Health Impairments, Annoyance and Learning Disorders Caused by Aircraft Noise

Synopsis of the State of Current Noise Research

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***Abstract*- The article reviews the results of scientific research on aircraft noise induced health impairments, annoyance as well as learning disorders and summarizes consequences for legislative and political decisions. The association of noise with an increased incidence of chronic arterial hypertension has been shown in large-scale epidemiological studies. Identified risks are up to 20% per 10 dB increase in day-evening-night level (above 50 dB(A)) and for nightly noise exposure within a range of 19-34% per 10 dB (above 30-35dB(A)). Identified risks regarding the use of antihypertensive drugs are partly higher. Also an increase in strokes is documented in recent epidemiological studies and understood as a consequence of hypertension. The same applies in the case of heart failure. Likewise an increase in myocardial infarctions has been confirmed in the recent studies with large populations included. Moreover, the annoyance due to aircraft noise has been significantly underestimated in the last 15 years. Compared to the EU-position paper of 2002 the sound level at a given extent of annoyance (25% HA) is at least 10 dB(A) lower. Impairments of cognitive performance in children attending schools exposed to high aircraft noise have been demonstrated in national and international studies up to the year 2014. As consequence of the present knowledge in noise effect research legal and political decisions must form the base to reduce aircraft noise exposure during the 24h-day to L_{den} = 50 and during the night to L_n = 45 dB(A).**

Keywords*- *Noise Research; Hypertension; Myocardial Infarction; Stroke; Health Impairments; Annoyance; Learning Disorders

I. INTRODUCTION

Several review articles on noise effects were published during the last decade [1-10]. Generally these prior studies are focused on only one aspect like hearing impairments, health impairments, annoyance, sleep disturbances or learning disorders.

Hearing impairment due to noise may occur in the form of damage to the inner ear starting from an equivalent continuous sound level of 80 dB(A), or at peak levels above L_{peak} =140 dB(A) [11]. In the case of air traffic, such high noise exposures do not arise in residential areas usually.

An increase in the incidence of chronic hypertension due to noise has been described in many studies beginning in 1968 and continued up to today [12, 13]. Myocardial infarctions may occur as a result of chronic hypertension. Beyond that, stress is discussed as a risk factor. The impairment of vascular reactions during (simulated) air traffic noise may constitute a link toward the genesis of arteriosclerotic lesions [14]. Hence, a positive relationship appears plausible, and the association was repeatedly documented in large scale studies with statistical significance. In addition chronic high blood pressure is also a predominant risk factor for strokes. Beyond the positive association in recent studies a causal relationship between noise exposure and increased occurrence of stroke is therefore plausible. This also applies to heart failure.

An increased incidence of depression as a result of noise has been described by several authors [6, 15-17]. A link between the occurrence of depression is plausible, if depression is recognized as “a process related with a feeling of hopelessness and helplessness” [18]. Thus high levels of aircraft noise can be seen as typical for causing a depression in people suffering from noise and in particular if they are being unable to leave their homes.

Noise annoyance is one of the best-documented noise effects. The continuous sound level at a given extent of annoyance has markedly dropped within the last years (e.g. [19]). From 1960 to 1995 a reduction of approximately 8 dB(A) was measured [20]. Up to 2011 the limit of annoyance has further dropped by an additional 8 dB(A). Noise-related annoyance is associated with sleep disorders, “negative emotional reactions”, “vegetative-hormonal regulation disorders” and with increased risks of illness [21 - 23].

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The strength of noise-induced sleep disturbances is dependent on the intensity and number of acoustic stimuli, and their structure over time, as well as on the stage of sleep of the affected person, and on the information hidden in the noise. Sufficient undisturbed sleep is a biological necessity for humans, and long-term disturbed sleep is a health hazard [6]. Night-time aircraft is therefore the most dangerous form of noise exposure.

Performance deterioration as a result of noise is familiar to everyone. It is one of the most common causes of complaints regarding the effects of noise. All mental performance and physical activities that require special mental control can be detrimentally affected by noise [24]. Accordingly, childhood learning disorders as a result of aircraft noise may be expected at schools or homes [25]. An important unresolved question regarding noise-related learning disorders in children is whether it constitutes a temporary restriction of learning abilities, which can later be recovered, or it represents permanent damage.

II. ACOUSTICS AND THE SPECIAL CHARACTER OF AIRCRAFT NOISE

A. How can noise exposure, including aircraft noise, be measured?

In order to describe noise impacts objectively and to compare them, defined acoustic parameters are required. The unit for measuring sound pressure levels is the “decibel” (dB). When directly describing two sounds, a level difference of approximately 1 dB is barely perceptible. Sounds consist of various frequency components. The unit for measuring frequencies is “Hertz” (1 Hz = 1 oscillation/s). To describe the effect on humans by means of the sound pressure level, that level must be adapted to the human auditory capacity. That is accomplished by means of a standardized frequency weighting (A-weighted). This “hearing-related” frequency weighting is represented in formulas with the indicator A, or in connection with acoustic measurement values as dB(A), where A stands for auriculum, the ear.

Usually environmental noises are not constant, but rather change over time. The most important measure for fluctuating noise over time is the equivalent continuous sound level (L_{Aeq}) (cf. [26]) or average sound level (L_m). This continuous sound level is the level of a (theoretical) continuous sound with the same acoustic energy as the same sound fluctuating over time. Accordingly, the continuous sound level is a single digit value, which exclusively describes the effect of a noise situation in the period of time to be assessed, but which cannot be heard.

The equivalent continuous sound level is, as a rule, insufficient to comprehensively describe the noise’s effect on humans. Beyond tonality, the impulsiveness of the sound and the increased sensitivity of humans during the evening hours must be taken into account. These effects are accounted for by means of standard adjustments.

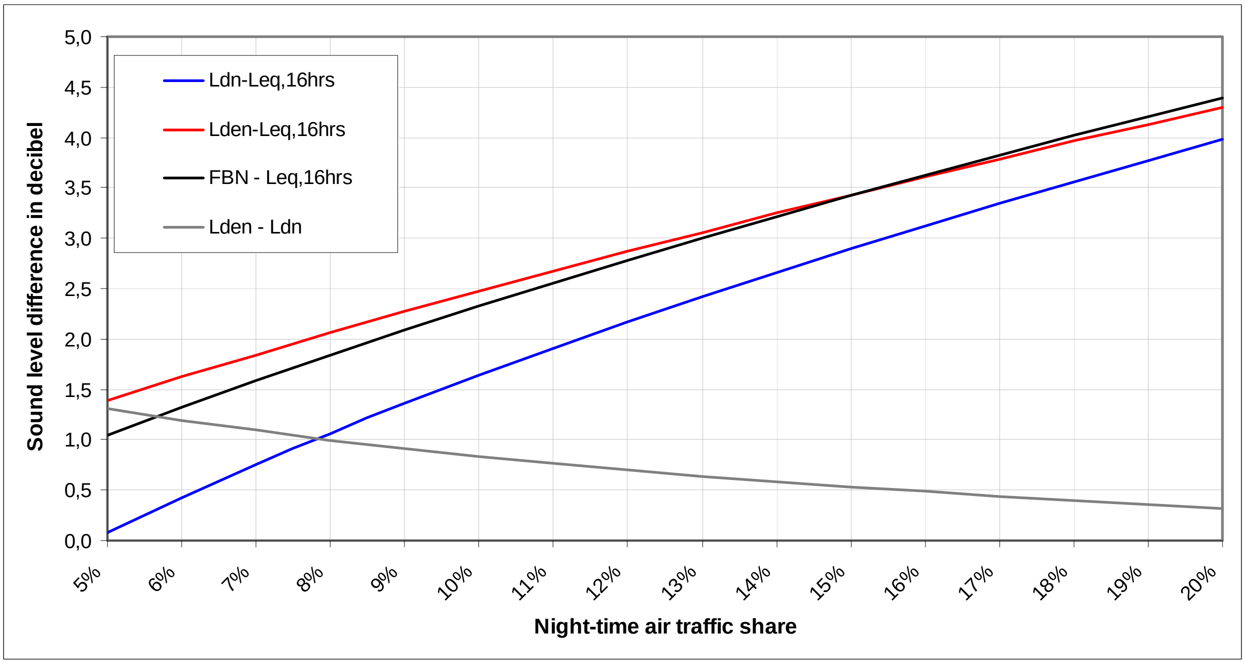

Fig. 1 Sound level differences between L_{den}, FBN, L_{dn} and $L_{Aeq,16hr}$ (y-axis), depending on the night-time air traffic shares (x-axis). Equal day-time and night-time aircraft mixes: the noise level during the 4-hr or 3-hr evening period corresponds to the noise level for the 12-hr day (without adjustments). The diagram indicates for example that the L_{den} is approximately 1dB higher than the L_{dn} with a night-time air traffic share of 8%.

Acoustic parameters for measuring and comparing air traffic noise exposure include day-night levels (L_{dn}), day-evening-night levels (L_{den}) (supplemented by L_{night}), and the noise rating level (L_r) for a 16-hr day and an 8-hr night. The matter is complicated by the fact that day-night levels (L_{dn}) and day-evening-night levels (L_{den}, FBN[1]) cannot simply be converted to

[1] FBN is a Swedish 24 h aircraft noise level

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one another, or recalculated as rating levels (L_r) for day-time and night-time hours. The required acoustical information is usually lacking, so comparing the acoustic parameters is possible only by means of estimates. Such estimates can be undertaken for example on the basis of night-time air traffic share estimates (see Fig. 1) and used in section 4.

The statement of continuous sound levels (with adjustments), lacks information about the structure of the sound over time. This could be a problem for such a strongly intermittent noise as it is aircraft noise, particularly for the night time (cf. section 4).

Aircraft noise is generally calculated with acceptable approximations to the measured values such as the integrated noise model, or the German Aircraft Noise Protection Procedure [27]. The calculation errors for continuous sound levels in the vicinity of airports are in general no greater than the errors occurring in measurement procedures.

B. Protection against aircraft noise

Road and rail traffic protection often consists of noise barriers, built between the noise sources and the recipients. Air traffic protection by shielding devices is usually not possible, since aircraft noise comes from above and contains a high proportion of low frequency sound which is poorly damped by walls. Noise-reducing measures on aircrafts in the past have been overcompensated by the increase of aircraft movements and the use of bigger aircraft (cf. e.g. [28]). Changes in traffic procedures simply redistribute aircraft noise. Noise-reducing flight procedures like continuous descent arrivals or steeper landing approaches can be applied only to a limited extent, due to flight capacity restrictions. The use of super-insulating noise protection windows in buildings and usage of ear protectors may be helpful. However, these options create considerable discomfort for many people. If windows are kept closed, ventilation units are required to avoid excessive CO_2 concentrations [29]. The installation of decentralized air supply devices is only appropriate if controlled exhaust ventilation is performed as part of a ventilation planning system, and if thermal comfort criteria are taken into account in the installation process (cf. e.g. [30]).

