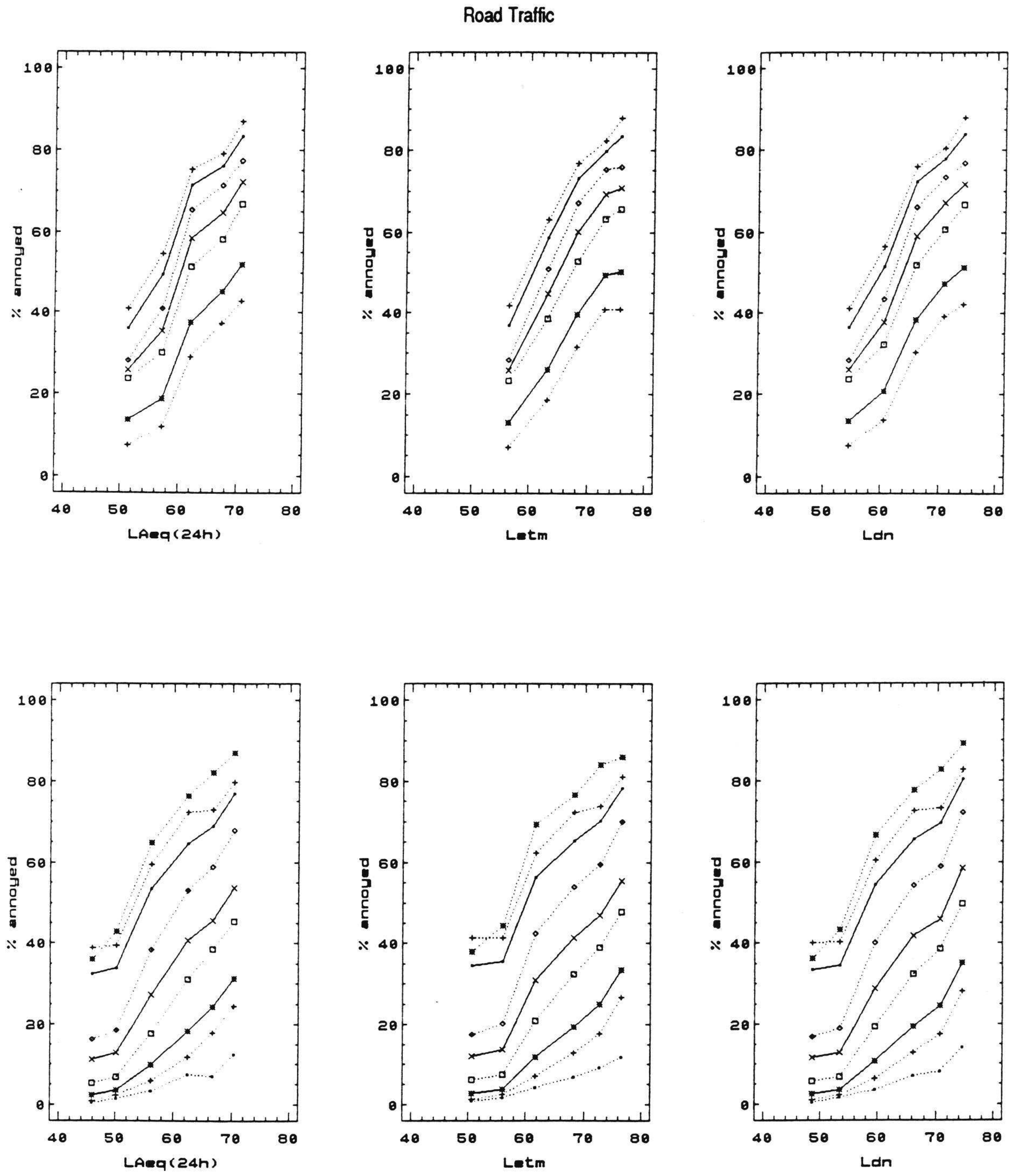


Figure 4.15 Optimal score of annoyance categories versus the a priori score (A=four, B=ten point annoyance scale).

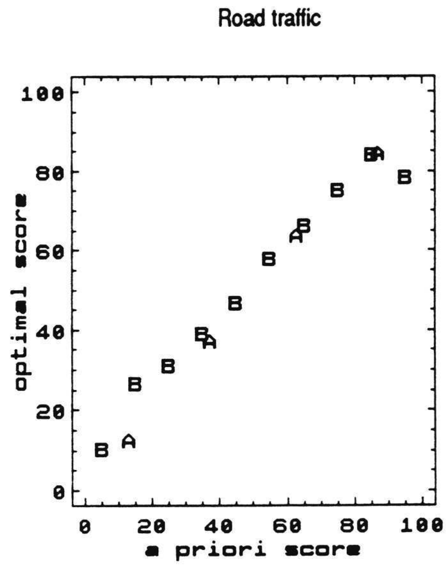


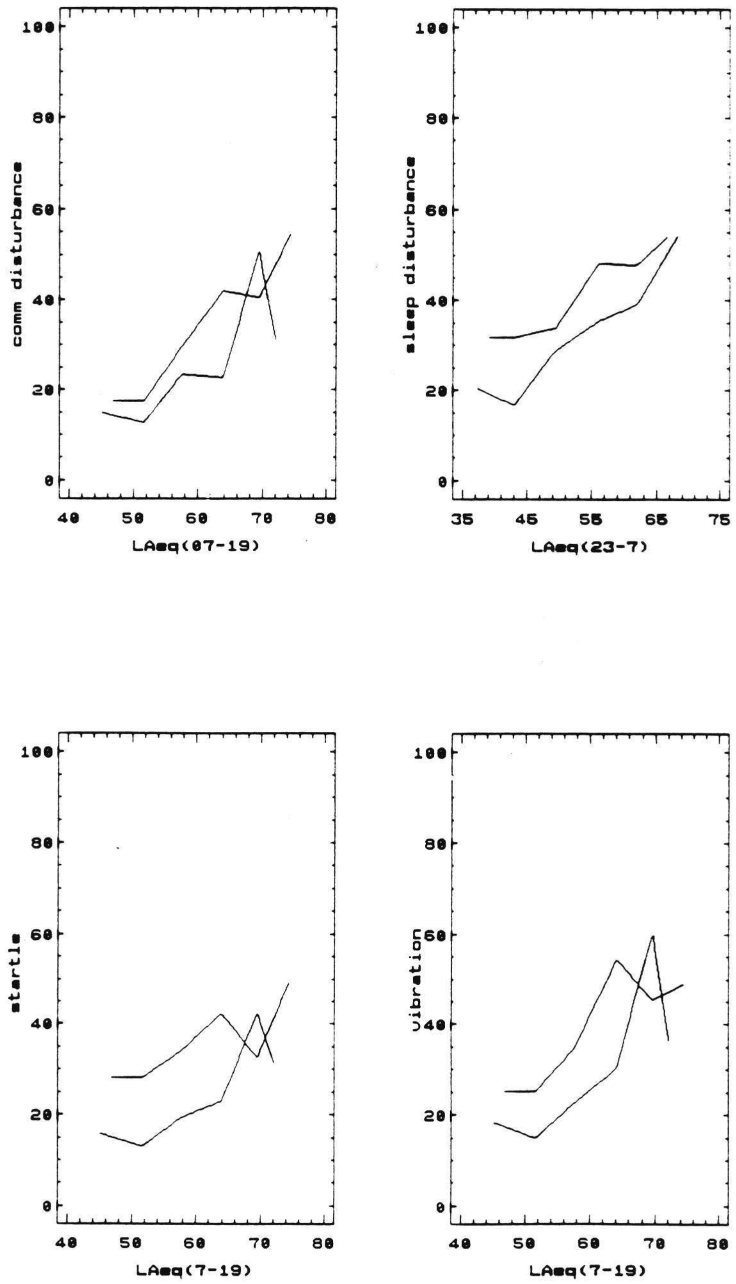
Figure 4.15 is directly pertaining to the question about the correctness of the a priori scoring. It is based on the four and ten category questions, which were contained in the EC study. With correspondence analysis for both questions the category scores were determined which maximize their correlation (see for further explanation section 4.1). The maximal correlation is .79. From this correlation and the figure it can be concluded that most persons responded consistently. The optimal scores that lead to this maximal correlation are shown for both questions in figure 4.15.

The overall pattern in that figure is that these optimal scores are a linear transformation of our a priori scores and, moreover, are nearly equal to the a priori scores. There are some deviations at the extremes, especially at the higher end. Detailed inspection of cross tabulations showed that this irregularity is for a large part due to several persons who choose opposite categories: the highest annoyance in case of ten categories the lowest in case of four categories. Since the general pattern is as would be expected and the irregularity is not a consequence of the scoring procedure, the result strongly supports the a priori scoring procedure.

Curves for specific annoyance are shown in figure 4.16. The only studies with specific annoyance questions for road traffic are the highway study and the German study, so that the results are based on these two studies.

Figure 4.16 Specific annoyance score as a piecewise linear function of L_{Aeq} for the day or night. Upper curves are for highways, the lower for other road traffic.

Road traffic



The correlation for communication is r = .49, for sleep r = .44, for startle r = .43 and for vibration r = .51 (N = 2458). The peak in the curves for non highway traffic is due to the reactions at the German village Strasskirchen, where many heavy vehicles passed at short distance from the houses. To be specific, there are 12.000 passages/24h, with 25% heavy traffic, at an average distance of 13 m from the house fronts with an average speed of 50 - 60 km/h. Presumably, the prediction would be considerably improved when the type of vehicle was taken into account. It appears that all four types of specific annoyance play a role in noise annoyance from road traffic.

4.4 Stationary sources

The results for stationary sources are based on an EC study on impulse noise carried in France, (West-)Germany, Ireland and the Netherlands and another study, encompassing impulse as well as other noise sources, in the Netherlands (see section A.11 and A.12). The results for impulse sources are presented first, thereafter those for shunting yards and for industries (without impulse noise).
It is well known that at a given overall sound level impulse noise is more annoying than transportation noise. In figure 4.17 the piecewise linear (r = .47 .47 .47) as well a convex piecewise linear (r = .46 .47 .47) response functions are shown (N = 1390). Although the convex function consists of five linear pieces the best convex fit is obtained by joining them as shown into two larger linear pieces.
Three comments can be made about the convexity. Firstly, if a relation above some annoyance threshold is linear but also levels much below that threshold are included, a convex function consisting of two linear pieces is to be expected. Secondly, there are a number of cases with very low exposure levels (5 - 10 dB(A)). Presumably, these are the cases for which it was hard to obtain clear noise measurements. For cases with low exposures true exposures may have been 10 to 20 dB(A) higher than the assigned values. Using true values would take away deviation from linearity. Thirdly, more than minimal annoyance at the very low levels is mostly found at a single location, Churchtown in Ireland. The noise there comes from a dairy. Impulses were due to loading and unloading. The noise source was atypical in two respects: noise was produced 24 hours by e.g. chillers and the impulse noise caused by the loading and unloading of crates with milk bottles commenced as early as 4 - 5 a.m.. None of the other sources was operating continuously or had a peak in the activities causing impulse during the night period.

Figure 4.17 Annoyance score as a piecewise linear and linear function of the overall exposure level.

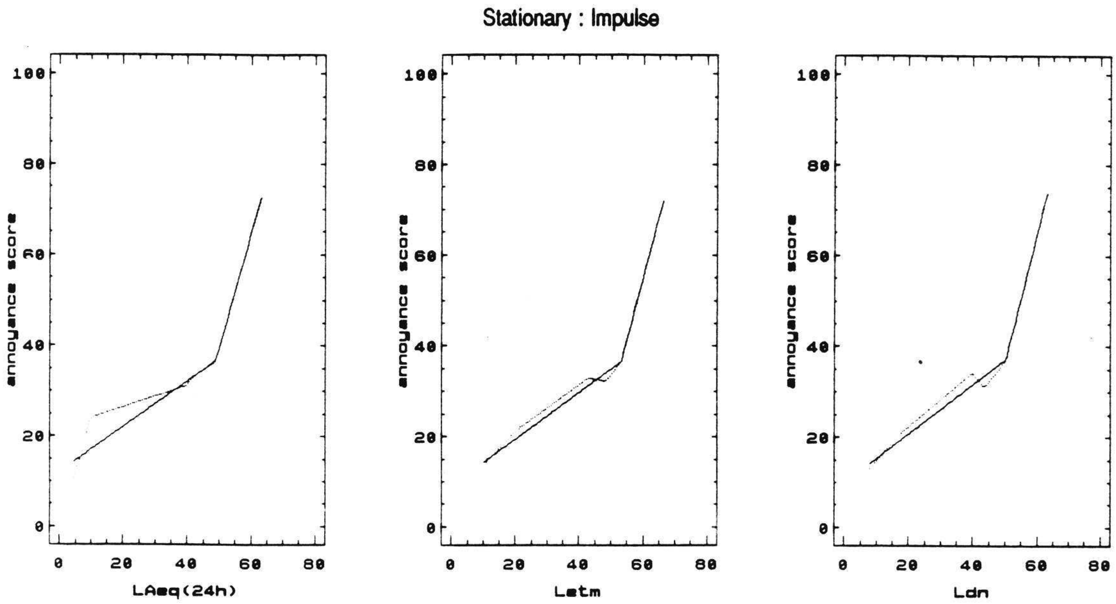


Figure 4.18 Annoyance score as a piecewise linear function of L_{dn}. The upper short line is for Churchtown, the other for the rest.

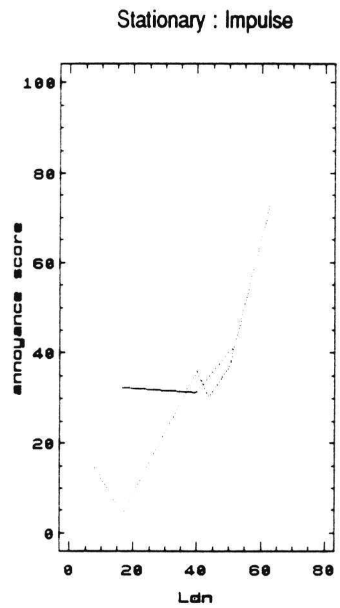


Figure 4.19 Annoyance as piecewise linear function of the overall exposure level. The dotted line consists of five, the solid of two pieces.

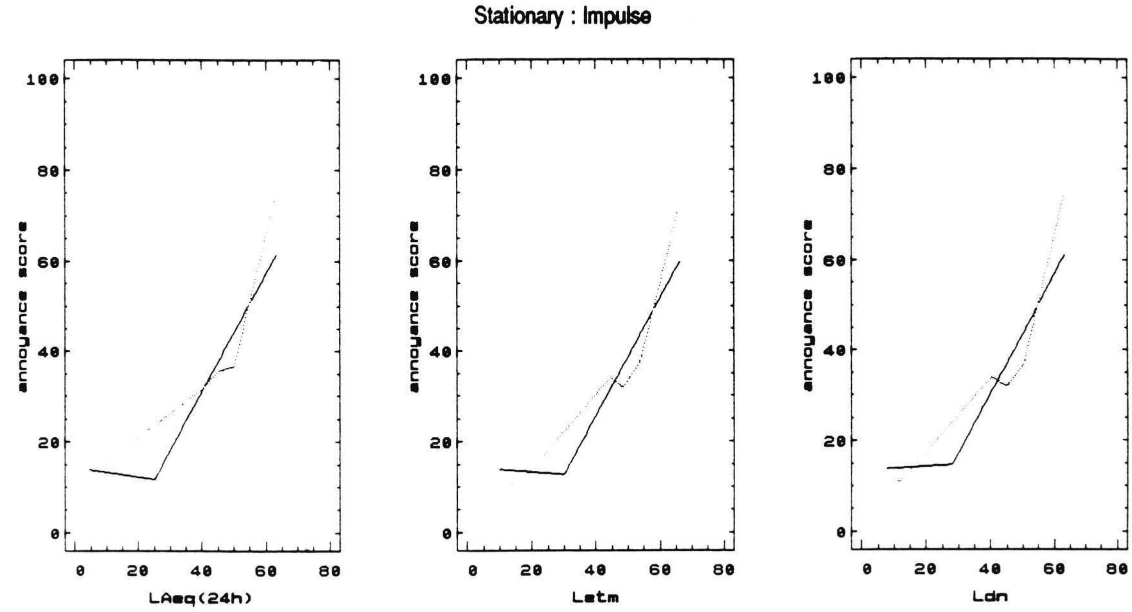


Figure 4.20 Differently determined percentages annoyed as a function of the overall exposure level (beginning with the highest curve: A_{10}, A_{20}, A_{28} = % at least moderately annoyed, A_{40}, A_{50} = % annoyed, A_{60}, A_{72} = % highly annoyed, A_{80}, A_{90}).

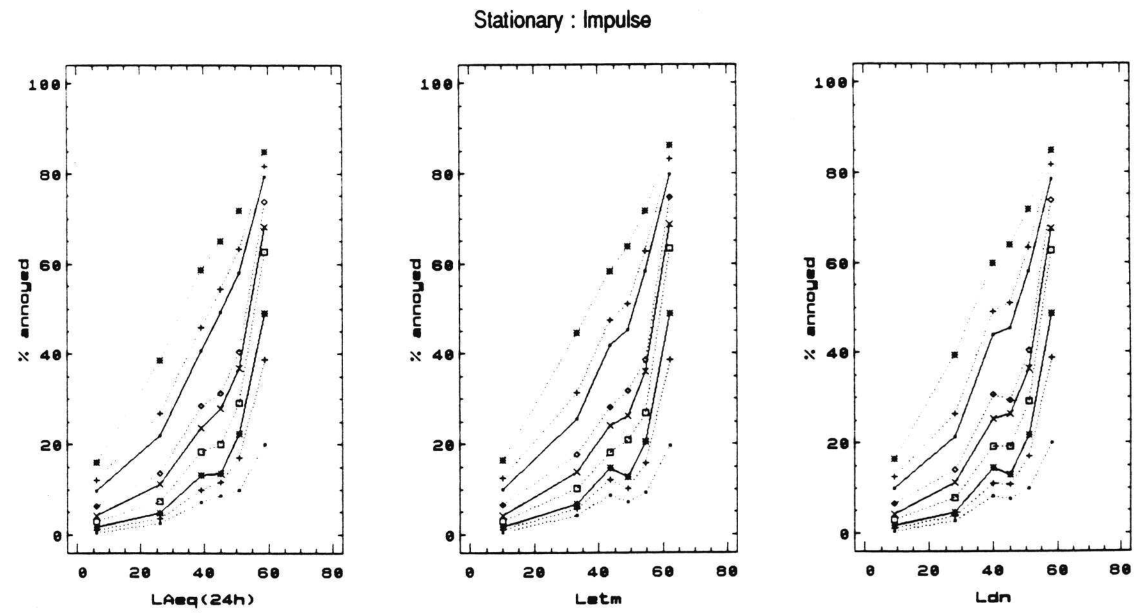
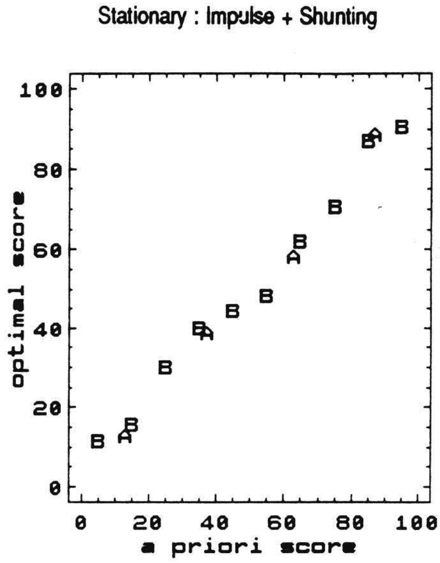


Figure 4.21 Optimal score of annoyance categories versus the a priori score (A=four, B=ten point annoyance scale).



Apparently, the features of the dairy just mentioned cause annoyance even at very low levels, as can be seen in figure 4.18 (r = .48). In order to eliminate these typical features, the dairy is excluded from the further analyses.

The piecewise linear (r = .50 .50 .50) as well as a function consisting of two linear pieces (r = .48 .47 .48) obtained after deletion of the dairy data are shown in figure 4.19 (N = 1285). The knots at 25 30 28 dB(A) for the latter functions are the highest levels which give a approximately horizontal first linear piece in the function. The nearly constant annoyance at these low levels is only slightly higher than 9, which is the minimal level that can be attained. The apparent discrepancy between the functions with five and two linear pieces around the single knot in the latter is not very significant since there are few cases in that interval.

In figure 4.20 the percentage curves are shown. The percentage highly annoyed vanishes only at levels where the impulse source will hardly be heard. At higher levels the increment in the percentage highly annoyed becomes very steep.

Figure 4.22 Specific annoyance as a piecewise linear function of L_{Aeq} for the day.

Stationary : Impulse

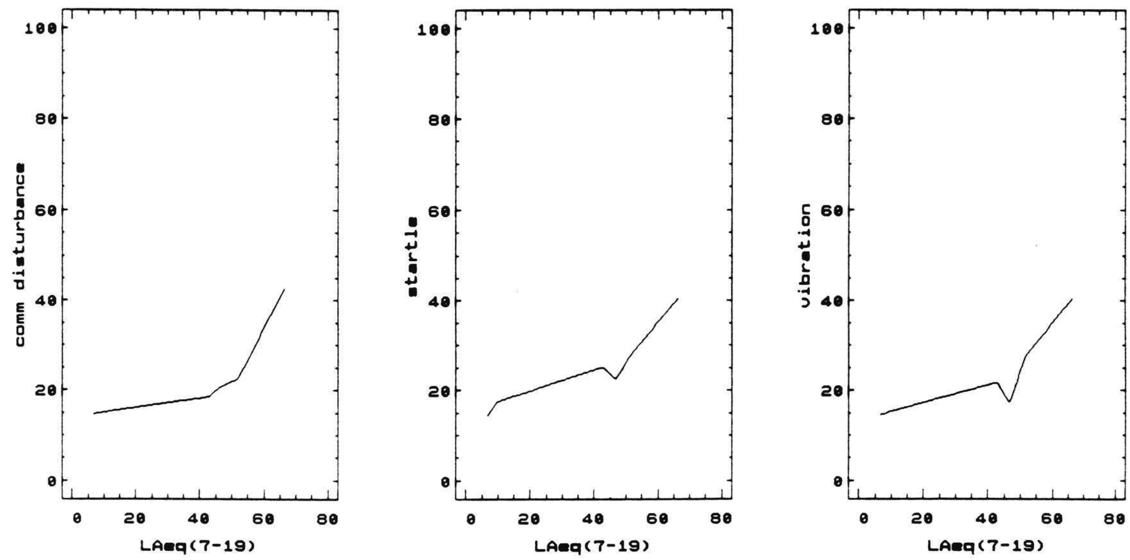


Figure 4.23 Average annoyance score versus the overall exposure level (E,F,G,M,N,X = industry; Y = shunting yard).

Stationary : Industry + Shunting

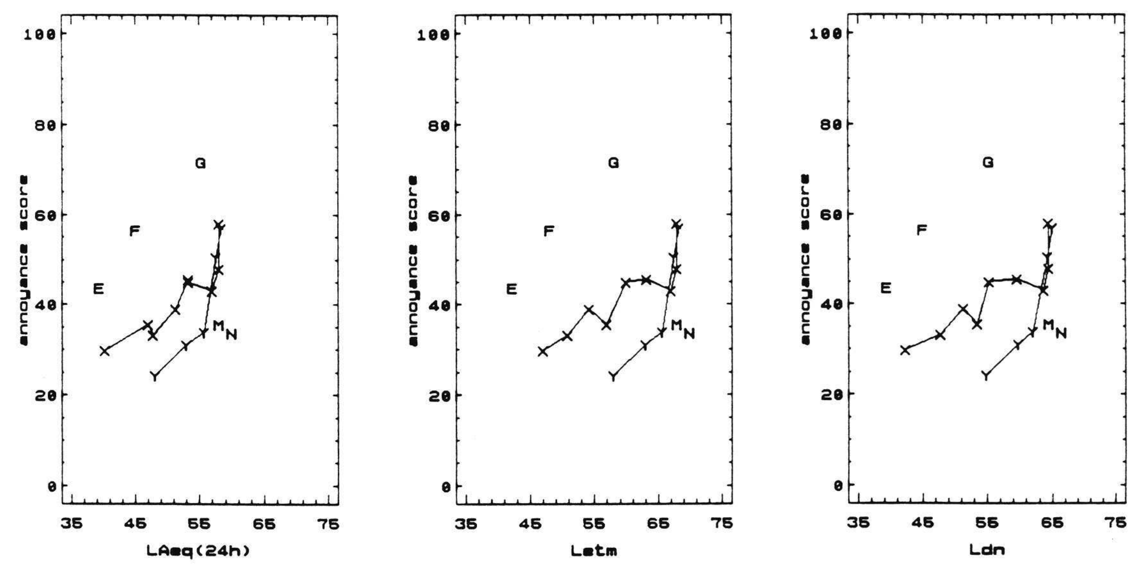


Figure 4.24 Average specific annoyance score versus L_{Aeq} for the day or night (E,F,G,M,N,X = industry; Y = shunting yard).

Stationary : Industry + Shunting

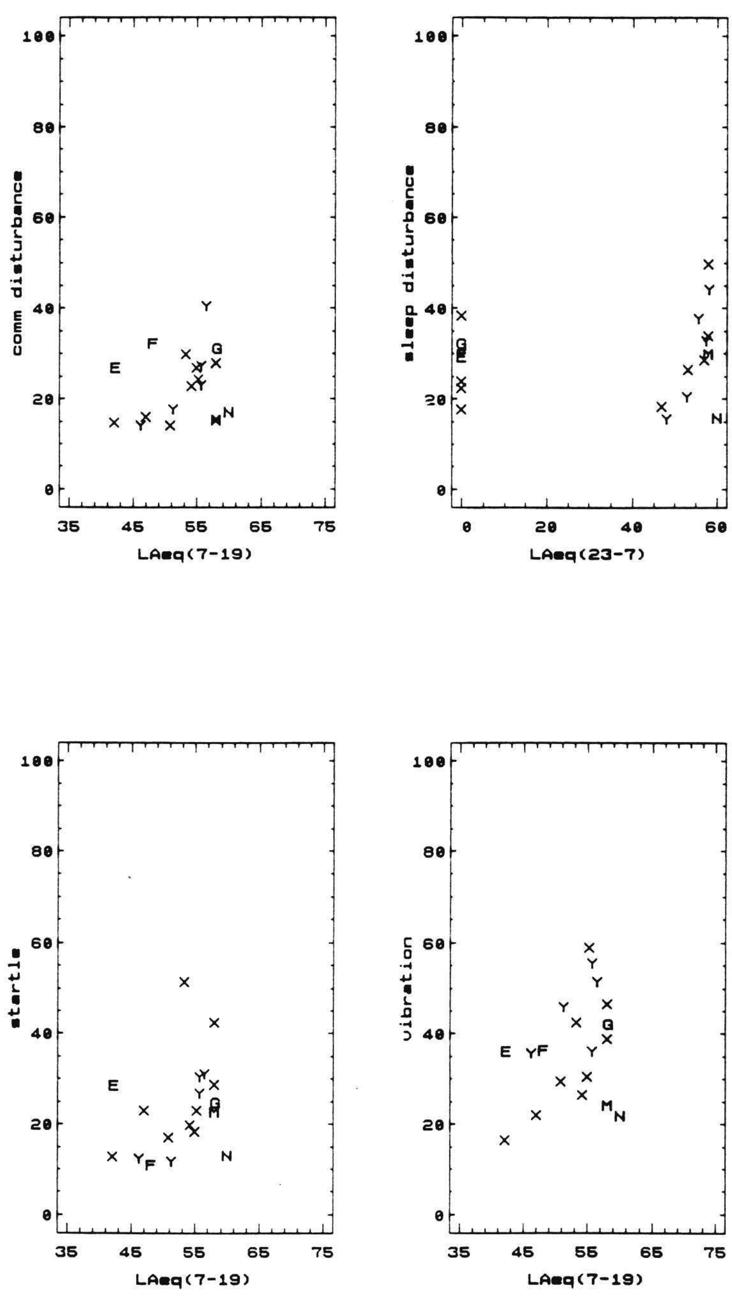


Figure 4.21 is directly pertaining to the question about the correctness of the a priori scoring (N = 1458). It is based on the four and ten category question from the EC study (including also the cases near shunting yards).

With correspondence analysis for both questions the category scores are found which maximize their correlation (see for further explanation section 4.1). The maximal correlation equals .94. From this correlation and the figure it can be concluded that most persons responded consistently.

The optimal scores that lead to this maximal correlation are shown for both questions in figure 4.21. The optimal scores are a linear transformation of our a priori scores and, moreover, are nearly equal to the a priori scores. This supports the a priori scoring procedure.

Curves for specific annoyance are shown in figure 4.22. The variation in the night level was too small to determine a relation with sleep disturbance. The correlation for communication is r = .34, for startle r = .28 and for vibration r = .32.

The annoyance curves for shunting yards and industry (without impulse sound) are shown in figure 4.23. For each location the average annoyance score is determined. The curves are obtained by interpolation. Locations with exceptionally low or high annoyance are not connected by the curve. Points E and F correspond to locations where concrete elements are made, G to a concrete mortar mill for which the sound is classified as tonal and points M and N to a food industry and a small chemical plant.

For industrial sources the relation of annoyance with the exposure level characterized by L_{Aeq}(24h), L_{etm} and L_{dn} is rather poor. None of the factors tonality, pauses or, as can be seen from the figure 4.23, night time penalty added significantly to the explanation of the annoyance.