C. The effect of aircraft noise compared with other traffic related noise sources

Despite equal sound levels, there are considerable differences with regard to the effect of various traffic noise sources. This has been shown by comparing annoyance or sleep disturbance caused by aircraft noise with the annoyance or sleep disturbance caused by road traffic and rail noise. On basis of the same sound level, aircraft noise yields the highest level of annoyance or sleep disturbance, rail traffic noise the lowest, while road traffic noise is in between. Moreover, with regard to air traffic noise recent investigations have shown higher annoyance or sleep disturbance levels than those shown in older investigations [31]. The following Fig. 2 and Fig. 3 show the exposure-response relationships of the European Commission (EU curves) [32] and the Night Noise Guidelines of the World Health Organisation (WHO) [6].

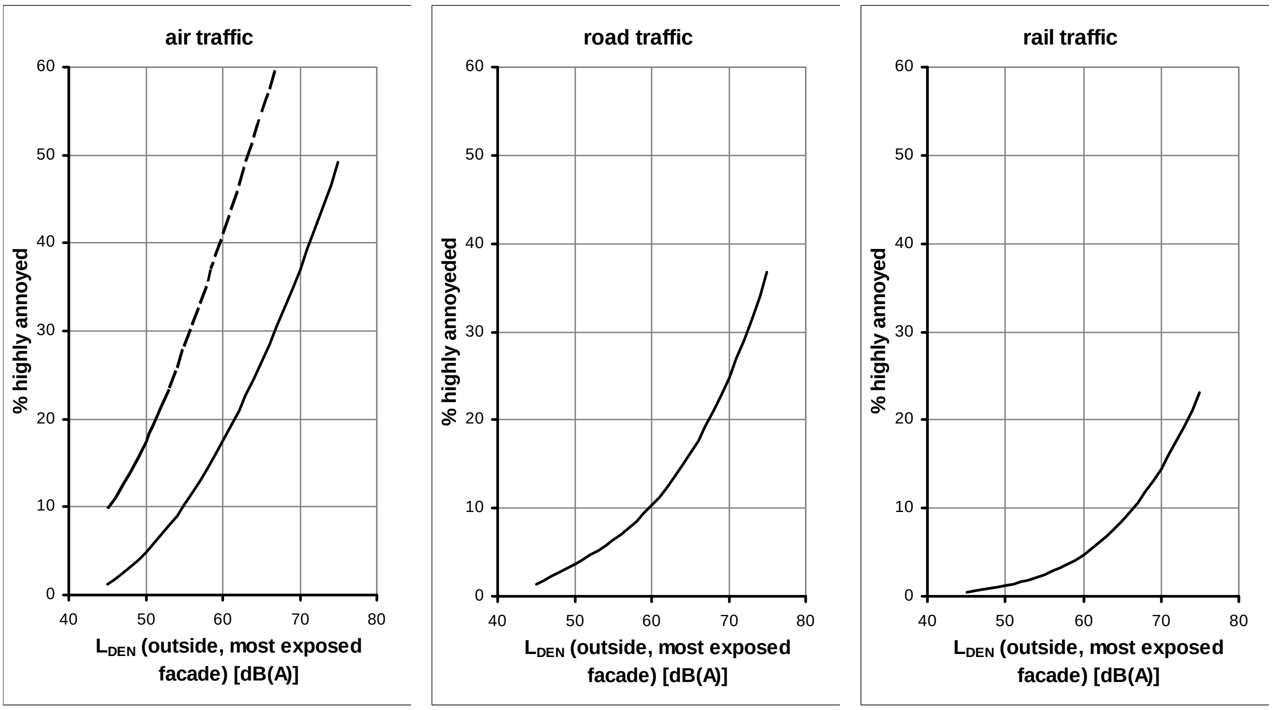

Fig. 2 Annoyance: The exposure-response relationships for highly annoyed persons (in %), with reference to day-evening-night levels (L_{den}), for the façade most highly exposed to aircraft noise (left panel), road traffic (middle panel) and rail traffic (right panel) (from [32]). For air traffic, an exposure-response relationship has also been added, shown by a dotted line, which only takes the latest studies into account, i.e. those published between 1996 and 2006 (from [31])

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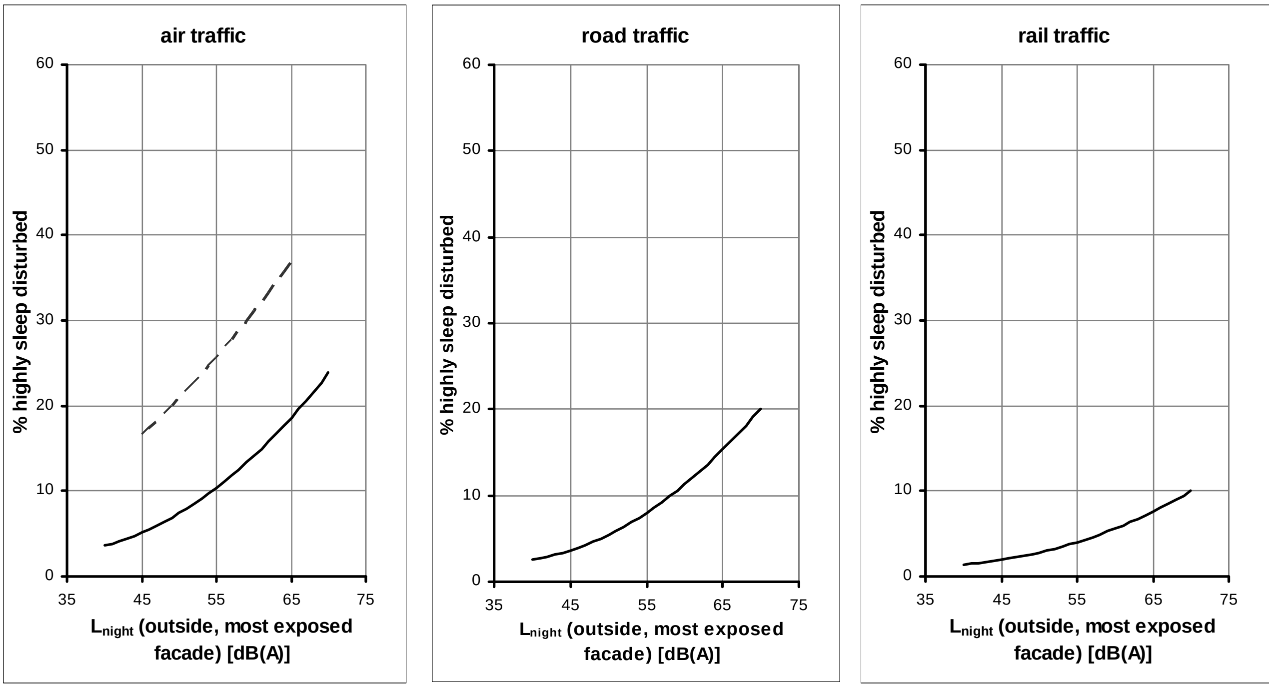

Fig. 3 Sleep disturbance: The exposure-response relationships for self-reported highly sleep-disturbed persons (in %), with reference to day-evening-night levels (L_{den}), for the façade most highly exposed to aircraft noise (left panel), road traffic (middle panel) and rail traffic (right panel) according to WHO [6]). For air traffic, an exposure-response relationship has also been added, shown by a dotted line, which only takes the latest studies into account, i.e. those published between 1996 and 2006 (from [31])

The exposure-response relationships depicted in Figs. 2 and 3 (solid lines) show that aircraft noise cannot be equated with road noise – or rail noise – in regard to noise effects.

III. SYSTEMATIC EVALUATIONS OF STUDIES

A. General considerations

Noise effects on annoyance, health and cognitive performance must be evaluated by assessing the results of epidemiological studies of the population. Experimental investigations are taken into account particularly in regard to pathophysiological mechanisms. The direct transformation of laboratory experimental results into practice is not possible because many conditions, contributing to noise effects in real life, cannot be simulated in the laboratory and health impairments may only emerge after years of exposure.

Statistical results from epidemiological studies are expressed as relative risk (RR) or odds ratio (OR). A relative risk with a value greater than 1, indicates a positive association between the examined risk factor, for example noise exposure, and a health endpoint. A statistically significantly increased risk exists, when the confidence interval (95% CI) of the RR does not enclose the value 1. By means of advanced statistical techniques only the OR can be calculated. OR and RR are similar, when the probability to fall ill is low. This is mostly valid for environmental risk factors.

Investigations exploring the effects of civilian aircraft noise on humans published between 2000 and 2014 were assessed. Searches were conducted in the databases of German Institute of Medical Documentation and Information (DIMDI) and PubMed, using the keywords "annoyance", "cardiovascular disease", "hypertension", "high blood pressure", "myocardial infarction", "stroke", "depression", "cognitive performance", and "reading ability" each in combination with "noise", in both German and English, and were supplemented by the literature listed in references of relevant articles and by the literature of the authors. We focused on epidemiological studies, but also used other investigations in the case that they represent basic research or may contribute to understand epidemiological findings. Relevant articles that were published while the overview work originated were additionally included. Excluded were studies with the terms "occupational", "work" and "tinnitus". In a further step, studies were excluded which evidently had no relevance to the issues at hand, or which, due to their design (information value), or size (avoidance of random errors) were not considered useful. Care was take to include all investigations with negative results.

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B. Hypertension

Pathophysiologically, noise-induced hypertension is attributed to disturbance of the resting process. If the capacity for coping is exhausted, a permanent increase in blood pressure results. Hypertension-related disease as a result of chronic noise stress often occurs only after five to 15 years of exposure [12, 33]. Chronic arterial hypertension affects a large part of the population, and is an important risk factor for heart attacks and strokes [34]. Since arterial hypertension is a mass endemic disorder, even an increase or decrease by a few percentage points is of major practical significance.

In 2001, from an examination of aircraft noise exposure to 2959 adults (response rate: >70%), Rosenlund found a significant relation (OR 1.6 95% CI 1.0-2.5) between increased hypertension and the Swedish day-evening-night level (FBN) over 55 dB(A), and maximum levels over 72 dB(A) around Stockholm's Arlanda Airport [35].