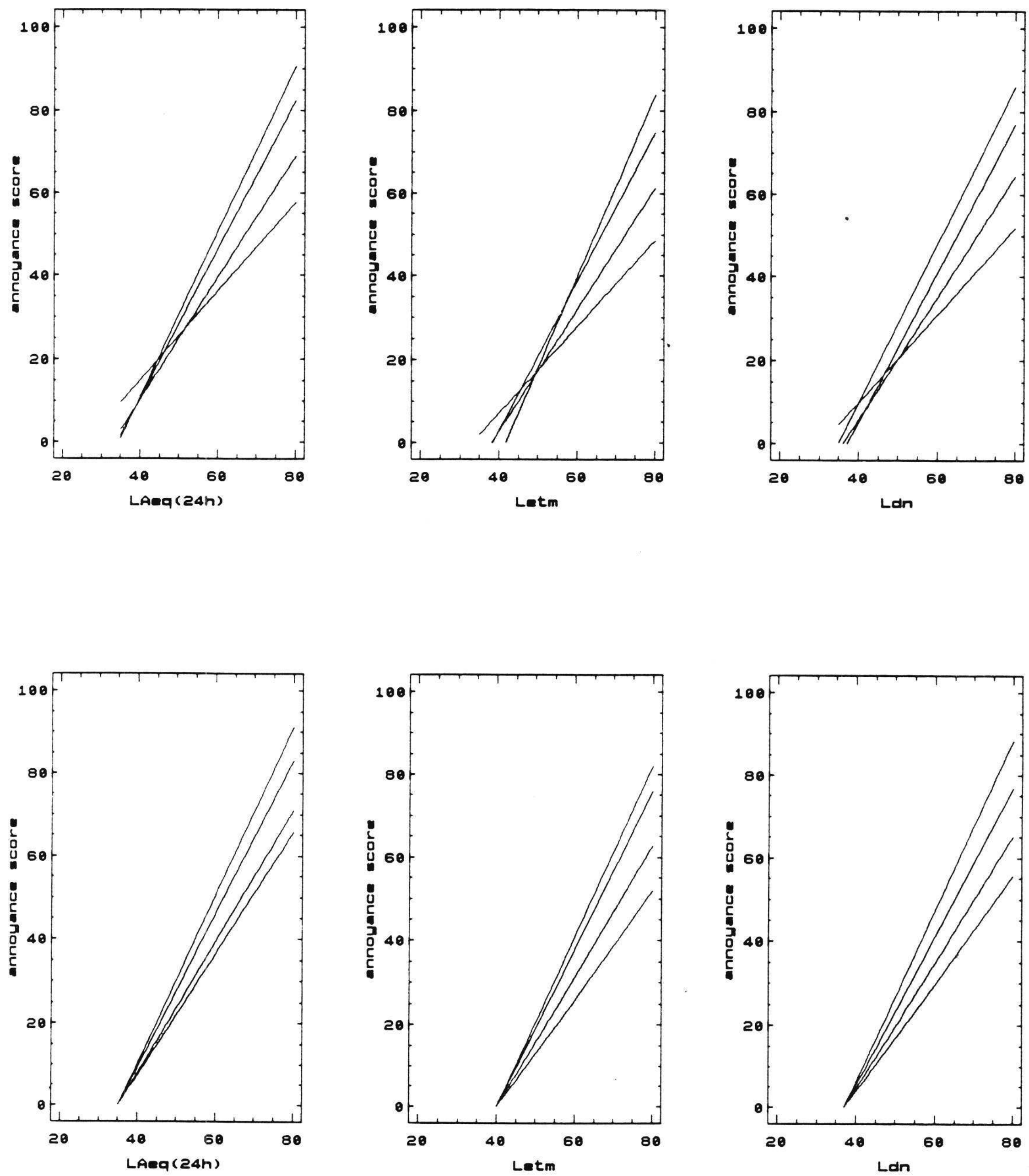
For specific annoyance the average scores per location are shown in figure 4.24.

4.5 Comparison of relations for different types of sources

For transportation noise sources we have found that annoyance is linearly related to L_{Aeq}(24h), L_{etm} as well as L_{dn}. The piecewise linear function hardly gave a better correlation. Since these piecewise linear function have considerable flexibility to follow the variations in the data, it is not to be expected that other functions will improve the their fit and thus the fit of the simple linear function. The linear relations are shown in figure 4.25 (overall r = .50 .50 .50).

Figure 4.25 Annoyance score as a linear function of the overall exposure level, with free intercepts (upper row) or forced through zero at a common point (bottom row). The lines are from the highest to the lowest, for aircraft, highway, other road traffic and railways.

Transportation



When necessary to cover the common domain from 35 40 37 to 80 80 80 dB(A), the lines are extrapolated beyond the range where data points were available. The lines converge at lower levels, suggesting that there the difference between the sources becomes less important. With the exception of railway noise, the lines reach zero annoyance at nearly the same point. The line for railway noise may be a bit flattened by some British locations with extremely high exposures which did not seem to disturb the respondents much. In any case, although there is no compelling reason why the lines should reach zero annoyance at *exactly* the same point, there appears to be no good reason why the lines should cross just above zero, in the way they do. When all lines are forced to be zero at 35 40 37, the result is as shown in figure 4.25 (overall r = .49 .50 .50). This set of lines is preferred because the number of parameters for describing the four relations is reduced from eight (4 intercepts, 4 slopes) to five (1 intercept, 4 slopes) at hardly any cost in terms of correlation. The equations for the lines are given in table 4.1.

Table 4.1 Equations for annoyance score as function of the overall exposure level. Plots are shown in figure 4.25

	aircraft	highway	other road	railway	impulse
annoyance	2.02(L_{Aeq} -35)	1.85(L_{Aeq} -35)	1.58(L_{Aeq} -35)	1.40(L_{Aeq} -35)	1.30(L_{Aeq} -15)
score: AS=	2.05(L_{etm} -40)	1.90(L_{etm} -40)	1.57(L_{etm} -40)	1.29(L_{etm} -40)	1.32(L_{etm} -20)
	2.05(L_{dn} -37)	1.79(L_{dn} -37)	1.51(L_{dn} -37)	1.29(L_{dn} -37)	1.30(L_{dn} -15)

In figure 4.26 the curves for stationary sources are plotted in combination with the straight lines for transportation noises. It is clear that, at least up to 60 65 65 dB(A), impulse noise is more annoying than any transportation noise. Around L_{etm} = 50 dB(A) the difference with the equally annoying level for other road traffic is about 15 dB(A). At lower levels the difference is somewhat larger, at higher levels somewhat smaller. For the difference between equally annoying levels of impulse noise and other road traffic noise, 15 dB(A) is a reasonable approximation by a single value.

It is more difficult to give a concise statement about annoyance from (non-impulse) industrial sources and shunting yards relative to the annoyance from transportation noises. The relative position of the industrial curve depends on the exposure measure used, as can be seen in figure 4.26. With L_{Aeq}(24h) industrial noise is more annoying than any transportation noise at equal level. With the other measures the industrial curve crosses the lines for aircraft and highway noise.

Figure 4.26 Annoyance score as a function of the overall exposure level. The straight lines are the same as in the bottom row of figure 4.25. The other curves are, from the highest to the lowest for impulse sources, (non-impulse) industrial sources and shunting yards.

All sources

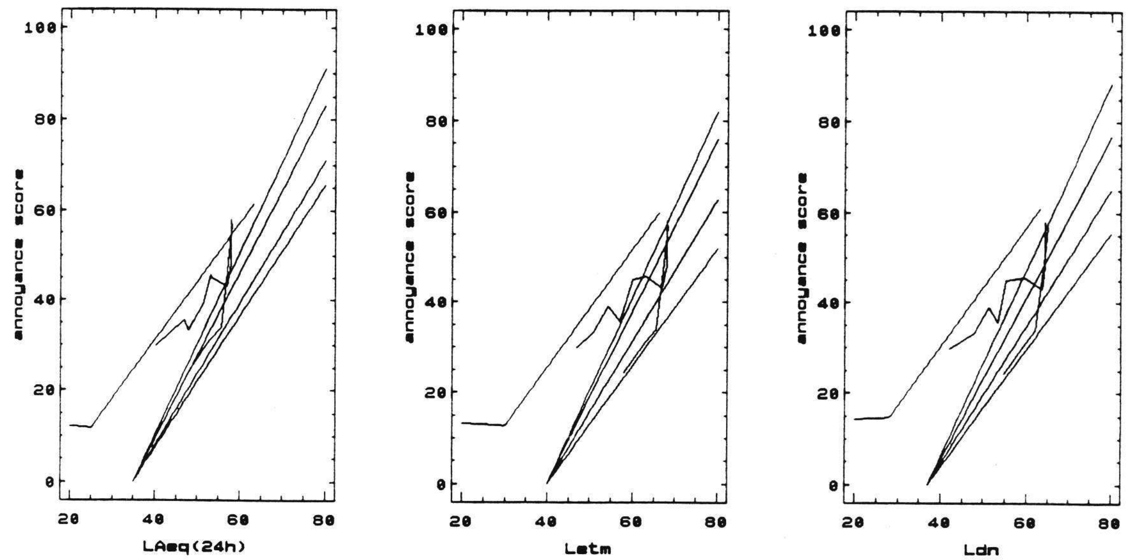


Figure 4.27 shows the percentage highly annoyed, annoyed, and (at least) moderately annoyed (A_{72}, A_{50} and A_{28}) as a function of L_{Aeq}(24h), L_{etm} respectively L_{dn}. High annoyance can be described with a quadratic power function. For the percentage annoyed a linear term is needed in addition. For moderate annoyance only the linear term is needed. The equations for the curves are given in table 4.2.

Figure 4.27 Percentage highly annoyed (first row), annoyed (second row) and at least moderately annoyed (third row) as function of the overall exposure level (A=aircraft, H=highway, O=other road traffic, R=railway, I=impulse sources).

Transportation + Impulse

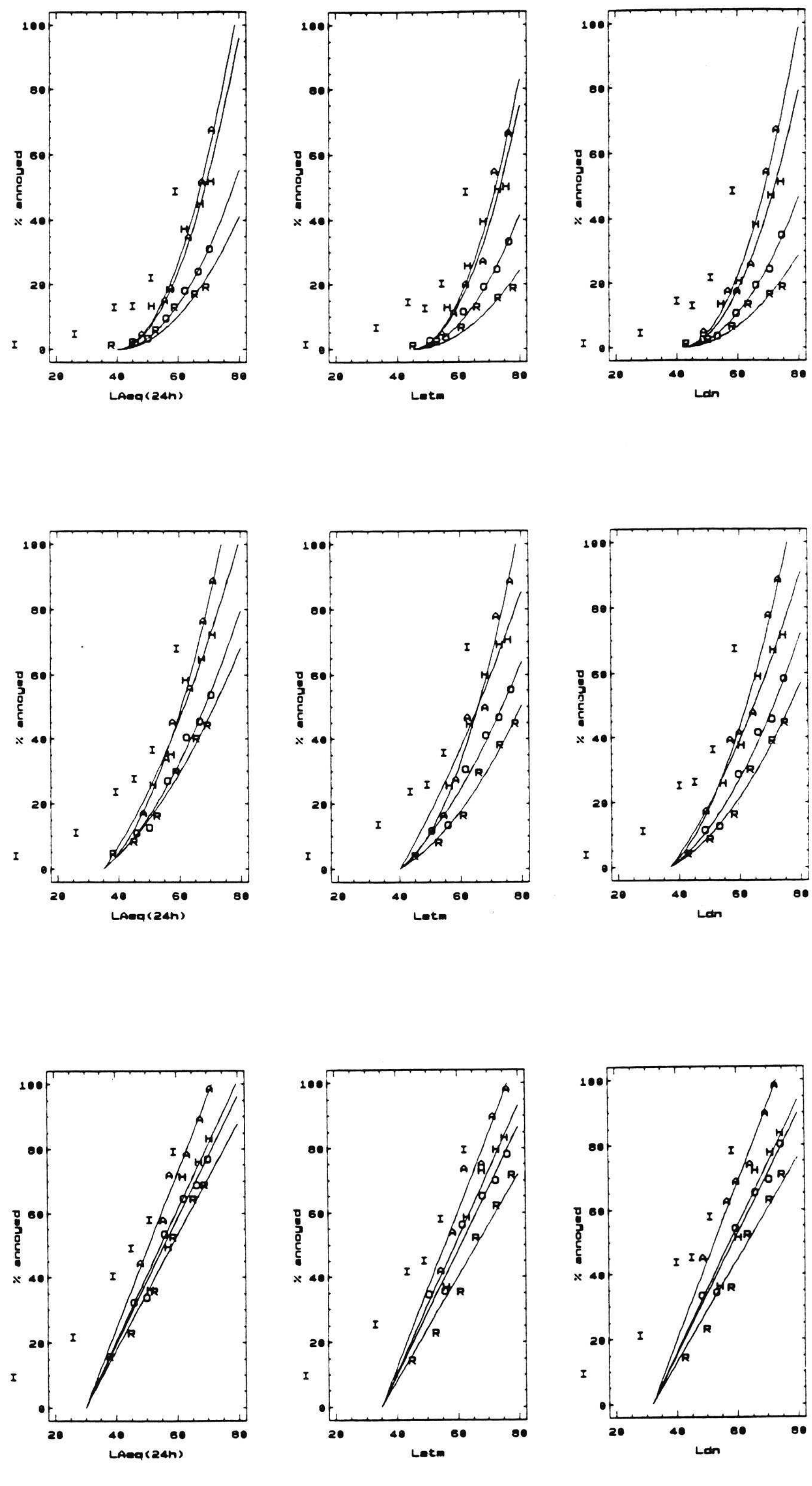


Table 4.2 Equations for percentage annoyed (A_{28}, A_{50}, A_{72}) as function of the overall exposure level. Plots are shown in figure 4.25

	aircraft	highway	other road	railway
% highly annoyed: A_{72}=	$.0671(L_{Aeq}-40)^2$ $.0678(L_{etm}-45)^2$ $.0684(L_{dn}-42)^2$	$.0600(L_{Aeq}-40)^2$ $.0612(L_{etm}-45)^2$ $.0547(L_{dn}-42)^2$	$.0346(L_{Aeq}-40)^2$ $.0340(L_{etm}-45)^2$ $.0323(L_{dn}-42)^2$	$.0257(L_{Aeq}-40)^2$ $.0199(L_{etm}-45)^2$ $.0200(L_{dn}-42)^2$
% annoyed: A_{50}=	$.0475(L_{Aeq}-35)^2$ $+ .73\ (L_{Aeq}-35)$ $.0522(L_{etm}-40)^2$ $+ .61\ (L_{etm}-40)$ $.0447(L_{dn}-37)^2$ $+ .85\ (L_{dn}-37)$	$.0208(L_{Aeq}-35)^2$ $+ 1.33\ (L_{Aeq}-35)$ $.0132(L_{etm}-40)^2$ $+ 1.61\ (L_{etm}-40)$ $.0203(L_{dn}-37)^2$ $+ 1.24\ (L_{dn}-37)$	$.0228(L_{Aeq}-35)^2$ $+ .75\ (L_{Aeq}-35)$ $.0179(L_{etm}-40)^2$ $+ .88\ (L_{etm}-40)$ $.0243\ (L_{dn}-37)^2$ $+ .63\ (L_{dn}-37)$	$.0167(L_{Aeq}-35)^2$ $+ .76\ (L_{Aeq}-35)$ $.0179(L_{etm}-40)^2$ $+ .54\ (L_{etm}-40)$ $.0193(L_{dn}-37)^2$ $+ .49\ (L_{dn}-37)$
% moderately annoyed: A_{28}=	$2.39\ (L_{Aeq}-30)$ $2.40\ (L_{etm}-35)$ $2.43\ (L_{dn}-32)$	$2.02\ (L_{Aeq}-30)$ $2.07\ (L_{etm}-35)$ $1.96\ (L_{dn}-32)$	$1.93\ (L_{Aeq}-30)$ $1.92\ (L_{etm}-35)$ $1.87\ (L_{dn}-32)$	$1.75\ (L_{Aeq}-30)$ $1.60\ (L_{etm}-35)$ $1.59\ (L_{dn}-32)$

Several points can be noted about the differences between sources. The first point is that the magnitude of the difference between types of sources depends on the exposure measure used. Differences are smallest with L_{Aeq}(24h), larger with L_{dn} and largest with L_{etm}. A similar point holds for the annoyance score lines in figure 4.25. A second point is that the magnitude of the difference also depends on whether one looks at the percentage highly annoyed, annoyed, or at least moderately annoyed. Between aircraft and highway noise there is a difference in moderate annoyance, not in high annoyance. For highway and other road traffic the converse holds: there is a difference in high annoyance but not in moderate annoyance.

4.6 Comparison of the relations with the German multiple sources study (1976) and with the Schultz curve

In this section we compare our results with those from the German multiple source study, carried out in Hamburg (Finke et al., 1980), and with the synthesis curve determined by Schultz (1978). The German study is especially interesting because it encompassed most of the sources we dealt with.

The Schultz curve is interesting because it was proposed as a summary of a vast amount of data, not included in this compilation. The question whether it is adequate or not stirred intense discussions.

In figure 4.28 curves for transportation, impulse and (non-impulse) industrial sources are shown together with the Hamburg data. The results for highway and other road traffic are in good agreement, although of course there is some scatter of the points from Hamburg around our lines. For aircraft there are three Hamburg locations, all with flights only between 6 and 22h, mostly landings. One point is a little above our line, the two others are below it.
There are four locations for railway. At the two with the lowest levels the noise comes from elevated 'subways', at the two with the highest levels there are both trains and trams. The points are at or above our lines for railway noise. It may be noted that at both locations with trains there are 600 - 700 train passages/24h with as much as 45% freight trains. As suggested before, this may explain the relatively high annoyance.
Overall we consider the agreement for the transportation noises to be satisfying.
For two reasons we have special interest in the comparison of results for stationary sources. One reason is that our results for industrial sources are based on few cases compared to the results for transportation noises. Moreover, we excluded five outliers, three with high and two with low annoyance, before obtaining the curve by interpolation. The second reason is that the curve for industrial sources has no simple relation to that of transportation sources. Especially deviant is the high annoyance at low levels.
For these reasons the fact, that the Hamburg results are in reasonable agreement with it, contributes substantially to the confidence that the curves exhibit real trends. If anything is different, then in Hamburg somewhat higher annoyance was found at equal levels.
Schultz curve is shown with our curves for the percentage highly annoyed as function of L_{dn} in figure 4.29. The Schultz curve almost coincides with our curve for other road traffic. When we had combined rail and non-highway road traffic, we had found a curve for ground transportation below the Schultz curve and a curve for aircraft above it. Differences are especially found at high exposure levels. This constitutes evidence in favour of Kryter's position that different curves are needed for aircraft and ground transportation noise. On the other hand, the curves for aircraft and highway noise are similar.
Thus, our results indicate that distinctions are required, in addition to that between aircraft and ground transportation made by Kryter. Moreover, Schultz' hypothesis that other than transportation noise is also covered by his single curve is very unlikely. Figure 4.28 showed that especially at low levels stationary sources cause more annoyance than transportation sources.

Figure 4.28 Annoyance score as function of the overall exposure level. The curves are as in figure 4.26, with omission of shunting yard. The points are from the Hamburg study (A= aircraft, H=highway, O=other road traffic, S=stationary sources).

Comparison Hamburg

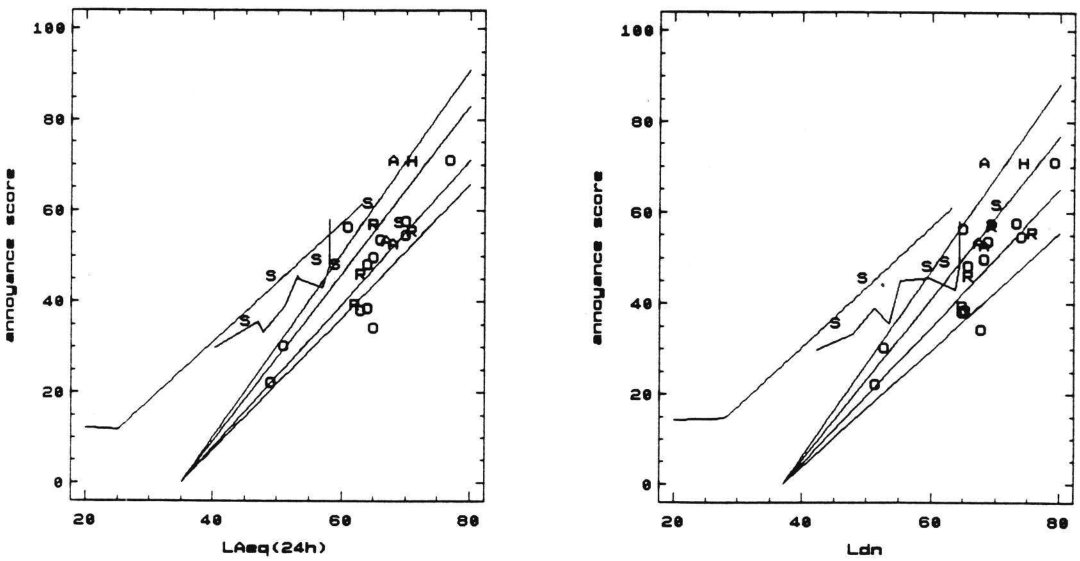
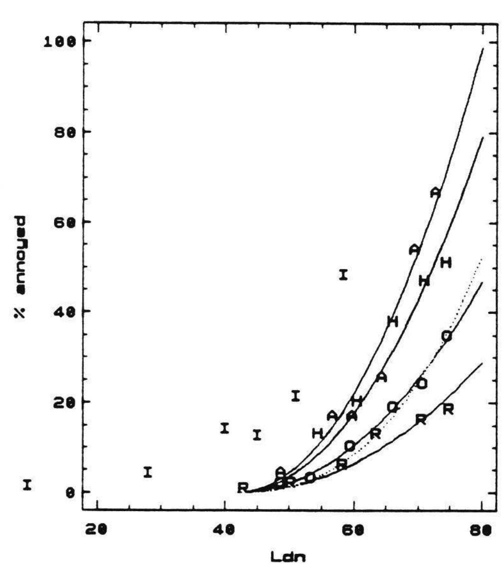


Figure 4.29 Percentage highly annoyed as function of L_{dn}. Points with fitted solid curves are from the present study (A=aircraft, H=highway, O=other road traffic, R=railway, I=impulse sources). Schultz' synthesis curve is dotted.

Comparison Schultz



5. DISCUSSION AND CONCLUSIONS

Results for noise from transportation and stationary sources are discussed separately. Subsequently, it is suggested how these results can be used in a procedure for the determination of the environmental quality. Finally, recommendations for further research are formulated.

Transportation noise

For transportation noise sources curves with simple equations were found to give good descriptions of the relation between the annoyance score or percentage annoyed on the one hand, and L_{Aeq}(24h), L_{etm} or L_{dn} on the other. These curves and the corresponding equations can be found in section 4.5. At equal exposure levels aircraft, highway, other road traffic and railway noise are not equally annoying. Especially at higher levels and especially when L_{etm} is used, annoyance decreases in the order in which the sources are mentioned.

Application of time of day penalties did not reduce, but tended to enlarge differences between types of sources. Therefore curves were determined per type of source. Then no clear superiority of one of the three exposure measures over the others was found. This does, however, not imply that there are no reasons to use a measure with a time of day penalty. The lack of superiority of penalized measures in the present analyses may be due to the high correlations, for a single type of source, between the levels for different day periods. Analyses directed specifically at this issue are needed to reach a conclusion about the desirability of time of day penalties.

No clear effect of tonality or pause on annoyance is found when the effect of L_{Aeq}(24h), L_{etm} or L_{dn} has been taken into account. Tramway situations classified as tonal were found to be more annoying, but for trains this was not found. The present lack of a clear effect of tonality does not change that tonal sounds can be very annoying. What it does show is that it is hard to identify when exactly tonality does contribute significantly to annoyance.

There is a beneficial influence of the presence of a relatively quiet side of the house. It appears that a considerable difference ($\geq$ 15 dB(A)) is needed for this effect to occur. The effect is found for all sources for which the required data were available (highway, other road traffic and railway). It is stronger when the exposure is higher. This result increases the likelihood of Kryter's hypothesis that aircraft noise is, in general, more annoying than ground transportation noise because, among other things, often all sides of a dwelling are exposed to it. It would be interesting to see whether the effect can also be found with comparisons of different aircraft noise conditions.

The result with respect to the beneficial effect of a quiet side can be used for the physical planning in neighbourhoods exposed to considerable ground traffic noise. Attention has to be paid to the reason why people are less annoyed when their homes have a relatively quiet side. This is probably because they have some quiet sleeping rooms, have a garden or balcony which is less noisy and they can open windows for ventilation without too much noise intruding into the house. It is of course not just the quiet side, but such facilities or opportunities at a quiet side which are beneficial.

Although the availability of a quiet side may explain some of the differences between sources, there are other factors. This is evident from the results for highway and other road traffic. Within subgroups of persons, all having or not having a quiet side, there was still a difference between these kinds of traffic.

One factor that is not taken into account in the present analyses, but is known to have an effect on annoyance, is the percentage of heavy vehicles (freight trains in case of railways and lorries in case of road traffic). At the same L_{Aeq}(24h) annoyance is higher when the percentage of heavy vehicles is higher. It may be that this factor contributes to the differences found between ground transportation noise sources. The effect of a higher percentage of heavy vehicles on annoyance may be due to higher peak levels, more night operations and to more low frequency sound and more vibration. With respect to the latter possibilities it may be noted that the A-weighted levels underestimate the loudness of low frequency sounds such as from heavy vehicles relative to the loudness of sounds from lighter vehicles.

At present there is still no adequate explanation for the differences between transportation sources. Knowledge about the causes of the differences would help to find the most applicable response function for individual situations. E.g., there is a smooth transition between highway traffic and other road traffic. With respect to annoyance some other road traffic situations may actually be more similar to highway traffic. There are atypical situations with sources that may be more similar to another type of source in aspects relevant for annoyance.

Noise from stationary sources

For stationary sources we distinguished between impulse sources, (non-impulse) industrial sources and shunting yards.

For impulse noise with levels above 25 - 30 dB(A) the annoyance score is linearly related to L_{Aeq}(24h), L_{etm} and L_{dn}. The degree of annoyance caused by impulse sources with levels slightly above 25 - 30 dB(A), is reached for transportation sources only at much higher levels. But with increasing level the difference with the equally annoying level from aircraft decreases. The

difference with non-highway road traffic noise is less variable and a single penalty of 15 dB(A) for impulse noise may be used as a reasonable approximation at all levels.
Qualitatively the results for (non-impulse) industrial sources exhibit a somewhat similar pattern, although less pronounced. That is, at low levels these sources are more annoying than any type of transportation source. But this extra annoyance disappears at higher levels. These differences with transportation noise are smaller than for impulse sources. Furthermore, for (non-impulse) industrial sources the picture is less clear because of outliers to both sides. At three locations annoyance was much greater and at two it was much less than the general trend.

The problem with stationary sources is that they constitute a far more heterogeneous group with respect to frequency spectrum and time pattern than each of the transportation sources. Furthermore, for a single factory several types of noises, related to different aspects of the production process, may cause annoyance.
Rise velocity (impulses or not) is an important factor to take into account for stationary sources: impulse noise is more annoying than (other) industrial noise. But neither time of day penalty, tonality nor pause contributed to the prediction of the annoyance. The remarks made when reporting similar negative results for transportation noise apply again.
It is our feeling that much may be gained by a better distinction between impulses and other sound. Detailed inspection showed that in the Netherlands stationary sources study respondents reported sometimes impulse sounds for sources classified by the acoustician as non-impulse. For the two concrete element factories, which were not included in the curve for non-impulse industrial sources because the annoyance was exceptionally high compared with other industries, half of the respondents reported impulses or sounds with sudden onsets as bangs and pouring of concrete. Another illustration is that at least forty percent of the respondents near the heavy industry sublocation, with noise classified as continuous, heard bangs, metal on metal and shunting activities. On the other hand, we mentioned that, e.g., in the EC impulse noise study chillers at a dairy contributed to the overall level of a source considered to be impulsive.
These observations suggest that the determination of noise emission from a factory should start with a systematic inventory of the noise sources and their operation times. Especially impulse sources, such as loading and unloading of containers or crates, hammering, sorting of metal, etc. should be separated from the rest, such as the noise from cranes carrying containers, ventilators, traffic at the factory terrain, refinery installations, etc.. From measurement data for the separate sources and their operation times two L_{Aeq} levels can be determined for each relevant time period:

one for impulse noise and one for other noise. These can be combined by a method described by Miedema (1992b) for the evaluation of combined noise sources.

But also when one starts with an inventory of sounds which contribute to the L_{Aeq}, carefully distinguishing impulse from non-impulse sources, incidental sounds which may contribute significantly to the annoyance are probably not taken into account. E.g. at a large chemical industry, included in the Netherlands stationary sources study, occasional restarting of the production process, e.g. after maintenance work, gives rise to flames at stacks which produce a loud roaring sound. It would not be difficult to give a list of examples of incidental sounds at factories that probably contribute to annoyance, although their influence on L_{Aeq} is negligible. We believe that such sounds are partly responsible for the slow decrease of the annoyance curve for impulse and industrial sources when the overall sound level decreases.

Evaluation of noise situations

The present results are incorporated in an evaluation, which consists of the following steps:

<u>step 1</u>: Inventory of the sources contributing to the L_{Aeq} levels.

An inventory of the sources contributing to the L_{Aeq} levels is made. For each source the L_{Aeq} is determined for the relevant periods, as 7 - 22 and 22 - 7h for L_{dn}, and 7 - 19, 19 - 23 and 23 - 7h for L_{etm}. Sources to be distinguished are:

mobile	aviation	large aircraft: A small airplanes: ? jet fighters: ? helicopters: ?
	road	highways: H other road: O
	rail	train: R tram: R metro: R
	water: ?	
stationary	airports: ?	
	industry	impulse sources: I non-impulse sources:?H?
	shooting ranges: I	
	recreation: ?	
	etc.	

It has to be decided for each source which response function is most likely to give a good indication of the annoyance caused by that source. We indicated for each source which response function can be used (A = aircraft, H = highway, O = other road traffic, R = railways, I = impulse noise; see table 5.1 and 5.2). A question mark means that the present study does not give sufficient information to determine the most appropriate response function.
For non-impulse industrial sources the response function for highway noise may be considered as giving a lower bound. Because of acoustical similarities its use appears most appropriate for continuous sources such as refineries, chemical plants, power plants, ventilation or refrigerating installations. For fluctuating or intermittent sources, e.g., other road traffic may be thought to be more similar. However, the noise annoyance found in this and the Hamburg study for intermittent and fluctuating stationary sources clearly exceeds that of other road traffic. Moreover, it is known that intermittent road traffic noise, e.g. near traffic lights, is more annoying than noise from free-flowing road traffic. Hence, the highway curve seems to provide a better approximation.
Similar reasoning and additional literature may be used to arrive at response functions for the sources with a question mark. Additional research into the factors explaining the differences between sources could reduce the uncertainty involved in this kind of reasoning.

step 2: Inventory of the incidental or atypical features.
An inventory of the incidental or atypical features is made. Features are included if they contribute significantly more to the annoyance than would be expected on the basis of their contribution to the L_{Aeq}(24h), L_{etm} or L_{dn} of the source. The necessity of abatement directed at these sound features cannot be derived from these overall sound levels. There are many examples. Sometimes relatively simple or cheap measures directed at such features may give a relatively great annoyance reduction. When the noise climate is only judged by the overall sound measures, these sources of nuisance would be neglected.
Examples from industry are the roaring flame burning occasionally at a chemical plant, a steam whistle which goes twice a day at a food industry or a telephone bell or signal for breaks at a workplace adjusted to be heard also outside.
Examples for mobile sources are low altitude flying by jet fighters (high rise velocity at onset of sound, see figure 2.1), small airplanes showing commercials (active especially at summer days when people are outside or have windows open and therefore are more vulnerable to noise), joints causing bumping sounds and curves causing squealing sounds from trams (see figure 4.7), mopeds in road traffic (for decades high in the list of most annoying sources in the Netherlands, (De Jong 1988), points where road traffic accelerates e.g. at traffic lights (Langdon, 1976).