A Swedish investigation by Öhrström et al. showed a close association between noise level, hypertension and the increased administration of blood-pressure reducing medications [36]. A random sample of 1953 test persons aged 18 to 75 with a response rate of 71% was examined. All test persons were exposed to a traffic-induced continuous sound level (road, rail, aircraft) of at least 45 dB(A) over the course of 24 hours. Aircraft noise exposure ($L_{eq,24hr}$ = 45-70dB(A)) was established with address precision by means of GIS technology, and compared with surveyed medicinal endpoints. For men, the results yielded uniformly increased exposure-response diagnoses, both for hypertension and for anti-hypertension medication intake. Among the hypertension diagnoses, the first significant level class (upcoming from the lowest class) was ascertained at $L_{eq,24hr}$ = 60-70 dB(A) (OR 4.0 95% CI 1.3 -13); for anti-hypertension medications, it was at $L_{eq,24hr}$ = 55-60 dB(A) (OR 2.7 95% CI 1.1 – 6.6). It should be noted that the upper level classes contain few cases in this partial assessment.

Increased administration of medications associated with aircraft noise exposure, was also found by a Dutch investigation with more than 11,000 participants (response rate: 39%). In this study, the exposure was established only approximately on the basis of postal codes [37]. The clearest increase in use involved the day-evening-night level, which may, in part, be due to the fact that night-time flight operations are legally restricted in Amsterdam.

The most extensive study on the administration of medications was carried out in the areas surrounding the Cologne-Bonn Airport. Here, health insurance data of 809,379 insured individuals exposed to both aircraft and road traffic noise was collected address-precise, using GIS technology [38]. The study yielded significant relationships between the intensity of aircraft noise and the amount of blood pressure reducing medications prescribed per patient. Medication prescriptions correlated most significantly with night-time air traffic between 3 AM and 5 AM, the time period when the greatest night-time air traffic noise exposure occurs at that airport. Blood pressure reducing medications prescribed for women during this time window increased significantly, by 29%, even at an aircraft noise induced continuous sound level of between 40 and 43 dB(A), and by 48% in the level range of between 48 and 61 dB(A). For men, the increase in prescriptions was 12% at a continuous sound level of 40 to 43 dB(A), and 32% at 48 to 61 dB(A) [39].

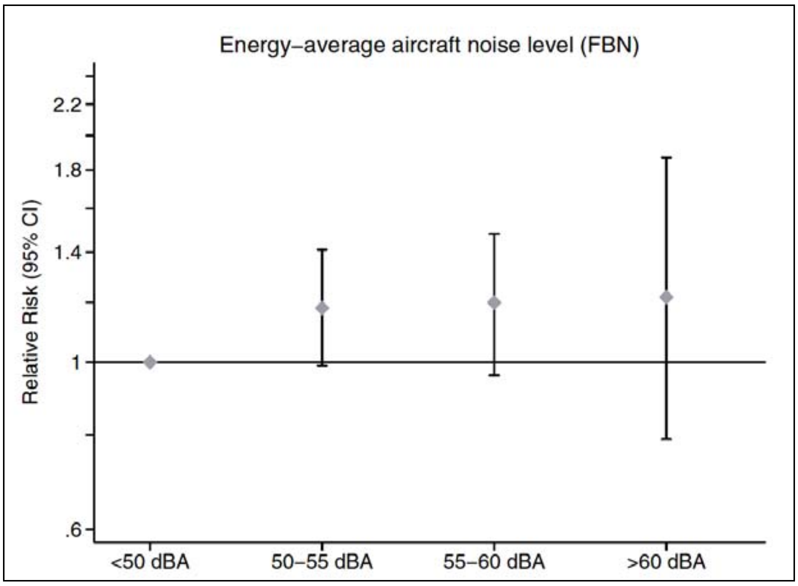

Fig. 4 Relative Risks of hypertension for men in Stockholm in relation to aircraft noise (FBN). Adjusted for age and BMI. The error bars denote 95% CIs for the categorical analysis [41]

With respect to the early stages of hypertension, time-series study in the area surrounding Frankfurt Airport showed that even in the physiological blood pressure range, a relationship exists between aircraft noise and early-morning blood pressure [40]. Two groups were followed over a period of three months. They were exposed to night-time outdoor aircraft noise of 50

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dB(A): the "Western Group" for 75% of the time, and the "Eastern Group" for 25% of the time. The evaluation of a total of 8266 blood pressure measurements from 53 individuals yielded a statistically significant higher blood pressure level of 10/8 mm Hg above that of the Eastern Group.

Eriksson et al. investigated 2037 men in Sweden aged 40 to 60 over a period of ten years, with respect to cases of hypertension (incidence) [41]. The hypertension findings were ascertained by means of repeated physicians' examinations, including blood pressure measurements, and supplemented by questioning on treatment for cardiovascular complaints and regarding risk factors. Aircraft noise exposure of above FBN = 50 dB(A) was associated with a significant increase in hypertension risk of 19% (RR 1.19 95%, CI 1.11-1.50), cf. Fig. 4.

The particular significance of night-time noise for the development of hypertension can be seen from the HYENA study [42]. Here, 4861 adults between the ages of 45 and 70 were investigated in the areas surrounding six European airports. Continuous sound levels were established address-precise, with a precision of 1 dB for day-time and night-time. Blood pressure levels were ascertained by means of repeated measurements, and supplemented by questioning regarding cardiovascular treatment.

Hypertension prevalence corrected for age and sex was between 49% and 57% in the participating countries. With a night-time increase of the continuous sound level by 10 dB, the chance of illness increased by a significant 14%. The first significant level class was in the level range of 40 to 44 dB(A). For day-time continuous sound levels, the chance of illness also grew. However, this rise was not significant. The essential results are shown in Fig. 5.

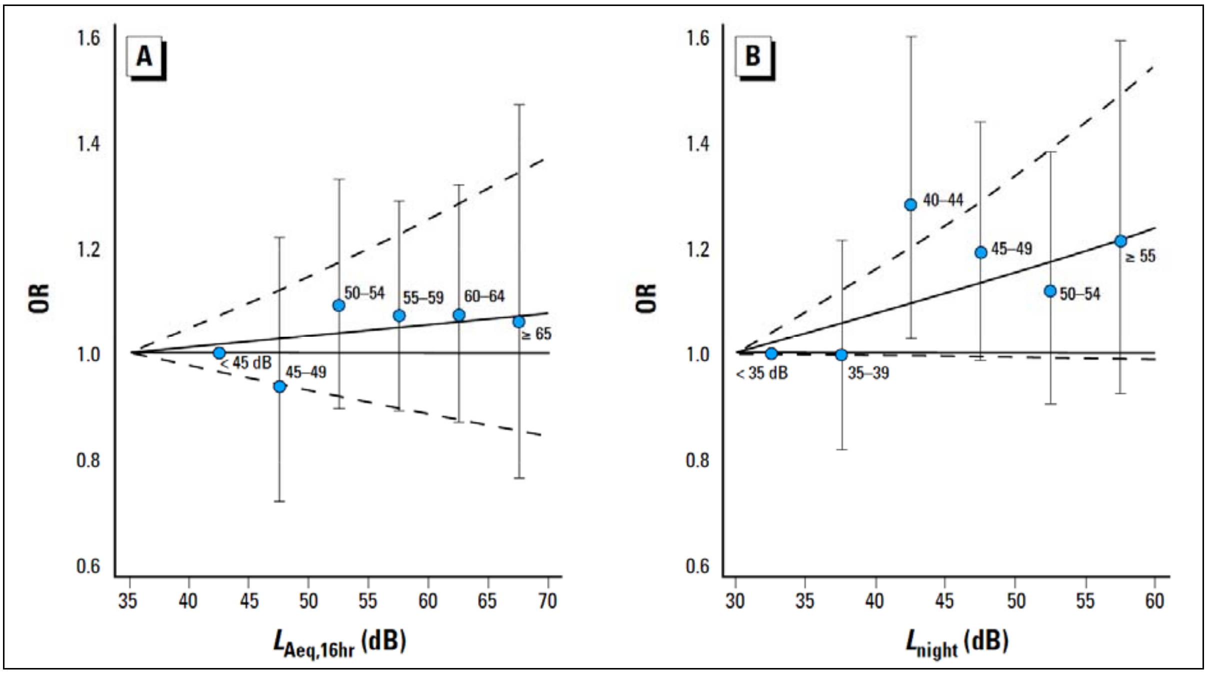

Fig. 5 Odds Ratios of hypertension in relation to aircraft noise (5-dB categories). $L_{Aeq,16hr}$ (A) and L_{night} (B) separately included in the model.Adjusted for country, age, sex, BMI, alcohol intake, education, and exercise. The error bars denote 95% CIs for the categorical (5-dB) analysis. The unbroken and broken curves show the ORs and corresponding 95% CIs for the continuous analysis [42].

An Italian study, working with a small study group, found no statistically significant association between address-precise 24 hour aircraft noise exposure (> 75 dB(A) vs. < 65 dB(A)), and hypertension (RR 0.72, 95% CI 0.36-1.45) [43]. A total of 578 adults aged 45 to 70 years, who had lived in the study area for at least five years were examined. The response rate was moderate and reached 50%. The assessment methodology (adjusted regression models) was not clear, and with the exception of road traffic (indirect), no control variables were used or reported.

In another Swedish study, it was not possible to confirm an increased hypertension risk for an overall random sample by means of address-precise aircraft noise exposure [22]. In this study, hypertension incidence rates of 4721 adults (35-56 years baseline), who lived in the greater Stockholm area (8- to 10-year follow-up) were examined. The incidence risk in the level class $L_{den} \geq 50$ dB was 1.02 (95% CI: 0.90 -1.15). However, half of the participants in this study had family histories of diabetes, which may have impaired the generalizability of the results. The assessment of individuals who did not smoke during blood pressure measurements yielded a significant increase in risk for men at a day-evening-night level of 50 dB(A) for L_{den} (RR 1.21 [95% CI 1.05–1.39] per 5 dB), and a hypertension risk level for men with aircraft noise exposure of ≥ 50 dB(A) vs. < 50 dB(A)(RR 1.25 1.04–1.51). Both women and men who stated that they suffered from aircraft noise annoyance displayed significantly higher rates of hypertension risk (RR1.42 95% CI 1.11–1.82).

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Greiser et al. evaluated the concluding diagnoses of persons discharged from hospital [44]. This involved 500,000 people 40 years and older living in the vicinity of the Cologne-Bonn Airport, and insured by the German health funds, based on the documents available from those funds. Individual noise exposure was established on the basis of residential addresses, and assessed separately according to various time windows. Particular emphasis was placed on the night-time hours, because the Cologne-Bonn Airport has an unusually high share of night-time flights. The investigation yielded significant associations between exposure and response, starting at an $L_{eq,3\text{-}5hr}$ of 39 dB(A), meaning that increased noise correlated with increased cardiovascular illness [44] .