The contribution of such sounds to annoyance probably is greater than would be expected from their contribution to the overall noise level. In some cases these features may be a reason for using another response function for the source. For example, it could be that for low flying jet fighters the curve for impulse noise is more appropriate than a curve determined near military jet fighter bases.

step 3: Environmental noise quality rating per source.
To arrive at consistent ratings two elements are needed: I. A rating system for L_{Aeq}(24h), L_{etm} or L_{dn} values from a single source e.g. non-highway road traffic; II. Translations of exposure levels from other sources into the equally annoying L_{Aeq}(24h), L_{etm} or L_{dn} levels of that source.
The following is a proposal for a *rating system* for L_{etm} of non-highway road traffic noise immissions in residential areas. All boundaries are about 5 dB(A) lower when L_{Aeq}(24h) is used and about 3 dB(A) lower for L_{dn}.

non-highway road traffic L_{etm}	rating
< 40	good
40 - 45	rather good
45 - 50	reasonable
50 - 55	moderate
55 - 60	rather bad
60 - 65	bad
65 - 70	very bad
≥ 70	extremely bad

The motivation for this system is as follows. A situation is considered good up to the level where annoyance starts (L_{etm} = 40 dB(A)). When one third is negatively affected in the sense that they report at least moderate annoyance, ten percent is annoyed and some people are highly annoyed, we do not longer call a situation rather good or reasonable but start calling it moderate (L_{etm} = 50 dB(A)). At the point where the majority of the population becomes at least moderately annoyed, a quarter is annoyed and five to ten percent is highly annoyed we start calling a situation bad (L_{etm} = 60 dB(A)). When the large majority (two thirds) is negatively affected in the sense that they report at least moderate annoyance, the majority is annoyed and a quarter is highly annoyed we start calling a situation extremely bad (L_{etm} = 70 dB(A)).
For the *translation* of exposure levels from other sources into the equally annoying L_{Aeq}(24h), L_{etm} or L_{dn} levels of road traffic the response functions referred to in step 1 can be used. The following

rating system is implied by these response functions and the above rating system for other road traffic:

	L_{etm}					
rating	other road	highway	aircraft	railway	impulse	non-imp industry
good	< 40	< 40	< 40	< 40	< 20	< 40
rather good	40-45	40-44	40-44	40-46	20-26	40-44
reasonable	45-50	44-48	44-48	46-52	26-32	44-48
moderate	50-55	48-52	48-51	52-58	32-38	48-52
rather bad	55-60	52-57	51-55	58-64	38-44	52-57
bad	60-65	57-61	55-59	64-70	44-50	57-61
very bad	65-70	61-65	59-63	70-77	50-56	61-65
extremely bad	≥ 70	≥ 65	≥ 63	≥ 77	≥ 56	≥ 65

It should be noted that atypical features as meant in step 2 are not taken into account in the above rating procedure. For these features a separate approach is needed, complementary to the approach directed at reducing overall exposure levels.

<u>step 4</u>: Environmental noise quality rating for combined sources.

Often there is more than one noise source. Also, a single factory may sometimes be better treated as a combination of impulse and non-impulse sources. In order to arrive at a rating of the overall environmental noise quality, we need to translate a combination of exposure levels into e.g. the road traffic exposure level which is equally aversive. This can be done with a method described by Miedema (1992b). After the translation a quality rating can be obtained, by using the above rating system for road traffic.

The method is not only applicable to combinations of environmental noise sources but can also take into account the effect of environmental odour sources. The response curves for environmental odour are provided in Miedema (1992a).

An illustration of the application of the approach to residential surrounding of an industrial area in Arnhem, the Netherlands, with road traffic, railway and non-impulse industrial noise as well as odour from chemical plants can be found in Miedema (1992b).

Research recommendation

The present study has demonstrated that a compilation of existing data can be useful to investigate the relations between effect measures and exposure measures for noise. A prerequisite for a compilation to be useful is that effect measures and exposure measures are defined in the same way for the data from different studies.

The following recommendations are directed at extending the basis for response functions and increasing knowledge about the proper classification of sources. It is recommended to extend the compilation in two ways:

- extending the compilation with data on the same variables that were considered in this study. Data from new projects can be added directly after they are finished. For some projects which are already closed there is some urgency because of the risk that data are lost or become inaccessible;
- addition of data on some variables, such as percentage of heavy vehicles for ground traffic.

Issues that require further analysis and therefore direct the choice of the variables to be added to the compilation are:

- the reliability and validity of annoyance reports. Here, some results were reported, which indicated satisfying reliability and validity. But because there generally is a critical attitude towards self reported effects, it seems worthwhile to analyze some of the large amount of data available for clarifying this issue.
- the factors that explain the differences between sources. There is a need for clarification of this point, because it would clarify which response function is most appropriate for a given source.

In this report results from a German study, of which the research data are lost, were used for comparison. The third recommendation is to compile results extracted from publications of such studies:

- compilation of results from publications of studies, for which the original data are lost, in such a way that the results can meaningfully be compared with results from analyses of compiled original data.

One possibility would be to combine the points in a continuing project, which leads, say, every third year to a revised and enlarged edition of the present report. International cooperation via the International Commission on Biological Effects of Noise and the European Community could be helpful to obtain data and to discuss the harmonization of consequences attached to evidence with respect to effects of environmental noise.

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APPENDIX: STUDIES IN THE COMPILATION

CONTENTS page

Each study is described in a separate section. Each section starts with a reference to the original research reports. After some general remarks about the study a more detailed account is given of the relevant sound and annoyance measures. Of special importance is the derivation of the common measures which are used here in the analyses. To characterize noise exposures we use L_{Aeq}(24h), L_{etm}, L_{dn}, a classification as tonal or not, rise velocity, percentage of quiet minutes and the level difference between most and least exposed side. For the calculation of L_{Aeq}(24h), L_{etm} and L_{dn} we had to know L_{Aeq}(7-19), L_{Aeq}(19-22), L_{Aeq}(22-23) and L_{Aeq}(23-7). For the annoyance we used nonspecific annoyance, communication disturbance, sleep disturbance, startle and vibration of the house.

A.1 European community aircraft study (1984)

ATKINSON BJ, CRITCHLEY JB, DEVINE E. (1985) 'CEC Joint study of community response to aircraft noise, 1984: noise measurements near Glasgow Airport. DR communication 8506, Civil Aviation Authority, London

DIAMOND I, WALKER JG. (1986) CEC Joint research project 'Community reactions to aircraft noise', University of Southampton ISVR, Southampton.

DIAMOND I, Walker JG, Critchley JB, Richmond GC.(1986) 'CEC Joint study of community response to aircraft noise 1984: main report', DR report 8601, University of Southampton ISVR, Southampton.

PACHIAUDI G, TANGUY Y, BRUYERE JC, FRANCOIS J, VALLET M.(1985) 'Community reactions to aircraft noise' report AER 3.2/6, Institut de Recherche des Transport CERN, Bron. (except title in French)

The primary purpose was to study annoyance from aircraft. But sound and annoyance measurements were also carried out for road traffic noise. The road traffic aspects of the study are described in section A.8.

Due to exhaustion of funds the study has never been extensively described. The above mentioned final integral report by Diamond and Walker consists only of five pages of text, plus some tables and figures. Apart from that, there are for the British part more detailed final reports and for the French part a final but incomplete noise measurement report, which are also mentioned above.

Fortunately we were able to obtain the complete dataset and additional information from unpublished material and personal communication with researchers in each of the three countries involved.

The study was carried out around Paris-Orly, Amsterdam-Schiphol and Glasgow(-Abbotsinch) Airport. The French survey was carried out in June and July, the Netherlands' survey in October, November and the first week of December. For the British survey we only know that it commenced at the end of May.

There were 1758 respondents. In each country locations were selected with different high/low combination for aircraft and road traffic noise. In France there were 7 locations with a total of 570 respondents, in the Netherlands 9 locations with 581 respondents and in Great Britain 3 locations with 607 respondents.

A.1.1 Sound measures

For a number of periods L_{Aeq} was determined by a combination of measurements for different types of aircraft - both during landing and take-off -, and detailed flight data from the airport. The measurements for Amsterdam-Schiphol were made away from any obstacle but may have included some reflection from the ground. From the description of the microphone positions for Glasgow airport the contribution of reflections is estimated to be less than 2.5 dB(A), but not known exactly. For Paris-Orly no information on the possible inclusion of reflections in the measured aircraft sound is available to us. At all locations measurements were made at reference points only. The British acoustic report contains information that deviations within a location go in both directions.
For Paris-Orly flight data for the three months period mid-June to mid-September were used, for Amsterdam-Schiphol and Glasgow Airport the flight data for 28 days preceding the survey. From these flight data and the measurement data, day period L_{Aeq}'s were calculated, taking together the same periods of different days.
From the L_{Aeq}'s available in the dataset we calculated L_{Aeq}(7-9), L_{Aeq}(19-22), L_{Aeq}(22-23) and L_{Aeq}(23-7).
The dataset also contained the (average) number of passages per day from which we calculated the percentage of quiet minutes. For each passage one quiet minute was subtracted from the 1440 minutes in a day.
In the French acoustic report there was a remark that at one location (Lonjumeau) there were 22 apartments with a 10 dB difference between front and rear facade. Since we were not able to identify these respondents - and we had no relevant information for the other French locations - this difference was coded as missing for the French respondents. In the Netherlands, and two of the three British locations, all respondents lived directly under the flight paths. The difference there between most and least exposed facade was classified as < 5 dB(A). For the third British location (Knightswood) it is set missing.

Table A.1 Acoustic summary for the European Community aircraft study (1984).

overall level L_{Aeq}(24h)	48 - 71 dB(A)
with time of day penalty L_{etm}	53 - 77 dB(A)
with time of day penalty L_{dn}	48 - 72 dB(A)
tonality	?
rise velocity	< 10 dB/s
pause	84 - 97 %
quiet side	< 5 dB(A) (? for French and one British location)

A.1.2 Annoyance measures

The questionnaires in the three countries had a common core. The questions used here belong to this core. The introduction of the questionnaire did not focus on noise, but the questions used here were preceded by a number of other questions on noise annoyance.

For nonspecific annoyance we used two questions (19a and 24a in the French and British survey, 26 and 63a in the Netherlands' survey):

Taking all things into account, how much would you say the noise from aircraft around here bothers or annoys you?

	upper category boundary	score
very much	100	87
moderately	75	63
a little	50	37
not at all	25	13

Just to make sure I have it all straight, how do you feel overall about:

the noise from aircraft		
1. not at all annoyed	10	05
2.	20	15
3.	30	25
4.	40	35
5.	50	45
6.	60	55
7.	70	65
8.	80	75
9.	90	85
10. very much annoyed	100	95

For the analysis the scores from both questions were averaged for each respondent. The percentages annoyed were determined as follows. A10, A40, A60 and A90 were obtained from the second question only. A28 by linear interpolation between A25 from the first and A30 from the second question. Similarly, A72 by linear interpolation between A75 from the first and A70 from the second question. Finally, A50 is determined by averaging the A50 values for both questions.
For specific annoyance we used parts of question 21 in the French and British survey and of questions 38-41 in the Netherlands' survey:

Now I would like to ask you some further questions about aircraft noise. Again I will concentrate firstly on weekdays and then on weekends for each item (For each item below, ask:)

a)	Do the aircraft ever .... on weekdays?
b)	Do the aircraft ever .... on weekends?

When they ......, how annoyed does this make you feel?

		score
Startle you		
(do ever)	yes	
	no	13
(annoyance)	very much	87
	moderately	63
	a little	37
	not at all	13

idem for 'interfere with conversation', 'prevent you from sleeping in the middle of the night', 'wake you up in the early morning' , 'make the house vibrate or shake' and, in the French and Netherlands' survey only, 'prevent you from falling asleep in the evening'.

The two or three 'sleep' questioned were combined by taking the maximum. The scores on weekday and weekend questions (for the sleep questions the maxima) were averaged for each respondent.

A.2 British railway study (1975/76)

FIELDS JM, & WALKER JG. (1980). Reactions to railway noise: a survey near railway lines in Great Britain, University of Southampton ISVR, technical report 102, vol. I and II, Southampton.

One purpose was to study the relation of different noise measures with annoyance. The survey was conducted between mid-October 1975 and the end of January 1976 at 75 locations all over Great Britain. There were 1453 respondents.
Criteria for the location selection were estimated railway peak levels of at least 65 dB(A), an estimated number of passages per day of least 20 and a distance of at least 300 m from any marshalling yard.

A.2.1 Noise measures

Noise measurements combined with information about train passages were used to determine L_{Aeq} values. The sound measure did include reflections from a facade 1 m from the microphone. Based on measurements of the effect of reflecting surfaces reported in Vol. II, Appendix ZC, we subtracted 2.5 dB(A) from the levels in the database.
The available dataset contains L_{Aeq}(7-19), L_{Aeq}(19-22) and L_{Aeq}(22-7). Assuming little change in operation schedules before 23 h, we set L_{Aeq}(22-23) equal to L_{Aeq}(19-22). Consequently we set L_{Aeq}(23-7) equal to 10log{[9 antilog L_{Aeq}(22-7)/10] - [antilog L_{Aeq}(22-23)/10]}/8.
There were two types of information in the dataset that could be used to determine whether there were substantial tonal sounds at a location. In open question 26 it was asked whether there were 'any particular types of noise from trains that are especially annoying such as a clanging, or squealing, or clickety clack, or ....?' Furthermore, there was a registration by the noise measurement

team whether train wheel squeal was heard. The alternatives are 'never heard', ' hear barely', 'hear definitely' and 'loud as some trains'. All respondents at a (sub)location are considered to be exposed to tonal railway noise when at that (sub)location at least 15 % mentioned a high pitch tonal sound and the team reported 'hear definitely' or 'loud as some trains' for train wheel squeal, at least for some respondents. For respondents at other (sub)locations the exposure is considered nontonal.

From reports at question 26 of 'clickety clack' or 'chunk chunk' and especially registrations by the noise measurement team of rhythmic sound of wheels on joints it appeared that these rhythmic sounds were not uncommon. From these types of sounds however no detectable effect is expected (see also Vol. I, par. 3.4.1.5). More important are sounds as banging, clanging, bumping and thumping. Since at question 26 there were very few reports of these types of sound and no (sub)locations could be discriminated as having more of these sound, the rise velocity of passages as a whole is considered as characterizing the onset of railway sounds at all locations. Hence, rise velocity is classified as < 10 dB/s.

The number of train passages per 24 h was included in the dataset so that the percentage of quiet minutes could be determined directly, subtracting one quiet minute for each passage.

There was no information available to estimate the difference between most and least exposed side of the house. Therefore it was set missing.

Table A.2 Acoustic summary for the British railway study (1975/76)

overall level L_{Aeq}(24h)	23 - 77 dB(A)
with time of day penalty L_{etm}	32 - 85 dB(A)
with time of day penalty L_{dn}	29 - 82 dB(A)
tonality	only at (sub)locations: Ealing, Sheffield, Tunbridge Wells, Hucknall, Hartlepool, Long Eaton, Bexhill and Luton.
rise velocity (V)	< 10 dB/s
pause	19 - 100 %
quiet side	?

It may be noted that the range of the levels and pauses is large. For pause this is a consequence of a range for the number of passages from 6 to 1158.

A.2.2 Annoyance measures

In the introduction letter noise was not mentioned as topic of the survey. But there are other noise annoyance questions preceding the nonspecific annoyance questions used here. We used question 17:

Can I just check, you said you did/ did not hear train noise here?

	upper category boundary	score
hears trains		
does not hear (skip annoyance question)	25	13

Does the noise of the trains bother or annoy you?

very much	100	87
moderately	75	63
a little	50	37
not at all	25	13

Note that we consider those who do not hear the trains as not at all annoyed, whereas in the original study they were treated as missing.
For specific annoyance we used question 18 in combination with the first part of 17:

Can I just check, you said you did/ did not hear train noise here?

	score
hears trains	
does not hear (skip annoyance question)	13

Do the trains ever startle you?

yes	
no	13

When they startle you how annoyed does this make you feel?

very	87
moderate	63
a little	37
not at all	13

idem for 'wake you up', 'make the house vibrate or shake', 'interfere with conversation' and 'interfere with sleep in any other way'.

For each respondent the answers for both sleep questions were combined by taking the maximum.

A.3 Netherlands railway study (1977)

PEETERS AL, JONG RG de, KOPER JP, TUKKER JC. (1984). Hinder door spoorweggeluid in de woonomgeving. Ministerie VROM: ICG-RL-HR-03-03, Leidschendam.

One purpose was to study the relation between sound exposure and annoyance. The study was carried out in the autumn of 1977 at 9 locations in the Netherlands. For each of 3 different combinations of the number of passenger trains and the number of good trains (high/high, high/low and low/low) 3 locations were included. Another criterion for location selection was absence of special characteristics as bridges, viaducts, stations, crossings with roads, curves with small radius, junctions or shunting yards. There were 671 respondents.

A.3.1 Noise measures

Noise measurements combined with detailed information about the passages, provided by Netherlands Railways (NS), were used to determine L_{Aeq} values. The sound measured did include reflections from a facade 1 m from the microphone. For this reason 3 dB(A) was already subtracted in the original database.

The available dataset contained L_{Aeq}(7-19), L_{Aeq}(19-23) and L_{Aeq}(23-7). Assuming no significant changes in operation schedules between 19 and 23 h, we set L_{Aeq}(19-22) and L_{Aeq}(22-23) both equal to L_{Aeq}(19-23).

Since locations without curves with short radius and without stations were selected, no tonal components due to squealing of wheels or breaks were expected. For wheel squealing this was confirmed by question 43. For several sounds it was asked how often one could hear them: 'passing a junction', 'breaking', 'passing a curve' or 'passing a bridge or viaduct'. The response alternatives were 'never', 'seldom', 'sometimes' and 'often'. For passing a curve only 1% responded with one of the two latter categories. But as much as 23% reported hearing breaks sometimes or often. Respondents at locations where this percentage exceeded 35% are considered to be exposed to tonal railway noise. For the others the exposure is considered to be nontonal.

Since the locations were selected, if possible without joints, bridges or viaducts it was unlikely that impulsive sounds play a significant role: the confirmation by the above question proved that the selection was successful on this point. Only 4% and 2% responded with 'sometimes' or 'often' for joints respectively bridges/ viaducts. Therefore, the onset of passages as a whole is considered to be most important for railway sounds at all locations. Hence, rise velocity is classified as < 10 dB/s.

The number of passages was included in the dataset, so that the percentage of quiet minutes could be determined directly.

The dataset contained L_{Aeq}(24h) for the most and least exposed side. Hence, the difference between most and least exposed side could be calculated and classified.

Table A.3 Acoustic summary for the Netherlands railway study (1977)

overall level L_{Aeq}(24h)	32 - 68 dB(A)
with time of day penalty L_{etm}	39 - 79 dB(A)
with time of day penalty L_{dn}	37 - 75 dB(A)
tonality	only at (sub)locations Best-south, Rijen-south and Olst
rise velocity	< 10 dB/s
pause	77 - 94 %
quiet side	all three categories

A.3.2 Annoyance measures

The introduction of the questionnaire was general, not focused on noise. Before the nonspecific annoyance questions used, the respondent was asked a number of other noise questions. These were mixed, however, with non-noise questions.
For nonspecific annoyance we used the following questions (34c and 35c):

I will mention some sounds. Please indicate for each of these sounds whether you hear them here, in or around your house, and if you hear them, how often.

	upper category boundary	score
never (skip annoyance question)	20	10
seldom (skip annoyance question)	20	10
sometimes		
often		

I will now mention once again the sounds, which you indicated to hear. Please indicate, using this card, to what degree they annoy you?

definitely not annoying	20	10
not annoying	20	10
just not annoying	40	30
neutral	40	30
just annoying	60	50
annoying	80	70
very annoying	100	90

A peculiar aspect of the scale is the insertion of the neutral category. Because of this we deviated here from the general procedure of determining cut off points and scores, described in section 3.3. The determination of specific annoyance was also unusual. There were questions for the situation with the windows closed which were only asked when annoyance was reported for when the windows are opened. Because of this we again adapted the general procedure. The following questions (53, 54, 59, 60, 61, 62, 63 and 64) were used:

Are you occasionally disturbed by trains during a conversation when you have the windows opened?

	score
yes	
no (skip next question)	10

And when you have the windows closed, how often are you then disturbed during a conversations?

often	90
sometimes	70
seldom	50
never	30

Are you occasionally disturbed by trains during resting or sleeping when you have the windows opened?

yes	
no (skip next question)	10

And when you have the windows closed, how often are you then disturbed by trains during resting or sleeping?

often	90
sometimes	70
seldom	50
never	30

Are you occasionally being startled or are you frightened when you hear a train when you have the windows opened?

yes	
no (skip next question)	17

And when you have the windows closed, are you then occasionally startled or frightened when you hear a train?

yes	83
no	50

Does your house occasionally vibrate because of the train noise?

yes	
no (skip next question)	17

Do you consider this unpleasant or don't you care?

unpleasant	83
don't care	50

A.4 German railway study (1978/81)

SCHÜMER - KOHRS A, SCHÜMER R, KNALL V, KASUBEK W.(1983) Interdisziplinäre feldstudie über die besonderheiten des schienverkehrlärms gegenüber dem strassenverkehrslärm, Vol. I and II, Planningsburo Obermeyer, München.

One purpose was to compare the annoyance from railway and road traffic noise. The study was carried out in two parts, one from winter 77/78 until summer 78, one from autumn 80 until the first part of 81, at 22 locations all over the former West-Germany. The locations were selected such that the relative importance of the sources varied. There were 7 locations with predominantly road traffic noise, 7 with predominantly train noise, 4 where these sources were expected to be about equally important 2 with noise from trams and 2 locations with little noise at all. There were 1651 respondents.
Among the criteria for the selection of a location was the electrification of the line and the passing of freight as well as passenger trains and the absence of other noise sources.

A.4.1 Noise measurements

Sound measurements combined with information about passages from records at a nearby railway station were used to determine L_{Aeq} values. The sound was measured in free field conditions. The available dataset contained L_{Aeq}(6-22) and L_{Aeq}(22-6). We set L_{Aeq}(7-19), L_{Aeq}(19-22) and L_{Aeq}(22-23) equal to L_{Aeq}(6-22). And we set L_{Aeq}(23-7) equal to L_{Aeq}(22-6). Based on information about the number of passages per hour, available for the dominant rail and mixed areas, this procedure was estimated to introduce no significant errors in L_{etm} and L_{dn} which are derived from these L_{Aeq}'s.

From the description of the locations in Appendix A3 of Band II, including maps with the railway lines (more detailed in a 1979 report), it was judged to be very unlikely that tonal sounds would occur. Mostly there was no curvature and in case there was, it was rather low. For one location (Augsburg) a radius of 700 m is reported. Only for one other location (Langenprozelten) this radius appeared to be somewhat smaller. Furthermore, since no locations in the immediate neighbourhood of stations were selected, tones due to breaking are assumed to be nonsignificant. Based on foregoing considerations, the exposure of all respondents was considered nontonal.

The rise velocity for entire passages is considered characteristic for the noise events, although there is some uncertainty for respondents at Munich and Veitsbronn, who appeared to live near a junction. The rise velocity was classified as < 10 dB/s.

The number of train passages per 24 h is reported in Appendix A4 Band II so that the percentage of quiet minutes could be directly determined. The number of passages per hour, presented in the same appendix for railway dominant and mixed areas, came nowhere close to 60.

Initially we tried to classify the differences between the levels at the most and least exposed side using the location descriptions, including maps, in Appendix A3 Band II. However, because of too much uncertainty about the proper classification, the difference was considered missing.

Table A.4 Acoustic summary for the German railway study (1978/81)

overall level L_{Aeq}(24h)	44 - 70 dB(A)
with time of day penalty L_{etm}	50 - 79 dB(A)
with time of day penalty L_{dn}	48 - 75 dB(A)
tonality	no
rise velocity	< 10 dB/s
pause	50 - 97 %
quiet side	?

A.4.2 Annoyance measures

The questionnaire has a general introduction, but prior to the nonspecific annoyance questions there were some other questions dealing with noise, including railway (and road traffic) noise. For nonspecific annoyance we used the following question (47):

To what extent do you feel annoyed by the noise of the railway?

	upper category boundary	score
not	20	10
a little	40	30
moderately	60	50
rather	80	70
very	100	90

For specific annoyance we use the following questions (50):

Please tell me, using this scale for every answer, to what extent the following occurs in your house as a consequence of railway noise.

vibration and rattling in the house

	score
not	10
a little	30
moderately	50
rather	70
very	90

idem for 'disturbing the conversation in the house', 'disturbing when going to sleep', 'waking up at night' and 'startle'.

For sleep disturbance the maximum of both questions concerning sleep is used.

A.5 Netherlands tramway study (1983)

MIEDEMA HME, BERG R van den. (1985), Hinder door geluid van tram- en wegverkeer. Ministerie VROM: geluidreeks GA-HR-08-04, Leidschendam.

Acoustic and annoyance data with respect to tram and road traffic were collected at 30 locations in Amsterdam, Rotterdam and The Hague. The survey was carried out at the end of June and beginning of July. Apart from obtaining dose response relations, a point of special interest was the influence of masking of tramway noise by road traffic noise on annoyance. (It is directly obvious that masking the other way around, i.e. of road traffic noise by tramway noise, is negligible).
Five types of locations were selected with a total of 798 respondents: 5 locations with curves (123), 8 with stops (149), 6 with crossings (161), 9 with free straight tracks (294) and 2 with tracks to or from a depot (71). At the selected crossings there were also curves. The straight tracks were separated from the road traffic. For each type, locations were selected with the four high/low combinations for the number of tram and car passages.

A.5.1 Sound measures

L_{Aeq} was determined for all two hour periods of week days, saturday and sunday separately. This was done by a combination of measurements for different types of tram passages with detailed schedules of the number of those type of passages per two hour period. Each combination of a tram type and track followed was distinguished as a separate type of passage. Since the measurements were made 2 to 3 m from the facade, no subtraction of reflected sound was needed.
There were 70 measurement spots for 798 respondents at 30 locations. If necessary L_{Aeq} values were determined by inter- or extrapolation from the measurement spots.
The available dataset contained L_{Aeq}(7-19), L_{Aeq}(19-23) and L_{Aeq}(23-7). From the detailed information on the number of tram passages per location, which was not reported but still available, it is clear that, except for one location, L_{Aeq}(19-22) and L_{Aeq}(22-23) could be set equal to L_{Aeq}(19-23). The exception (Harstenhoekstraat) was a location at tracks to and from a depot, with high peaks in the number of passages early in the morning, around evening rush hour and just after midnight. The number of passages from 22-23h was at most 2. No error in the L_{Aeq} values with significant consequences for L_{etm} or L_{dn} was caused by taking it to be zero. Thus, for the exception L_{Aeq}(19-22) was set equal to L_{Aeq}(19-23) + 1.2 and L_{Aeq}(22-23) was set equal to zero.
Tonal sounds as scrunching and squealing could occur at curves, crossings and, due to breaking, at stops. The questionnaire contained questions with respect to these types of sounds (23a, b), where

people could report hearing them never, seldom, sometimes, often or always. All respondents at locations where the percentage of respondents in the two latter categories exceeded 35%, were considered to be exposed to railway sound with tonal components. The exposure of other respondents was considered to be nontonal. The classification of locations is reported in table A.5.
The questionnaire also contained questions about rattling or bumping (23c), where people could report hearing this never, seldom, sometimes, often or always. All respondents at locations where the percentage of respondents in the combined two latter categories exceeded 35% were considered to be exposed to impulses. The exposure of the other respondents was considered to be non-impulsive. The classification is reported in table A.5.
The number of tram passages was included in the dataset so that the percentage of quiet minutes could directly be derived from it. Only at one location (Rijswijkseplein) the number of passages per two hour period exceeded 120 (known from unpublished information). For that location the percentage is obtained as follows. There were only three two hour periods with less than 120 passages (37, 0 and 3) so that the estimated number of relatively quiet minutes was 320, i.e. 22%.
To estimate the category for the difference between the levels at the most and least exposed facades of the houses the location descriptions and maps in Appendix 1 were studied. The classification is shown in table A.5.

Table A.5 Acoustic summary for Netherlands tramway study (1983)

overall level L_{Aeq}(24h) with time of day penalty L_{etm} with time of day penalty L_{dn}	42 - 71 dB(A) 45 - 76 dB(A) 44 - 75 dB(A)
tonality	railway sound with tonal components at all curves except Melis Stokezijde; at stops Oudedijk, Crooswijksestraat and Claes de Vrieselaan; at all crossings except Laan van N.O. Indie x Juliana van Stolberglaan and Stuyvesantplein; at no straight tracks; at depot line through Harstenhoekweg.
rise velocity	railway sound with impulses at Meppelweg and no other curve; at all stops except 1e Middellandstraat, Gouverneurlaan and Oudemansstraat; at all crossings except Schieweg x Bergselaan and Stuyvesantplein; at no straight track; at both depot lines.
pause	22 - 98 %
quiet side	a difference ≥ 15 dB(A) at all locations except 5 - 15 dB(A) for Leyweg, Geestbrugweg, Rijswijkseplein, Laan van N.O. Indie x Juliana van Stolberglaan, Johan Evertsenstr. x Witte de Withstr. x Admiraal de Ruyterweg, Boergoense Vliet, Gevers Deynootweg and < 5 dB(A) at the Meppelweg.

A.5.2 Annoyance measures

The respondents were not focused on noise when they answered the nonspecific annoyance questions. Nonspecific annoyance was determined with the following questions (18b + 19b):

I will mention some sounds. Please indicate, using this card, for each of the sounds how often you hear them when you are inside your house?

trams	upper category boundary	score
never (skip next question)	20	10
seldom (skip next question)	20	10
sometimes		
often		

I will mention the sounds which you have indicated to hear in your house. Please indicated to what extend you consider those sounds to be annoying or not annoying. Use this card for your answer.

very annoying	100	90
annoying	80	70
just annoying	60	50
just not annoying	40	30
not annoying	20	10

Taking people who say that they 'never' or 'seldom' hear the sound as not annoyed may lead to an underestimation of annoyance.