The relationship between aircraft noise and road traffic noise exposure on the one hand, and medically prescribed medications (anti-hypertension medicines, antacids, anxiety reducing medications, sleeping pills, anti-depressants, and asthma medicine) on the other hand were investigated by Floud et al. in the vicinities of six European airports [45]. This involved the assessment of data collected in the HYENA study. In Great Britain, an increase in aircraft noise exposure by 10 dB during the day-time hours, significantly increased the risk (OR 1.35 95% CI: 1.13 to 1.60); during night-time hours, the value was 1.34 (95% CI: 1.14 -1.57) in Great Britain and 1.19 in the Netherlands (95% CI: 1.02 – 1.38)). In Italy, a significant protective effect was ascertained for the day-time hours, while in the other countries, no increased risk could be statistically confirmed. Significantly higher risks for the use of anti-hypertension and anti-anxiety medications were shown for people who felt annoyed by aircraft noise (day-time and night-time).

In summary, a causal relation between exposure to noise and elevation blood pressure appears to be scientifically confirmed.

TABLE 1 SELECTION OF INTERNATIONAL AIRCRAFT NOISE STUDIES ON HIGH BLOOD PRESSURE (HYPERTENSION) AND CARDIOVASCULAR MEDICATION/DIAGNOSES

No.	First author (Study name)	Year pub-lished	Study design	Persons	Exposure, (technique; PNF %)	Terminal point, data collection	Stratification and/or control variables	Results (selected terminal points)
1	Rosenlund, M.	2001	Cross-sectional study	2,959 adults (f, m) age 19-80 years	Aircraft noise (aircraft noise contours, 4-7%)	Questioned hypertension diagnoses	Age, sex, smoking, education, physical activity, fruit consumption, type of home	Hypertension (resp.-rate > 70%) OR 1.3 (0.8-2.2) for trend per 5 dB above 50dB(A) FBN; OR 1.6 (1.0-2.5) for FBN >55dB(A) vs. FBN < 55dB(A)
2	Franssen E.A.M	2004	Cross-sectional study	11,812 adults (f, m) age >18 years	Aircraft noise (postal codes, 8%)	Medication use (cardio-vascular endpoints)	Age, sex, smoking, BMI, education, family status, occupational noise	CV-drugs (resp.-rate 39%) trend per 10 dB L_{den} above 50 dB(A) OR 1.30 (1.06-1.6) 1st signif. level class L_{den} =50-55dB(A)
3	Öhrström, E. (LERUM Studie)	2005	Cross-sectional study	1,953 adults (f, m) age 18-75 years	Road, rail, aircraft noise (GIS technique, 4–7%)	Questioned medication use and hypertension diagnoses	Age, sex, smoking, BMI, education, family status, occupational noise	hypertension for men (resp.-rate 71%) OR 1.1 at 50-55 dB(A) to 1st signif. level class OR 4.0 (1.3-13) 60-70 dB(A) ($L_{eq,24h}$) Antihypertensive drugs (resp.-rate 71%), OR 1.6 at 50-55 dB(A) to OR 5.3 (1.5-19) at 60-70 dB(A) ($L_{eq,24h}$) 1st signif. level class 55-60 dB(A)
4	Greiser, E. (Cologne-Bonn Airport Study)	2006	Cross-sectional study	809,379 insured persons, all ages (f, m)	Night-time aircraft noise (GIS technique, 15-20%)	Medication prescription (cardio-vascular drugs & other pharmaceuticals)	Age, sex, prevalence of social welfare, density of nursing homes for elderly, interaction of aircraft noise & age, night-time road and rail traffic noise	Antihypertensive drugs (night-time 3-5 AM) men OR 1.117 (1.029–1.212) at 40-43 dB(A); trend per 1dB OR 1.020 (1.014–1.026) Woman OR 1.297 (1.206–1.395) at 40-43 dB(A); trend per 1dB OR 1.049 (1.042–1.056) (highest quartile of social welfare)
5	Aydin, Y.	2007	Time-series study (3 months)	53 adults (f, m) age 14-76 years	Aircraft noise (Aircraft noise changes from day to day, 12%)	8,266 measurements of blood pressure, heart frequency and perception of aircraft noise	Age, sex, BMI, smoking, pharmaceuticals, window position at night (parallelized groups)	Mean RR in "Western Group" ($L_{eq,16h}$ = 50 dB(A) ¾ of time) 10/8 mmHg, significantly higher than in "Eastern Group" (50 dB(A) ¼ of time) The Western Group showed a diminished relaxation capacity
6	Eriksson, C.	2007	Cohort study (follow-up study)	2,037 men age 35-56 years	Aircraft noise (GIS technique, 4–7%)	Medical hypertension diagnoses using blood pressure	Age, smoking, BMI, physical inactivity, HL, SES, family histories (diabetes), reduced glucose tolerance	Hypertension incidence for men (Response-Rate ~69%) Trend for 5 dB RR 1.1 (1.01-1.2) above FBN 50 dB(A) RR 1.2 (1.03-1.4) for FBN ≥

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						measurements und anamnesis		50dB(A) vs. FBN <50 dB(A)
7	Jarup, L. (HYENA study)	2008	Cross-sectional study	4,861 adults (f, m) age 45-70 years	Aircraft noise & road traffic noise (GIS technique, 4–5% on average) separate for day-time and night-time	Hypertension diagnoses using blood pressure measurements as well as medical treatments	Country, age, sex, BMI, alcohol intake, physical activity, education	Hypertension (resp. rate ~40%) night-time trend for 10 dB OR 1.14 (1.01-1.29) above 35 dB(A); 1st signif. level class 40-44 dB(A) trend for 16hr-day OR 0.928 (0.829–1.038)
8	Ancona C. (Campino Airport study)	2009	Cross-sectional study	478 adults (f, m) age 45 -70 years	Aircraft noise (GIS technique)	Hypertension diagnoses using blood pressure measurements	road traffic noise (indirect)	Hypertension (group comparison) $L_{eq,24h}$ <65; 65 – 74; >74 dB RR 0.72 (0.36 – 1.45) blood pressure (extreme group comparison) increased blood pressure in evening, not in morning for $L_{eq,24h}$ >74 dB
9	Greiser E. (Köln-Bonn Hospital Study)	2010	Case-control study	~550,000 insured persons (f, m) age > 40 years	Night-time aircraft noise (GIS technique, 15-20%)	Cardio-vascular diseases (hospital release diagnoses)	Age, sex, prevalence of social welfare cases, road traffic noise, rail traffic noise	Results only in graphic form. Increasing cardio-vascular disease with night-time continuous sound level (11 PM-1 AM) for women and men above 40 dB(A)
10	Eriksson C. (Stockholm County study)	2010	Kohorte (follow up)	4,721 adults (f, m) age 35-56 years baseline	Aircraft noise (GIS technique, 4–7%)	Hypertension diagnoses using blood pressure measurements	Age, sex, SES, smoking, BMI	Hypertension incidence (men) (response rate ~72%) Trend for 5 dB RR 1.21(1.05–1.39) above L_{den} 50 dB(A) RR 1.25(1.04–1.51) for L_{den} ≥ 50dB(A) vs. L_{den} < 50 dB(A) (for persons who did not smoke during blood pressure measurements)
11	Floud (HYENA study)	2011	Cross-sectional study	4,641 adults (f, m) age 45-70 years	Aircraft noise (& street traffic noise) (GIS, 4-5% on average) separate for day-time and night-time	Medication prescriptions (cardio-vascular drugs & other pharmaceuticals)	Age, sex, BMI, Alcohol intake, physical activity, education	Antihypertensive drugs night-time risk increase per 10 dB OR 1.34 (1.14 - 1.57) in UK, OR 1.19 (1.02 - 1.38) in Netherlands, each above L_{night} 30 dB(A). Risk increase 16hr-day for 10 dB OR 1.35 (1.13 to 1.60) in UK, risk decrease per 10 dB in Italy OR 0.82 (0.71 to 0.96) above $L_{eq,16h}$ 35 dB(A)

C. Myocardial Infarction

In most western countries, the incidence of cardiac infarction and the related mortality rate have been reduced significantly over the past ten to 20 years. This reduction has been due to the interaction of a number of different factors, such as improved health consciousness, the reduction in cigarette smoking among men over 50, who are the most strongly impacted group, changed eating habits, increased exercise, and improved medical care. However, for example in Germany, more than 50,000 new heart attacks per year still occur [46]. Cardiac infarction is therefore still a mass endemic disease, the avoidance of which justifies all efforts. In contrast to the risk factors which can be influenced individually, the effect factors, such as transport noise and particulate matter, cannot be controlled by the individual, and are of increasing importance.

Until only a few years ago, the existence of a causal relationship with noise was uncertain. In 2005, the German Federal Environment Agency (UBA) compiled all available studies and assessed the relationship between increased occurrence of cardiac infarction on the one hand and noise on the other hand as probable, but not proven. In 2010, this assessment was changed, and the relationship was classified as certain [47]. The changed assessment was primarily based on a large-scale study in the vicinity of the Cologne-Bonn Airport, funded by the UBA [16, 17].

In that study the data of more than 500,000 people insured by the statutory health insurance were analyzed. The individual aircraft noise exposure was compared with the incidence of cardiovascular diseases. The investigation showed a statistically significant increase in the incidence of cardiac infarction. A comparison between the extent of noise exposure and the increase in the incidence was shown to constitute an "exposure-response relationship" (i.e. the more noise, the more heart attacks). There was a particularly clear relationship with the extent of night-time aircraft noise. The data was further analysed by Greiser, and an age dependence of the noise effect was found, which to our knowledge had not been described before [48].

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The main point of criticism of Cologne-Bonn investigation is the lack of information about individual risk factors. If individual risk factors change in parallel with aircraft noise exposure, the causal relationship could be called into question. For example, this limitation cannot be excluded for the known risk factor of cigarette smoking.

In another major study, the Swiss register of cause of death of 4.6 million people, a figure equal to the entire population of Switzerland above the age of 30, was tracked over a period of five years [33]. During the examination period, 15,523 deaths from cardiac infarction occurred. The incidence of cardiac infarction as the cause of death was associated with individual exposure to noise. An increase in aircraft noise levels was accompanied by an increase in the incidence of cardiac infarction as the cause of death. A comparison of persons with residential noise exposure of up to 45 dB(A) with those exposed to noise exposure levels of 60 dB(A) or more, showed an increase of 30%. Both values were not significant. However, for people who had lived at the same place for 15 years or more, the increase was statistically significant, and amounted to 50%. The authors assume a causal link, because a clear exposure-response relationship could be derived from the findings.

It should be noted that such studies on mortality are to a limited extent comparable with studies on the incidence of illness. The increase described in myocardial infarctions in contrast to strokes could be connected with the fact that the rate of death from acute cardiac infarction is very high. When cases of mortality prior to delivery to the hospital are included the rate of death is approximately 30%.

Another major study tracked a total of 3.6 million London residents living in the vicinity of the large Heathrow Airport with respect to illness and deaths caused by cardiac infarction, strokes, and cardiovascular disease [49]. In the study, the area was divided into 12,110 segments, each with approximately 300 inhabitants. All cases of hospitalization with the diagnoses of cardiac infarction, stroke or cardiovascular illness were recorded.

During the period of investigation, a total of 64,448 cardiac infarctions, 16,983 strokes, and 48,347 hospitalizations for cardiovascular illness occurred. The incidence of these diagnoses in the particular geographical segments was compared with the day-and-night noise level, which were available for a 10 x 10 m grid. An increase in incidence of all three diagnoses was shown to correlate in a linear form with the increase in aircraft noise.

The number of deaths from cardiac infarction was 22,613, and from strokes 9,803. Both for the mortalities as for the cases of disease, this study found a significant correlation with the amount of aircraft noise.

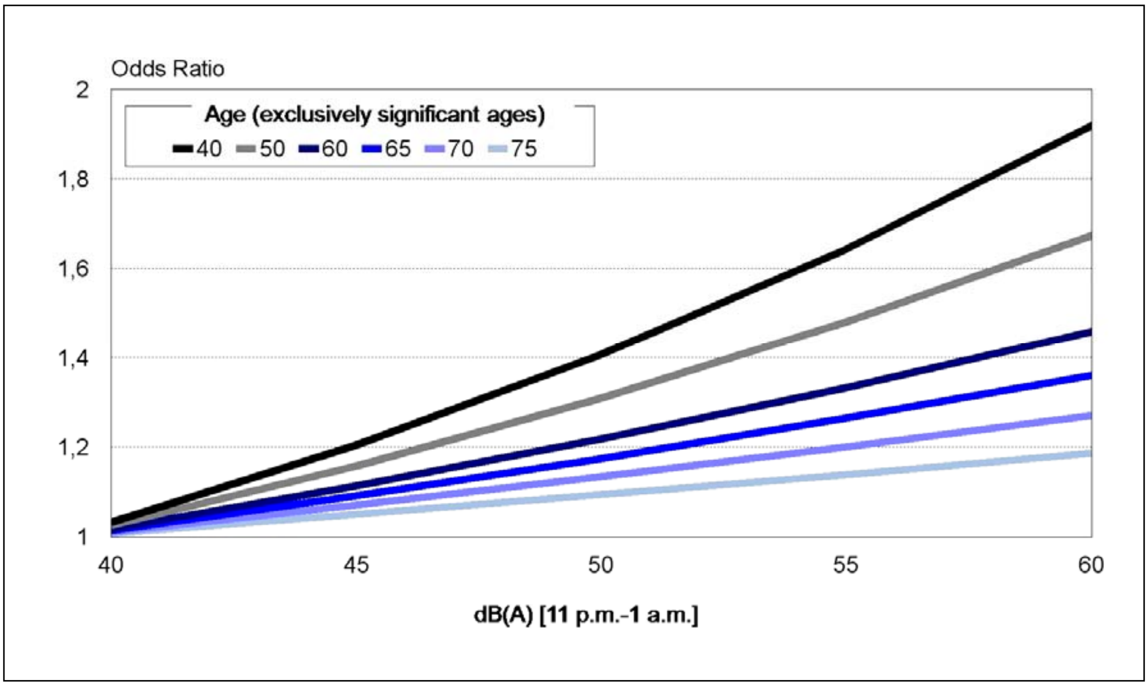

Fig. 6 The effect of night-time aircraft noise (11 PM-1 AM) and the risk of cardiovascular disease (MI, heart failure, CHD, stroke) among men and women (total population) [48]. An age dependency of the effect is demonstrated.

The authors also investigated the risk factors that might have had an effect independent of aircraft noise, and which might be unevenly distributed in terms of distance from the airport. This included ethnic affiliation, which, in England, correlates with the incidence of infarction. Smoking habits were indirectly incorporated by including cases of lung cancer as a surrogate parameter into the calculations. Taking these additionally recorded effect factors into account, the correlation between noise and incidence of illness/death quantitatively was reduced; nonetheless, these correlations remained statistically significant and dose-dependent. The comparison of night-time and day-time noise revealed no differences. However, the two parameters were so closely correlated with one another in the present case that no differentiation could be expected.

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In 2013, a major American study on the health effects of aircraft noise was published [50]. The authors noted that this was the first major American study on the issue within the last 30 years. It covered more than 6 million people (6,027,363) living in the vicinities of 89 airports. All were patients 65 years or older insured in Medicare (the U.S. health insurance program for the elderly). The question being examined was whether there was a relationship between exposure to aircraft noise and the incidence of hospitalization due to cardiovascular illness. The most significant and most frequent particular diagnoses were cardiac insufficiency, cardiac infarction and strokes. In addition, hospitalizations due to cardiac arrhythmia and peripheral vascular disease were recorded. There was a statistically significant increase in cardiovascular disease of 3.5% for every increase in the noise level of 10 dB L_{dn}.

With this study, the correlation between aircraft noise exposure and cardiovascular disease was again confirmed on the basis of a very large group of patients. The extent of the increase was however not very great. By comparison, the latest overview of all available studies given by Basner et al. shows a value of 7-17% increase per 10 dB (L_{dn}) for aircraft noise induced cardiovascular disease [8]. However, if we take into account the age progression of noise effects described by Greiser, the values in the American study do not contradict his findings (see Fig. 6). For 75-year-olds the increase was less than 10%, while for younger individuals it was up to 40% per 10 dB (night-time, 11 PM-1 AM). Greiser attributes the reduction caused by age to the increase in hearing disabilities among the elderly.

On the other hand, in the US study, the assessment of noise exposure with the aid of postal codes records individual exposure inadequately, so that an underestimation of the influence of noise is possible. Altogether, taking the major new studies into account (including Floud [51]) the UBA and WHO assessments regarding the certainty of the relationship between aircraft noise exposure and the incidence of cardiac infarction are confirmed.

An important question in practice is the incidence of relapse after suffering of a cardiac infarction. Whether there is a relationship to noise exposure in this respect is currently being investigated by the Recurrence and Noise study (see section 3.9).

D. Heart failure

Cardiac insufficiency is one of the most common causes of death and illness. Morbidity in Germany (stationary hospitalizations) increased from 275 to 465 per100 000 during the period 1995 to 2011 [46]. An increased incidence of cardiac insufficiency is the inevitable result of increased chronic high blood pressure. The relationship between noise and high blood pressure as well as heart failure is therefore probable.

In most studies, cardiac insufficiency is included under the heading of cardiovascular disease. There are very few studies in which myocardial insufficiency is examined as a separate diagnosis. In the study of Greiser, this was done and he found an increase among men starting even at an $L_{eq,24h}$ of 35 dB(A), and amounting to approx. 3% per dB(A), with a significant increase in the night-time time window [16].

E. Stroke

Strokes are the most frequent cause of people needing medical care. There are more than 150,000 new cases in Germany each year [52]. After heart attacks caused by cardiovascular disease, and cancer, strokes are the third most common cause of death, accounting for 15% of mortalities. The less serious form the ischemic stroke, which occurs as a result of insufficient circulation accounts for 80% of cases, and is far more frequent than strokes caused by massive haemorrhaging.

The studies by Greiser showed a significant correlation between the diagnosis of stroke and the intensity of night-time aircraft noise, with a positive dependency on the amount of exposure and a negative correlation with age [16 - 17]. In the British study of 2013, the occurrence of both, the diagnosis of stroke and the incidence of stroke as a cause of death, were found to have a significant, exposure-dependent correlation [49].

In the large-scale American Medicare study of 2013, the stroke was one of three major diagnoses [50]. It was also ascertained that there was a significant increase in incidence of strokes. Thus, there are concordant findings with regard to the relationship between aircraft noise and the incidence of strokes. The Swiss study by Huss and associates, on the other hand, found no relation with respect to mortality caused by strokes [33]. The fact that the Swiss study did not find an increase in mortality could be deduced from the circumstance that in case of the most common form of strokes, the ischemic stroke, mortality is fairly low.

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TABLE 2 SELECTION OF INTERNATIONAL AIRCRAFT NOISE STUDIES ON MYOCARDIAL INFARCTION AND STROKE

No.	First author (Study name)	Year pub-lished	Study design	Persons	Exposure, (technique)	Terminal point, data collection	Stratification and/or control variables	Results (selected terminal points)
1	Huss A. (Swiss Register of Deaths)	2010	Cohort study	4,6 million Swiss (age > 30 years)	Aircraft noise, road traffic noise, particulate (GIS technique)	Causes of death from official Register of Deaths	Sex, education, socio-economic status of community	Mortality due to heart attacks aircraft noise 60 dB(A) 24 hr hazard ratio 1.3
2	Hansell AL. (Small-area study)	2013	Cohort study (follow-up study)	2,6 million adults (f, m) Heathrow Airport vicinity	Aircraft noise (GIS technique)	Hospitalizations	Age, sex, ethnicity, deprivation, smoking (indirect)	<51dB(A) vs. >63dB(A) stroke 1.24 (1.08–1.43) coronary artery disease 1.21 (1.12–1.31)
3	Correia AW. (multi-airport retrospective study)	2013	Cross-sectional study	6,027,363 seniors (f, m) (age ≥ 65 years)	Aircraft noise (postal codes)	Hospitalizations (Medicare)	Age, sex, race	Increase in cardio-vascular disease by 3.5% per 10dB(A) level increase above xx
4	Floud S. (HYENA study)	2013	Cross-sectional study	4,712 adults	Aircraft noise road traffic noise	Self-reported heart diseases and strokes	Age, sex, risk factors	Increase significant at >20-year residence, 25% per 10 dB (L_{night})

TABLE 3. SELECTION OF INTERNATIONAL AIRCRAFT NOISE STUDIES ON DEPRESSION

No.	First author (Study name)	Year pub-lished	Study design	Persons	Exposure, (technique)	Terminal point, data collection	Stratification and/or control variables	Results (selected terminal points)
1	Greiser (Cologne-Bonn Airport Study)	2006	Cross-sectional study	809,379 insured persons, all ages (f, m)	Night-time aircraft noise (GIS technique)	Medication prescriptions (cardio-vascular, medication, etc.)	Age, sex, prevalence of social welfare, density of nursing homes for elderly, interaction of aircraft noise & age, night-time road and rail traffic noise	Trend per 1 dB above 39 dB(A) ($L_{eq,3\text{-}5hr}$), highest soc. welfare cases, quartile)
2	Greiser E. (Cologne-Bonn Hospital Study)	2010	Case-control study	~550.000 insured persons (f, m) age > 40 years	Night-time aircraft noise (GIS technique)	Cardio-vascular (hospital release diagnoses)	Age, sex, prevalence of social welfare cases, road traffic noise, rail traffic noise	Results only in graphic form; increase in depression with night-time continuous sound pressure level (11 PM-1 AM) for women above 40 dB(A)

F. Depression

Earlier studies indicate a concentrated occurrence of noise-induced depression [6]. Given the increased use of sedatives and sleep-inducing medications, such a relation is plausible. In the study by Greiser, a statistically supported increase of occurrence among women was confirmed [16]. Taking the negative effects of age into account, that increase applied both to women and to men [48].