Specific annoyance was determined with the following questions (36, 37, 39 and 40):

Are you being disturbed during conversations by the sound of passing trams?

	score
often	87
sometimes	63
seldom	37
never	13

Are you being disturbed while resting, sleeping or going to sleep by the sound of passing trams?
idem

Does the sound of a tram once in a while startle you?
idem

Does your house vibrate once in a while when a tram passes?
idem

A.6 Netherlands road traffic study (1974/75)

BITTER C, KAPER JP, PINKSE WAH. (1978). Beleving geluidwerende voorzieningen in de woonsituatie langs Rijksweg 16 in Dordrecht. Ministerie VROM: ICG VL-DR-14-01, Leidschendam.
BITTER C, HOLST JHK, KANDELAAR HAC, SCHOONDERBEEK W. (1982) Beleving geluidwerende voorzieningen in de woonsituatie langs Rijksweg 10 in Amsterdam. Ministerie VROM: ICG VL-DR-14-02, Leidschendam.

This study has been carried out near two highways in the Netherlands. The primary purpose was to obtain information on the effect of acoustic insulation of dwellings. Acoustic and annoyance data were collected before and after insulation of housing units. Here only data from before the insulation are used. These were obtained in Dordrecht near the A16 in 1974 and in Amsterdam-West near the A10 in 1975. The studies at both locations were equal in all aspects which are relevant here.

A.6.1 Sound measures

Originally L_{Aeq}(24h) was calculated. Since then the calculation models have been improved, especially for situations with flat buildings as in this study, where shielding and reflections play a role. Because also some errors were discovered in the original input data, the calculations were repeated with adjusted input and the current standard calculation procedure in the Netherlands (Reken en Meetvoorschrift Verkeerslawaai, 1981: Standaardrekenmethode II). All relevant information needed to obtain for each respondent the L_{Aeq} at the most exposed facade was still available. The input corrections concerned traffic data, which now were obtained from detailed publications of the Ministry of Transportation, with traffic counts for the years 1974 and 1975 (Verkeerstellingen 1974 and Verkeerstellingen 1975). A rather detailed description of the recalculation can be found in Miedema (1988). The resulting L_{Aeq}(24h) values were 3 to 5 dB(A) higher than the original.

Since the available traffic data for the counting points closest to the research locations were not presented in sufficient detail to obtain the L_{Aeq} for different periods, the combined specification for all 18 basic counting points at highways in the Netherlands has been used. In 1975 the percentages of vehicles in the relevant periods were 78.9% for 7 - 19h, 9.9% for 19 - 22h, 2.4% for 22 - 23h and 8.8% for 23 - 7h. Thus the differences of the L_{Aeq} for the periods mentioned with L_{Aeq}(24h) are 2, -1, -2.4 and -5.8.
There are no tonal components in highway noise.
Beyond a certain distance individual passages can not be distinguished. But also close to the highway rise velocities are < 10 dB/s.
The number of passages per 24h was at that time 36000 in Dordrecht and 61000 in Amsterdam, which included 9200 lorries in Dordrecht and 5500 in Amsterdam. Thus the percentage of quiet minutes is set equal to zero.
The housing units, except a few family houses in Dordrecht, were flat apartments. Some flat buildings and all family houses were parallel to the highway, the other flats perpendicular. For all blocks, consisting of one flat or a row of attached family houses, the L_{Aeq} difference between most and least exposed side was estimated, taking into account shielding and reflection. For some respondents, who lived at the end of a (parallel) block, the difference is overestimated. Individual estimates were, however, considered too laborious.

Table A.6 Acoustic summary for the Netherlands road traffic study (1974/75)

overall level L_{Aeq}(24h)	45 - 72 dB(A)
with time of day penalty L_{etm}	49 - 77 dB(A)
with time of day penalty L_{dn}	48 - 75 dB(A)
tonality	no
rise velocity	< 10 dB/s
pause	0 %
quiet side	< 5dB(A) for respondents in blocks 1, 2, 6, 7, 18, 24, 25, 27, 29, 31, 33, 35 in Dordrecht and block 5 in Amsterdam; ≥ 15 dB(A) for blocks 3, 9 - 14, 16, 19 and 34 in Dordrecht and all blocks in Amsterdam except 5 and 9 in Amsterdam; 5 -15 for all remaining blocks.

A.6.2 Annoyance measures

At the annoyance questions respondents where focused on the noise of the highway by the introduction and previous questions. Nonspecific annoyance was determined with the following question (60a):

To what extent do you consider traffic sounds from the highway to be annoying or not annoying?

	upper category boundary	score
definitely not annoying	20	10
not annoying	20	10
just not annoying	40	30
not annoying	60	50
annoying	80	70
very annoying	100	90

Since the labels may have lead not annoyed persons to choose either of both lowest annoyance categories, these are combined into one category. As a consequence there are five effective annoyance categories.

Specific annoyance was determined as follows by questions 56a, h and 55:

Are you occasionally startled by traffic noise?

	score
never	13
seldom	37
sometimes	63
often	87

Does your house vibrate often, sometimes, seldom or never because of passing road traffic?

	score
never	13
seldom	37
sometimes	63
often	87

I am going to mention some activities. Would you please say whether you are being disturbed often, sometimes, seldom or never by traffic noise?

a conversation with someone	idem
to rest or sleep	idem

A.7 German road traffic study (1978/81)

SCHÜMER - KOHRS A, SCHÜMER R, KNALL V, KASUBEK W. (1983) Interdisziplinäre feldstudie über die besonderheiten des schienverkehrlärms gegenüber dem strassenverkehrslärm, Vol. I and II, Planningsburo Obermeyer, München.

A short general introduction and the railway part of this study are described in section A.4.

A.7.1 Noise measurements

The available dataset contained $L_{Aeq}(6\text{-}22)$ and $L_{Aeq}(22\text{-}6)$, which are based on sound measurements in free field conditions. For the road traffic dominant and mixed locations histograms with the number of motor vehicles per hour were given in Appendix A4 Band II. For those locations a presumably reasonably precise estimate of $L_{Aeq}(7\text{-}19)$, $L_{Aeq}(19\text{-}22)$ was obtained using $L_{Aeq}(6\text{-}22)$ and adding 10 times the logarithm of the ratio between traffic intensities for 6-22h and target period. Similarly $L_{Aeq}(22\text{-}23)$ and $L_{Aeq}(23\text{-}7)$ were obtained from $L_{Aeq}(22\text{-}6)$ and the proper intensity ratios. For the remaining locations we used the 'average' corrections on $L_{Aeq}(6\text{-}22)$ and $L_{Aeq}(22\text{-}6)$ to obtain the desired measures.

The rise velocity was classified as <10 dB/s.

For the locations for which the number of motor vehicle passages per hour was given, these were used to estimate the number of quiet minutes. For the other locations the number of these passages was only given for the periods 6-22 and 22-6h. Then these were used to estimate the number of quiet minutes.

Because of too much uncertainty about the proper classification, the sound level difference between most and least exposed side was considered to be missing.

Table A.7 Acoustic summary for the German road traffic study (1978/81)

overall level L_{Aeq}(24h)	43 - 71 dB(A)
with time of day penalty L_{etm}	47 - 78 dB(A)
with time of day penalty L_{dn}	46 - 76 dB(A)
tonality	no
rise velocity	< 10 dB/s
pause	0 - 89 %
quiet side	?

A.7.2 Annoyance measures

For nonspecific annoyance we use question 45, for specific annoyance question 48. Since the questions and the scoring of categories and their boundaries are similar, except the source mentioned, as questions 47 and 50 described in section A.4, we do not present them here.

A.8 Netherlands road traffic study (1983)

MIEDEMA HME, BERG R van den. (1985), Hinder door geluid van tram- en wegverkeer. Ministerie VROM: geluidreeks GA-HR-08-04, Leidschendam.

This is the same study for which the tramway noise part is described in section A.5.

A.8.1 Sound measures

The L_{Aeq} was determined for all two hour periods of week days, saturdays and sundays separately. This was done by measurements within two hour periods combined with interpolation for the periods for which no measurements were carried out. Since the microphone was 2-3 m from the facade, no corrections for reflections were applied to the measurements. For a period with measurements seven percentiles were determined for the A-weighted sound level distribution. By interpolation of each percentile, using the relative time pattern obtained from continuous measurement on a saturday, sunday, monday and tuesday until 10 a.m. and checked with other published time patterns, percentiles for periods without measurements were obtained. For each period the L_{Aeq} was derived from the seven percentiles.

This rather indirect procedure was motivated by the need of percentiles for the determination of measures sensitive to masking by road traffic, which are not considered here.

There were 70 measurement spots for 798 respondents. When necessary L_{Aeq} values for respondents were determined by inter- or extrapolation from the measurement spots. The dataset contained $L_{Aeq}(7\text{-}19)$, $L_{Aeq}(19\text{-}23)$ and $L_{Aeq}(23\text{-}7)$. From the relative L_{Aeq} pattern, derived from the continuous measurement referred to above, it was estimated that generally $L_{Aeq}(22\text{-}23)$ is about 2 dB(A) below $L_{Aeq}(19\text{-}23)$. Therefore we set $L_{Aeq}(22\text{-}23)$ equal to $L_{Aeq}(19\text{-}23) - 2$ and $L_{Aeq}(19\text{-}22)$ equal to $L_{Aeq}(19\text{-}23) + 0.5$.

There can be tonal components in city road traffic noise due to the squealing of bus breaks. There was no information available, however, to identify respondents exposed to this squealing.

At most location involved the speed limit was 50 km/h. Anyhow, rise velocities are < 10 dB/s.

The number of car passages was not registered.

The classification with respect to the difference between most and least exposed side is identical as for the tramway noise.

Table A.8 Acoustic summary for Netherlands road traffic study (1983)

overall level $L_{Aeq}(24h)$	51 - 71 dB(A)
with time of day penalty L_{etm}	55 - 76 dB(A)
with time of day penalty L_{dn}	54 - 74 dB(A)
tonality	?
rise velocity	< 10 dB/s
pause	?
quiet side	see table A.5

A.8.2 Annoyance measures

The respondents were not focused on noise at the moment of the nonspecific annoyance questions. Nonspecific annoyance was determined with questions 18d and 19d, which are the similar as 18b and 19b for trams, reported in section A.5. Only 'trams' is replaced by 'road traffic (thus cars, buses, lorries, mopeds and motors)'.

Specific annoyance questions were not asked for road traffic.

A.9 European community road traffic study (1984)

DIAMOND I, WALKER JG. (1986) CEC Joint research project 'Community reactions to aircraft noise', University of Southampton ISVR, Southampton.

DIAMOND I, WALKER JG, CRITCHLEY JB, RICHMOND GC. (1986) 'CEC Joint study of community response to aircraft noise 1984: main report', DR report 8601, University of Southampton ISVR, Southampton.

PACHIAUDI G, TANGUY Y, BRUYERE JC, FRANCOIS J, VALLET M. (1985) 'Community reactions to aircraft noise' report AER 3.2/6, Institut de Recherche des Transport CERN, Bron Cedex. (except title in French)

WALKER JG. (1986) CEC Joint research project 'Community reactions to aircraft noise: residual noise measurements in the vicinity of Glasgow Airport', memorandum 661, University of Southampton ISVR, Southampton.

This is the same study for which the aircraft noise part is described in section A.1.

A.9.1 Sound measures

Around Glasgow Airport L_{Aeq} was determined for a number of day periods. This was done by measurements per cluster plus adaptions for individual respondents based on the estimated effect of distance and obstacles. Since the microphone was placed 1 m from a facade, we subtracted 3 dB(A) from the levels in the database.

Around Schiphol-Amsterdam L_{Aeq} was determined fcr the same day periods by measurements in low exposure areas and by calculation (using the average traffic intensity over a week for that period) in high exposure areas. The standard calculation procedure in the Netherlands for situations without significant barriers or reflections (Reken en Meetvoorschrift Verkeerslawaai, 1981: Standaard methode I) has been used. The original data were without reflections.

Around Paris-Orly the L_{Aeq} was determined for the same day periods by measurements. In intervals with sufficiently low aircraft noise, the 'difference' between the total L_{Aeq} and that of the aircraft was taken as road traffic L_{Aeq}. At one location older traffic noise data had to be used because the measurement site was not representative for the road traffic noise exposure of the respondents at that location. Nothing is known to us about reflections.

From the L_{Aeq}'s available in the dataset we could calculate directly L_{Aeq}(7-19), L_{Aeq}(19-22), L_{Aeq}(22-23) and L_{Aeq}(23-7).

For locations in this study significant tonal components due to squealing of breaks are unlikely. Therefore respondents are considered to be exposed to nontonal sound.

Rise velocities are classified as < 10 dB/s.

Neither the number of car passages nor the information relevant for the estimation of the difference between most and least exposed side were registered.

Table A.9 Acoustic summary for European Community road traffic study (1984)

overall level (L_{Aeq}(24h))	39 - 72 dB(A)
with time of day penalty (L_{etm})	45 - 75 dB(A)
with time of day penalty (L_{dn})	44 - 74 dB(A)
tonality	no
rise velocity	< 10 dB/s
pause	?
quiet side	?

A.9.2 Annoyance measures

For road traffic nonspecific annoyance was determined with questions 19b and 24b in the French and British survey, and 27 and 64b in the Netherlands' survey. These questions are similar as those used for aircraft, which are reported in section A.1. Only 'aircraft' is replaced by 'traffic'.
Specific annoyance questions for road traffic were not included in the questionnaires.

A.10 Netherlands road traffic study (1984)

ERICZ WJ, NOORDAM A, SCHOONDERBEEK W.(1986). Trollificering van buslijn 9 in Arnhem. Onderzoek naar de effecten van geluidhinder. Ministerie VROM: Geluidreeks GA-HR-12-1, Leidschendam.
SCHOONDERBEEK W. (1986). Akoestisch onderzoek naar de effecten op de geluidbelasting door invoering van trolleybussen op buslijn 9 in Arnhem: Van Dorsser bv report 3880.A, Arnhem.

The purpose was to study effects on noise annoyance of the replacement of diesel buses by trolley-buses. The study was carried out in Arnhem. We used the first of the three parts of the study, with the noise and annoyance measurements before the change of bus type. At that time the traffic situation had not yet changed. The survey of this part was carried out in May.

A.10.1 Sound measures

In the study L_{Aeq}(7-19), L_{Aeq}(19-23) and L_{Aeq}(23-7) were determined by measurements and a combination of traffic counts during measurement periods and traffic counts for a week. The data already were corrected for reflections from the facade. L_{Aeq}'s were used to determine L_{etm}. Unfortunately, the basic L_{Aeq} values were not stored. However, since the differences between L_{etm} and L_{Aeq} values were reported per block of houses (and we could determine per respondent the house block), we could reconstruct the L_{Aeq} values for the three different periods. L_{Aeq}(19-22) and L_{Aeq}(22-23) were determined from L_{Aeq}(19-23) in the same way as described in section A.7, based on a time pattern for L_{Aeq} considered to be representative. Thus L_{Aeq}(22-23) was set equal to L_{Aeq}(19-23) - 2 and L_{Aeq}(19-22) equal to L_{Aeq}(19-23) + 0.5.

Squealing of bus breaks was rather frequently heard. The questionnaire contained a question with respect to this type of sound (23a), where people could report hearing it never, seldom, sometimes, often or always. However, because we can deduce only for this single study, with relatively few respondents, who are probably exposed to tonal road traffic noise, this information was not used.

At all locations involved the speed limit was 50 km/h. Anyhow, rise velocities are < 10 dB/s.