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G. Annoyance

Aircraft noise in the vicinity of airports is often the most seriously annoying source of traffic noise. This was demonstrated in a survey around the Frankfurt airport, 64% of the residents identified aircraft noise as the most serious disturbing noise source, while only 23% of the Hessian population[2] as a whole made that statement [53].

After assessing 55 cross-sectional annoyance studies carried out between 1967 and 1993 in Europe, North America and Australia, Miedema and Vos published generalized exposure-response relationships on annoyance due to aircraft noise [54]. After a number of updates, these exposure-response relationships were accepted by the experts' network of the European Commission as the standard for the European Union [32].

The validity of this exposure-response relationship (EU curve) has been called into question by more recent studies. Fig. 7 shows European studies carried out between 1991 and 2006. Most of these studies show higher annoyance values at equal day-night levels than those which can be seen from the EU curve (shown in red).

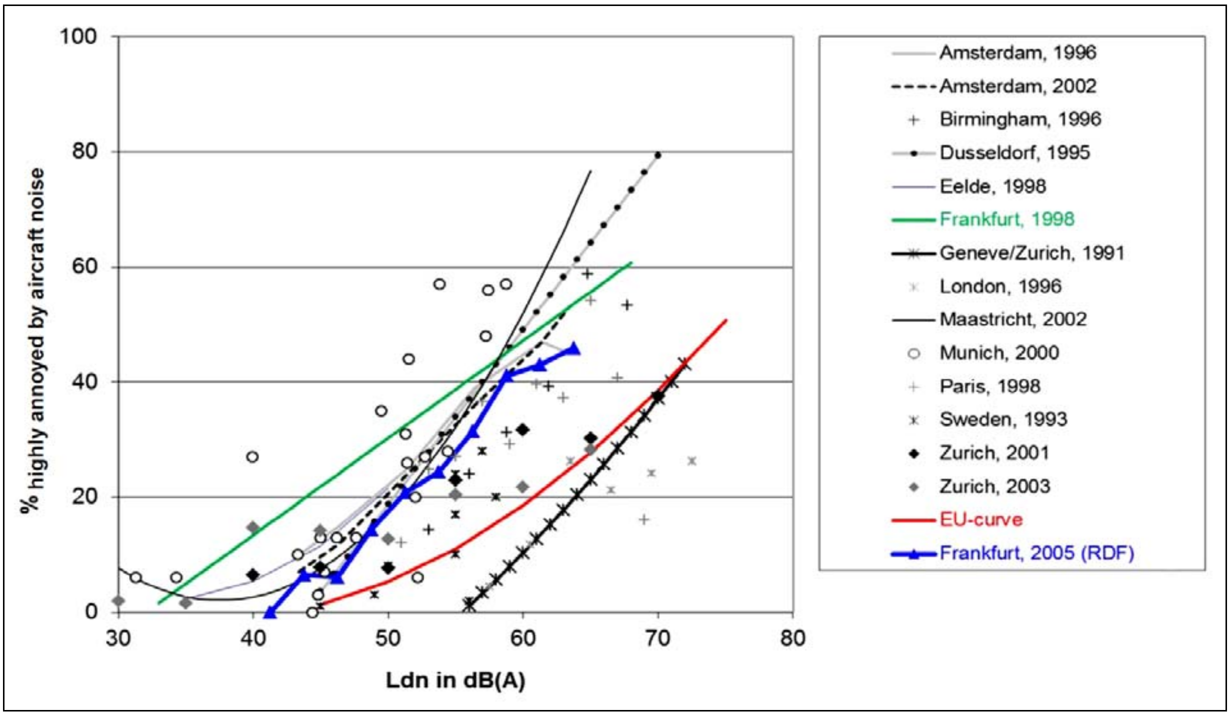

Fig. 7 The exposure-response relationships for highly annoyed persons [in %] with reference to day-night levels (L_{dn}), arising from 11 recently published studies including the EU curve [32] (red) [55].

In 2009, Janssen et al. published a generalized exposure-response relationship for annoyance due to aircraft noise from seven recent European studies conducted in Switzerland, Germany and the Netherlands between 1991 and 2006 [31]. For equivalent exposure levels, the results showed a significant increase in aircraft noise induced annoyance (Fig. 8), and confirmed the listing of studies in Fig. 7. At 25% highly annoyed people (25% HA) – the point at which significant annoyance is assumed – a level difference of approx. 11 dB can be derived [56].

[2] Population of the federal state Hessen; the Frankfurt airport is being located in Hessen.

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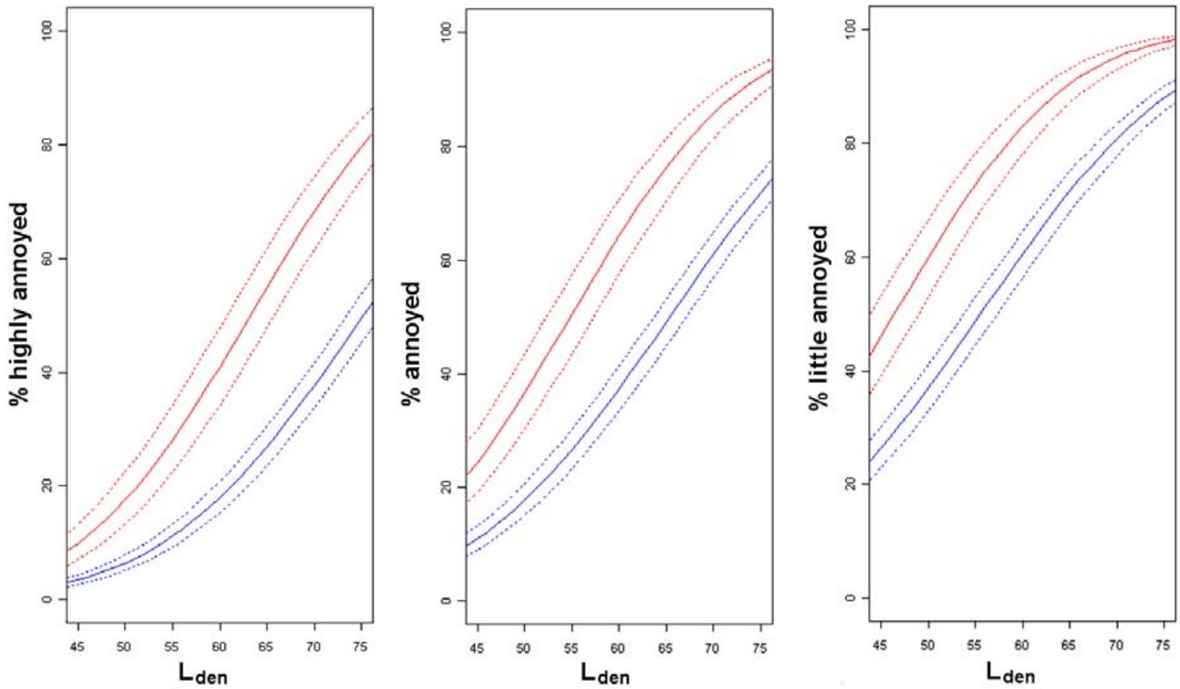

Fig. 8 Highly annoyed (%HA), annoyed (%A) and little annoyed (%LA) exposure-response relationships, as shown in older studies through 1993 (blue), and in more recent studies between 1996 and 2006 (red), with 95% CIs (dotted lines) [31].

1) Exposure-response Relationships on Aannoyance since 2006

The ANASE (Attitudes to Noise from Aviation Sources in England) study included two phases [57]. Phase 1 consisted of a series of pilot studies, while Phase 2 involved a national survey designed to ascertain attitudes toward aircraft noise, including annoyance in the vicinity of ten major British airports, in relation to A-weighted equivalent continuous sound levels (L_{Aeq}). The annoyance was assessed according to the five-stage International Commission on Biological Effects of Noise (ICBEN) scale; the survey involved 2132 people above the age of 18 (age 18 – 32: 32%; over 65: 18%); 47% of respondents were women. The response rate was 49%.

The previous major study in Great Britain regarding attitudes toward aircraft noise, including annoyance, was carried out in 1982, and published in 1985 [58]. It was called the United Kingdom Aircraft Noise Index Study (ANIS Study). Comparing the results of the ANASE Study with those of the ANIS Study makes it possible to review the consistency of annoyance reactions over time. Fig. 9 puts the results (regression lines) of the ANASE and ANIS Studies into the context of more recent studies (cf. Fig. 9).

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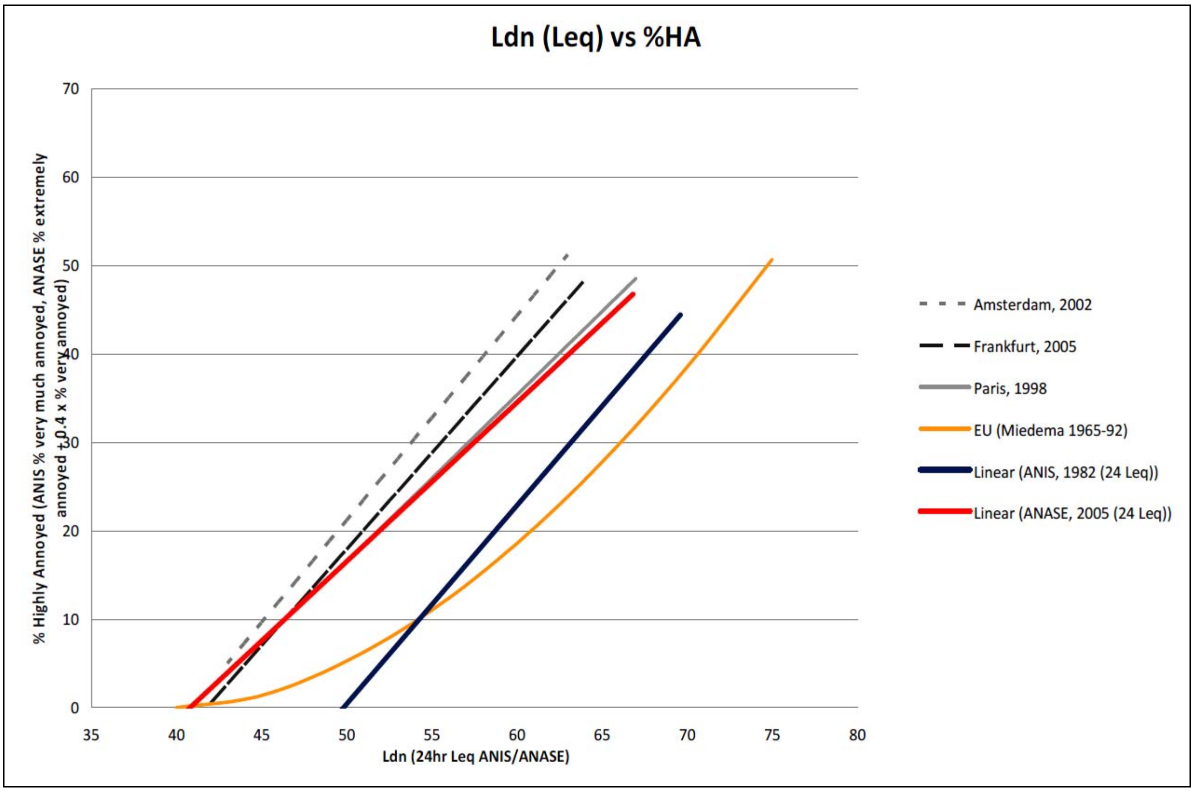

Fig. 9 Exposure-response relationships (regression lines) for aircraft noise (L_{dn}) and highly annoyed persons [in %] from selected aircraft noise studies, incl. ANASE and ANIS, compared with the EU Curve (orange) [59].

The consistency of the more recent studies (ANASE, Paris, Amsterdam, Frankfurt) is notable. At the same time, there is a recognizable difference to the trend of the old exposure-response relationships ANIS and the EU curve. The comparison also shows how annoyance has changed over the course of time in the same cultural environment.

In the HYENA Study, not only hypertension (cf. Sect. Hypertension), but also annoyance from aircraft and road traffic noise in the vicinity of six major European airports was examined. The survey included 4861 individuals (2467 women and 2404 men aged 45 to 70) [60]. Annoyance was assessed according to the 11-stage ICBEN scale. In the study, day-time (L_{den}) and night-time (L_{night}) annoyance were differentiated. Locations strongly affected by other noise sources, such as railroads, industry, etc., were largely excluded. Fig. 10 shows the results of the HYENA Study in comparison with the generalized exposure-response relationships as from Janssen (Studies 1996 through 2006) and the EU curve (Studies 1967 through 1993).

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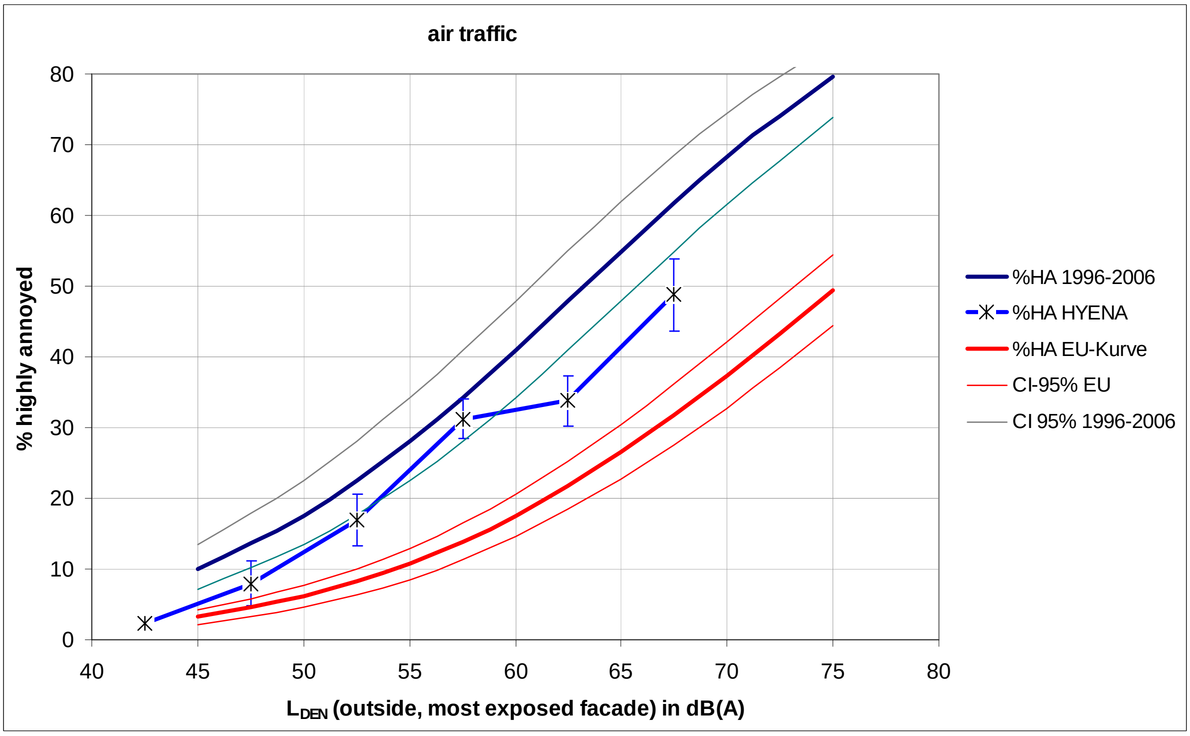

Fig. 10 Exposure-response relationships for aircraft noise (L_{den}) and highly annoyed persons [in %]. The Janssen curve, the EU curve and the HYENA curve (not including Athens and Milan), with 95% CIs, are illustrated.

The HYENA Study - with the same day-evening-night level – also shows a significant increase in aircraft noise related annoyance, as compared with the EU curve. With 25% highly annoyed persons (25% HA), air traffic (third-order trend) shows a level difference of approximately 9 dB compared with the generalized exposure-response relationship of the EU.

Particularly significant for the result of the HYENA Study is the additional assessment of annoyance due to road traffic noise. Fig. 11 shows, that the road traffic induced annoyance curve not substantial differentiate from the EU curve for road traffic. Only the annoyance due to aircraft noise has changed over the past 20 years.

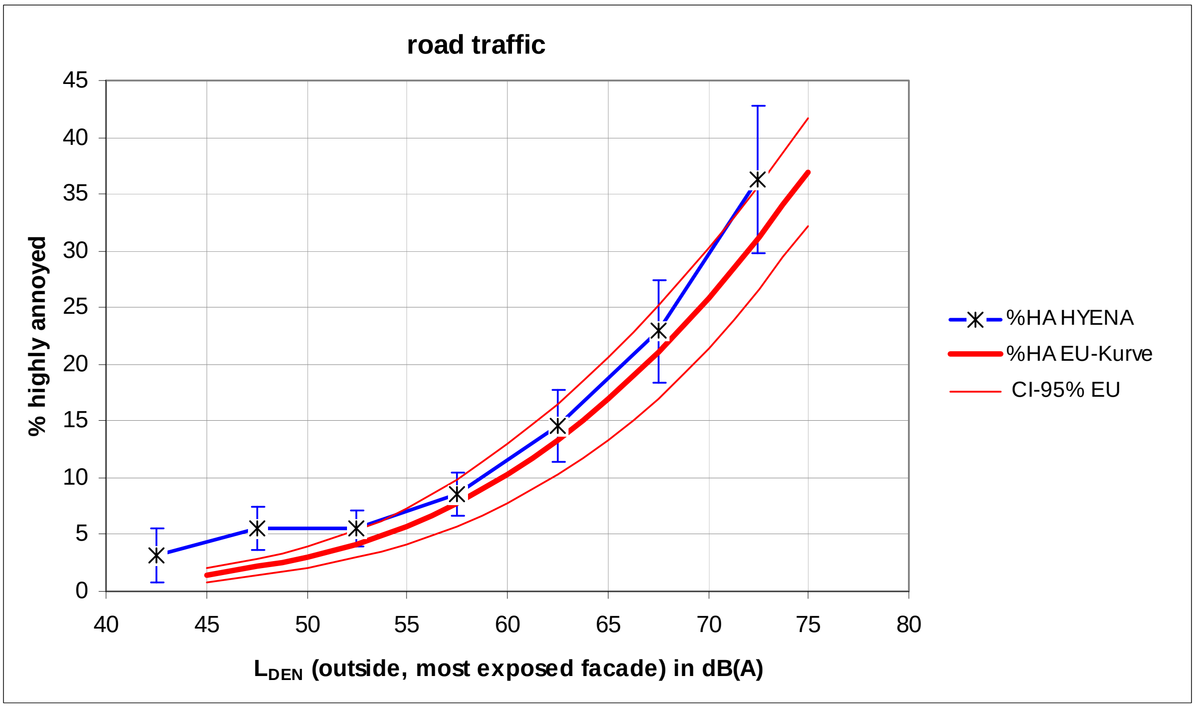

Fig. 11 Exposure-response relationships for road traffic noise (L_{den}) and highly annoyed persons [in %]. The EU curve and the HYENA curve (not including Athens and Milan) are almost identical.

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Exposure-response relationships are also available from Asia [61]. Annoyance was assessed among 764 residents of the vicinity of the Hangzhou-Xiaoshan International Airport, using the 11-stage ICBEN scale (response rate 51%); 55% of respondents were women. The aircraft noise – effective perceived noise level (LEPN) – was measured at 39 measurement stations over the course of the week. The relationship between highly annoyed individuals (%HA) and exposure to aircraft noise was determined by means of logistical regression. The Chinese exposure-response relationship is shown in Fig. 12, together with the results from Korea [62] and the EU curve [63], using the day-night level (L_{dn}).