The number of passages was available in the dataset. But to determine the percentage of quiet minutes more accurately, prints from the automatic counting equipment were used. The number of passages per hour over one week is given for each of the four counting points in Appendix 1 of the acoustic report. Quiet minutes occurred only during the night period. Percentages are given in table A.10.

The category for the difference between most and least exposed sides was estimated from the maps, which were included in the report. For several blocks the calculated exposures were shown on the maps for both most and least exposed facade. Our categorization is given in table A.10.

Table A.10 Acoustic summary of Netherlands road traffic study (1984)

overall level L_{Aeq}(24h)	49 - 65 dB(A)
with time of day penalty L_{etm}	55 - 71 dB(A)
with time of day penalty L_{dn}	52 - 69 dB(A)
tonality	?
rise velocity	< 10 dB/s
pause	Brabantweg(#1): 13%; Hollandweg(#2): 18%; Hollandweg(#3): 8%; Looierstraat(#4):9%
quiet side	block 1-3, 7, 8, 10, 19, 22, 28-37: < 5dB(A); block 4-6, 9, 16: 5-15 dB(A) block 13-15,17,18,20,21,23,24-27,38-41: ≥ 15 dB(A) block 11 and 12 : ?

A.10.2 Annoyance measures

At the nonspecific annoyance question the respondents were not focused on noise. The questionnaire used was very similar to the one used in the study described in sections A.5 and A.7. The nonspecific annoyance questions (8b for the frequency of hearing, 9b for the annoyance) are almost identical and consequently treated identically:

I now will mention some kind of sounds. Please indicate, using this card, how often you hear these sounds, when you are inside your house.

road traffic in general	upper category boundary	score
never (skip next question)	20	10
seldom (skip next question)	20	10
sometimes		
often		

I mention the sounds which you have indicated to hear in your house. Please indicate to what extend you consider these sounds to be annoying or not annoying. Please use this card for your answer.

very annoying	100	90
annoying	80	70
just annoying	60	50
just not annoying	40	30
not annoying	20	10

There were no questions included with respect to specific annoyance for road traffic in general.

A.11 Netherlands stationary sources study (1980)

GROENEVELD Y, GERRETSEN E. (1984). Karakterisering en beoordeling van industrielawaai - samenvattend rapport, Ministerie VROM. ICG-rapport IL-HR-09-02, Leidschendam.

The purpose was to study the relation between sound exposure and annoyance for industrial sources and shunting yards, with special interest in the role of tonality and impulse noise. The study was carried out at 23 locations in the Netherlands. The survey was carried out in January. The division of the 597 respondents over the sources is given in table A.1.

The industrial locations were selected after a pilot study including 75 locations. In this pilot study locations were sought for different combinations of time and frequency spectra. For frequency a distinction was made between tonal and nontonal sounds. The time patterns were characterized as continuous (= no significant fluctuation), fluctuating, intermitted, irregular impulsive or long impulse trains. Based on data from a previous acoustic inventory study, locations were tentatively assigned to one of the ten possible categories, obtained by crossing tonality and impulse classes. After a first selection of 50 locations a limited telephone survey was carried out to obtain further information on the selection criteria.

A.11.1 Noise measures

Noise measurements during the operation time of the source were used to determine the L_{Aeq} during operation time. We combined this with information about the time the source was in operation. It was reported for each of the periods 7-19, 19-23 and 23-7h whether the source was in operation during the whole period or, as a second possibility, during a part of it or sometimes within it. In cases where the source was operating during part or sometimes within the period, we set precise working hours as follows. For the period 7-19h partial/sometimes was reported for the five shunting yards involved. There we assumed that the source was active during the 4 hours within this period. A location with a paper and metal industry was reported to be partial/sometimes active in the period 19-23h. There we assumed that the source was active during 2 hours in the period 19-22h. Finally, for one shipyard and again the shunting yards partial/sometimes was reported for the period 23-7h. Here we assumed activity of the source during 4 hours within that period. L_{Aeq}(7-19), L_{Aeq}(19-22), L_{Aeq}(22-23) and L_{Aeq}(23-7) were calculated using the L_{Aeq} during operation time, the reported working period plus the above mentioned additional specification.

The characterization of the exposure in the data set as tonal or nontonal was used. It was based on explicit judgements of the acoustician who also performed the sound measurements.

For respondents in the vicinity of sources which irregularly emitted impulses or produced long impulse trains the exposure is characterized as > 1000 dB/s. Within this class shunting yards are coded as a separate subclass. For all other respondents the characterization < 10 dB/s is used.

The percentage of quiet minutes per day was based on the reported operation periods of the source plus the above described additional specification. For sources described as continuous (e.g. power plant), each minute during the operation time is counted as noisy. For sources characterized as intermitted (e.g. concrete mortar mill) or impulsive (e.g. construction workplace) there is uncertainty. As a 'best guess', we counted for those sources half the minutes during operation time as noisy.

We were not able to determine the difference between most and least exposed side of the house.

The sources and their characterization are shown in the following table.

Table A.1 Acoustic summary for the Netherlands stationary study (1980). For tonality 1: no, 2: yes. For rise velocity 1: <10 dB/s, 2: shunting yards, 3: ≥1000 dB/s.

industry	operation time	L_{Aeq}(24h)	L_{etm}	L_{dn}	tonality	rise velocity	N
concrete-mortar-mill	08-0-0-0	55	58	55	2	1	16
concrete-mortar-mill	08-0-0-0	51	54	51	1	1	20
concrete-mortar-mill,	08-0-0-0	63	66	63	2	3	10
stonebreakery	08-0-0-0	55	58	55	2	3	7
	08-0-0-0	50	53	53	2	3	9
concrete industry	08-0-0-0	39	42	39	1	1	33
concrete industry	08-0-0-0	49	52	49	2	1	9
	08-0-0-0	40	43	40	1	1	8
stone masonry	08-0-0-0	50	53	50	2	1	15
	08-0-0-0	40	43	40	2	1	8
chemical industry (major)	12-3-1-8	58	68	64	1	1	7
	12-3-1-8	56	66	62	1	1	17
	12-3-1-8	52	62	58	1	1	19
chemical industry (major)	12-3-1-8	58	68	64	2	1	11
chemical industry (minor)	12-3-1-8	58	68	64	2	1	11
construction workshop	08-0-0-0	56	59	56	2	3	14
power plant	12-3-1-8	47	57	53	2	1	35
paper/metal industry	10-2-0-0	54	59	54	1	3	14
ship yard	10-3-1-4	51	59	56	2	3	7
	10-3-1-4	46	54	51	1	3	24
food industry	12-3-1-0	53	60	55	2	1	7
food industry	12-3-1-8	60	70	66	2	1	44
heavy industry	12-3-1-0	40	47	42	1	1	41
	12-3-1-0	38	45	40	1	2	26
	12-3-1-0	51	58	53	1	2	8
	12-3-1-0	47	54	49	1	2	12
shunting yard	04-3-1-4	55	65	62	1	2	17
	04-3-1-4	62	72	69	1	2	15
shunting yard	04-3-1-4	58	68	65	1	2	28
	04-3-1-4	55	65	62	1	2	5
shunting yard	04-3-1-4	57	67	64	1	2	36
shunting yard	04-3-1-4	48	58	55	1	2	24
shunting yard	04-3-1-4	53	63	60	1	2	30

A.11.2 Annoyance measures

The introduction of the questionnaire did not mention noise. Previous to the core question about nonspecific annoyance there were others dealing with industrial noise. Nonspecific annoyance was determined in a complicated way by question 17 through 21, 24a and 35, together with directions C,B,F,G. In effect it was determined whether sounds from the industry or shunting yard were heard or not. If they were heard, their relative importance was asked. For the most important sounds from the industry or shunting yard an annoyance judgement was asked. This was done for maximally three sounds. The importance of a sound was based on a ranking of the sounds by the respondent with respect to the frequency of occurrence and loudness.

With the exception of 31 respondents, all mentioned only one important type of sound or gave for the two or three sounds mentioned the same annoyance judgement. For those cases we used this annoyance response. For the other respondents the maximum was used, which was, except for 6 cases, reported for the most important sound in the sense described above.

The nonspecific annoyance question, asked for maximally the three most important sounds, was question 35:

According to you, is the sound very annoying, annoying, a little bit annoying or not annoying?

	upper category boundary	score
very annoying	100	87
annoying	75	63
a little annoying	50	37
not annoying?	25	13

The specific annoyance questions were at first asked for situations with open windows and then, for those reporting to be at least sometimes disturbed, for situations with closed windows. The following questions (73, 74 and 79 through 83b) are used here:

How often does the sound of the industry/shunting yard disturb your conversation when the windows are opened?

	upper category boundary	score
often		
sometimes		
seldom (skip next question)		10
never (skip next question)		10

And when the windows are closed, how often does the sound of the industry/ shunting yard disturb your conversation then?

often	90
sometimes	70
seldom	50
never	30

(Similar pairs of questions were used for 'resting or sleeping' and 'startled or being afraid'.)

Does the sound of the industry/shunting yard sometimes cause vibrations of your house?

yes	
no (skip next question)	13

How often does your house vibrate?

often	87
sometimes	63
seldom	37
never	13

A.12 European community impulse noise study (1982/83)

GROENEVELD Y, JONG RG de,(1985) C.E.C. Joint research project 'Effects of impulse noise on human beings' (field study), NIPG-TNO, report 85008, Leiden.

GROENEVELD Y, BERG R van den, JONG RG de. (1985) Effects of impulse noise on human beings; the field study in the Netherlands, Ministry VROM, noise research series report GA-HR-04-01, 's-Gravenhage.

HAYDEN B, WHELAN B, DILLON M.(1984) EEC Joint research project on impulsive noise. Field study report, Volume I - main report Ireland, IIRS and ESRI, Dublin.

KASTKA J, RITTERSTAEDT U. (1984) Joint research project of effects of impulse noise on human beings - German study, University of Düsseldorf - Medizinisches Institut fur Umwelthygiene, Düsseldorf.

RABRAIT JM. (1984) Etude 'Gene due aux bruits impulsifs', SEDES, Paris.

The main purpose of the study was to determine whether impulse noise is more annoying than road traffic noise. And if so, to quantify the difference. The study was carried out at 18 locations in France, Germany, Ireland and the Netherlands. The survey took place between September 1982 and April 1983. The types of impulse sources involved were: shunting yard, civil and military shooting range, shipyard, scrap yard, metal works, pile driving and a dairy. The following table gives an overview of the divisions of the 1458 respondents over locations and types of impulse sources:

country source	France (451)	Germany (321)	Ireland (346)	the Netherlands (350)
Shunting yard (150)	Athis-Mons (150)			
Shooting range (422)	Antibes (149)	Resse (130)		Bussum (48) Driebergen (40) Vught (55)
Shipyard (124)			Rushbroke (85)	
Scrap yard (226)			Ringsend (79) Blackpool (76)	H.I. Ambacht (71)
Metal working (327)		Haan (80) Solingen (74) Plettenberg (37)		Sittard (38) Lekkerkerk (49) Raamsdonksveer (49)
Building site (152)	Saint-Benis (152)			
Dairy (106)			Churchtown (106)	

Note that pile driving is temporally activity and deviates in this respect from all other sources included in this compilation. The main criterion for the selection of locations was a sufficient number of respondents for various levels of an impulse noise. In the survey two more locations were included. One, a shooting range in Ireland, is not used here because there were activities only during a short time once a month. The other, a shipyard in the Netherlands, is not used because no information about the sound levels for impulse noise is available.

We do not use the road traffic part of the study since not road traffic but residual noise was measured. Unlike the EC study reported in section A.1 and A.8 where also the term residual noise is used, we had at least for the Netherlands and Ireland indications that, apart from road traffic, coincidental sources contributed significantly to reported sound levels.

A.12.1 Noise measures

Noise measurements during operation of the source were used to determine the L_{Aeq} during operation time. Since the microphone was only 1 to 2 m from the facade and no corrections were made for reflections, we subtracted 3 dB(A). By combination with information about the number of operation hours per 24h, L_{Aeq}(24h) was calculated. We consulted separate reports for the different countries involved and the members of the research units there, in order to determine the working periods of the sources. For some locations we had information that the operation periods of the impulsive source deviated from the official working period, of which the duration was originally used to determine L_{Aeq}(24h). To determine L_{Aeq}(7-19), L_{Aeq}(19-22), L_{Aeq}(22-23) and L_{Aeq}(23-7) the operation time L_{Aeq} was combined with the information about the operation periods of the source.

For all sources involved, except the shunting yard, it was considered unlikely that significant tonal sounds occurred. For the shunting yard we had no additional information. Thus for all respondents the exposure is characterized as nontonal, except those at location with a shunting yard, where we set the tonality characterization to missing.

All sources are impulsive, so rise velocities are classified as > 1000 dB/s. Shunting yards are coded as separate subclass.

The percentage of noisy minutes per day was directly determined from the data about the operation periods of the source, as presented in table 4.11.2. Half of the minutes in the operation period were counted as noisy.

We were not able to determine the difference between the most and least exposed side of the house.

Table A.12 Acoustic summary for European Community impulse study (1982/83)

overall level L_{Aeq}(24h)	5 - 62 dB(A)
with time of day penalty L_{etm}	10 - 70 dB(A)
with time of day penalty L_{dn}	8 - 66 dB(A)
tonality	no (? for shunting yards)
rise velocity	≥ 1000 dB/s
pause	0 - 92 %
quiet side	?

A.12.2 Annoyance measures

The questionnaire had a general introduction. But arriving at the annoyance questions used here, the respondents were focused on noise by previous questions. For nonspecific annoyance we used the following questions (23,28 in the Irish version and 48, 49, 58, 59 in the Netherlands):

When you are indoors at home these days, can you ever hear (here the local noise source is mentioned)?

	upper category boundary	scores
yes (only next question skipped)		
no		
don't know		
no response (following questions skipped)	missing	

Is this always true, even when you have your windows open?

yes (I never hear it)(following qns. skipped)	25/10	13/05
no (I sometimes hear it)		
don't know (following questions skipped)	missing	
no response (following questions skipped)	missing	

Can you indicate when being indoors to what extent the noise of (here the local impulsive noise source is mentioned) is annoying?

very annoying	100	87
annoying	75	63
a little annoying	50	37
not annoying	25	13

Could you give me a more precise idea of your reaction by using this scale?

0 not at all annoying	10	05
1	20	15
2	30	25
3	40	35
4	50	45
5	60	55
6	70	65
7	80	75
8	90	85
9 extremely annoying	100	95

For the analysis the scores of both questions were averaged for each respondent. The determination of the percentages annoyed, using the four and ten category question, was done as described in section A.1.2.

For specific annoyance we used the following question (26 in the Irish, 60 in the Netherlands) in combination with the question about hearing of impulse noise:

When you are indoors at home these days, can you ever hear (here the local noise source is mentioned)?

	upper category boundary	score
yes (only next question skipped)		
no		
don't know		
no response (following questions skipped)	missing	

Is this always true, even when you have your windows open?

yes (I never hear it)(following qns. skipped)	25/10	13/05
no (I sometimes hear it)		
don't know (following questions skipped)	missing	
no response (following questions skipped)	missing	

When you are indoors at home, how often does it happen that the noise (here the local impulsive source is mentioned) startles or frightens you?

	upper category boundary	score
often		87
sometimes		63
seldom		37
never		13

Idem for 'wakes you up', 'interferes with conversation', 'stops you falling asleep', 'makes your house vibrate or shake'.

The two sleep questions were combined by taking the maximum.

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