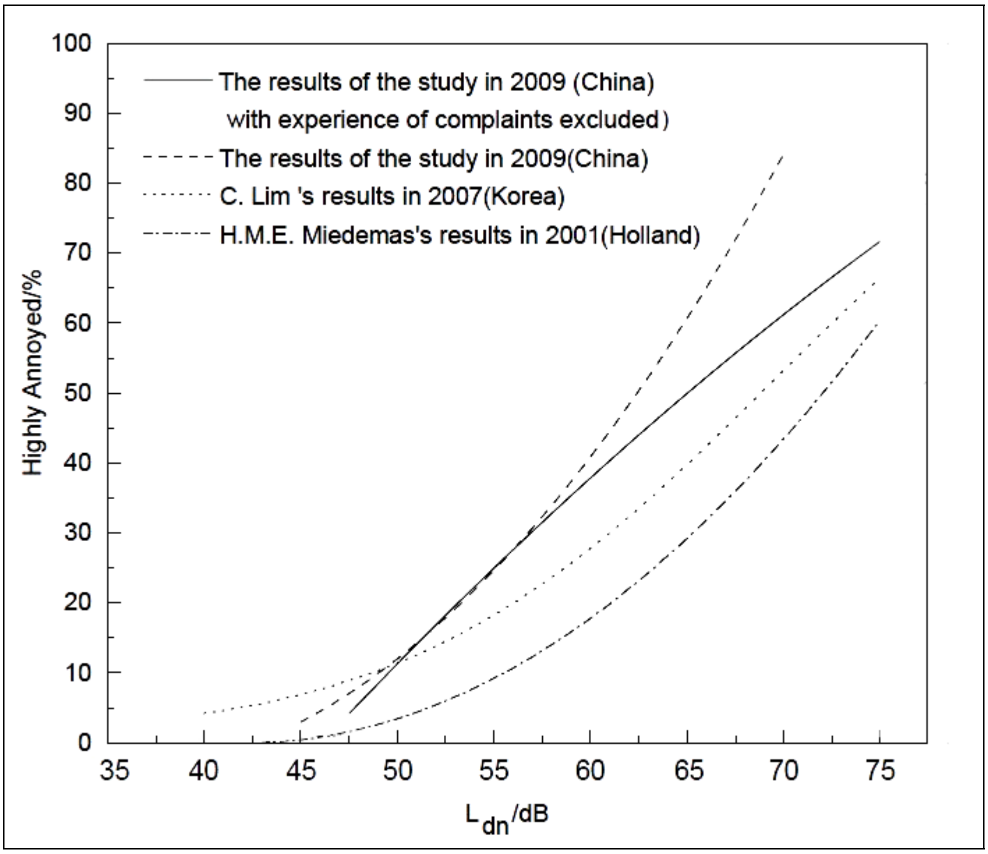

Fig. 12 Exposure-response relationships for aircraft noise (L_{dn}) and highly annoyed persons [in %] in the range of 40 to 75 dB(A) according to Guoqing [China], Lim [Korea] and Miedema [EU curve] (according to [61]).

Using the same day-night level, both the Chinese and the Korean studies show higher aircraft noise-related annoyance than the EU curve. The exposure-response relationship for the Chinese Hangzhou-Xiaoshan Airport states that at a day-night level of L_{dn} = 55.0 dB(A) (weighted effective continuous perceived noise level (LWECPN) 68.1 dB), 25% of residents were highly annoyed [61]. The Korean exposure-response relationship shows a day-night level of L_{dn} ~ 58 dB(A), with 25% highly annoyed individuals (%HA).

2) Conclusions for Annoyance due to Aircraft Noise

The exposure-response relationships of major epidemiological studies published after 2006 confirm that the EU curve has systematically underestimated the annoyance of residents surveyed today. For the planning process, exposure-response relationships from studies conducted after 1996 should be used.

The relation of annoyance to German acoustic indicators (e.g. 16-hour day L_{eq}), can be taken from the most recent survey of 2312 individuals through the Frankfurt Regional Dialogue Forum (RDF). Of those surveyed, 55% were women and 45% men, aged between 17 and 93. The exposure-response relationships with respect to the A-weighted continuous sound levels for the 16-hour day are shown in Fig. 13. In the RDF study, both the five-stage ICBEN scale and the 11-stage ICBEN scale were used.

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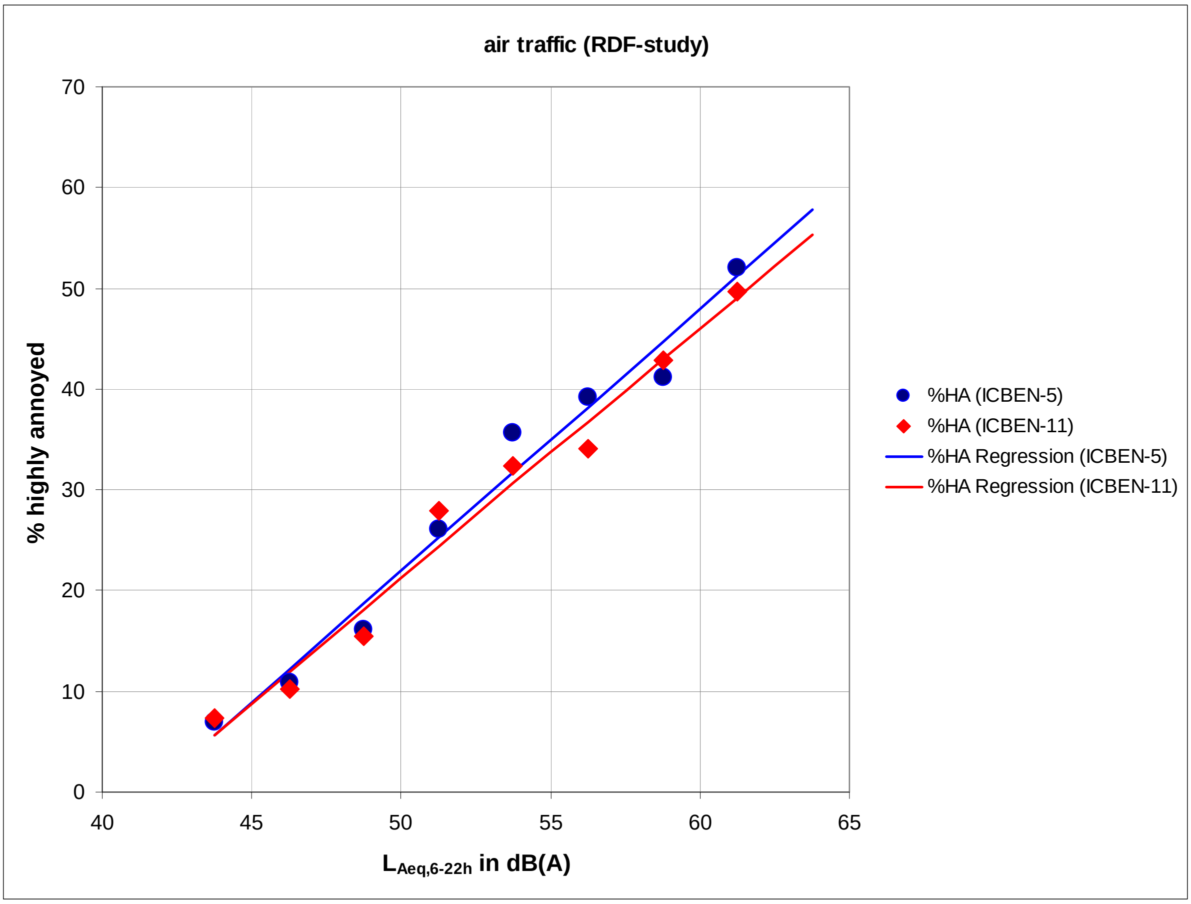

Fig. 13 Relationships between aircraft noise (L_{Aeq}) and annoyance over the course of a 16-hr day (RDF data ascertained using the five-stage ICBEN scale [ICBEN-5] and the 11-stage ICBEN scale [ICBEN-11]) (from [55]).

A 25% share of highly annoyed people (25% HA) is established, while the RDF study reveals a 16-hour continuous sound level (6 AM to 10 PM) of approx. 52 dB(A) (ICBEN-11). The frequently raised objection to using the RDF study is that the survey was carried out at a time when the expansion of the airport was imminent, and that the annoyance values compared with those of the EU curve were essentially due to this context of change.

However, no clear effect upon annoyance with respect to the context of change can be seen in comparison with the exposure-response relationships published after 2006. A re-evaluation of the present exposure-response relationship in the RDF study will be carried out after presenting the results of the Noise Related Annoyance and Health Study (NORAH).

H. Learning Disorders

In an early cohort study the learning capacity of primary school children subject to changed aircraft noise exposure was investigated [64,-65]. Prior to the opening of the new Franz-Josef Strauß Airport in Munich in November 1992, and the closure of the old Munich-Riem Airport, children in the vicinity of both sites, each with a control group with no aircraft noise, were recruited, and parallelized in terms of socio-economic status. A total of 326 children (average age: 10.4) participated in three surveys, one prior to the opening of the new Franz-Josef Strauß Airport, and two after the opening.

After flight operations were moved to the new airport, motivation, long-term memory and reading performance of the group in the vicinity of that airport, who were now exposed to aircraft noise, were impaired, while they improved in the group in the vicinity of the old airport, which was now no longer exposed to aircraft noise. In the group formerly exposed to aircraft noise, short term memory now also improved.

The study indicates that exposure to aircraft noise has to last for several years before deficits fully develop. Once aircraft noise exposure is terminated, these deficits can recover within several years.

Between 2000 and 2003, additional epidemiological studies on the effects of aircraft noise upon primary school children were carried out, primarily in Great Britain (cf. Table 4).

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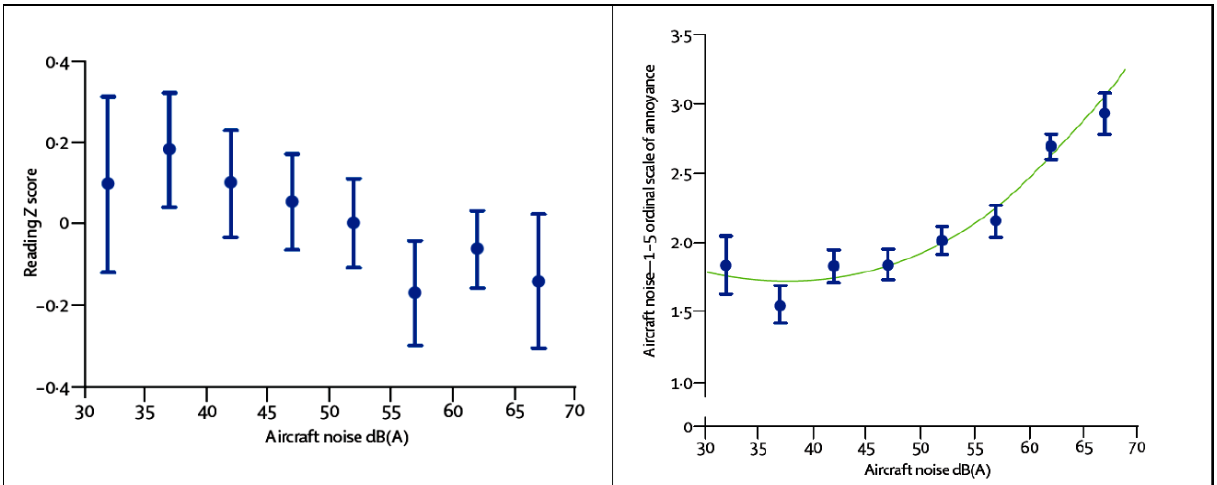
TABLE 4 EPIDEMIOLOGICAL STUDIES OF THE EFFECTS OF AIRCRAFT NOISE ON THE COGNITIVE ABILITIES OF PRIMARY SCHOOL CHILDREN

First author Year	Name Design	Area of investigation	Children	Selected results
Haines 2001a [66]	West-London-School Study Cross-section	Vicinity of London airports	451 children (age 8-11)	Reduced reading ability
Haines 2001 [67]	London-Heathrow Study Cross-section	Heathrow Airport vicinity	380 children (age 8-11)	High annoyance, poor reading comprehension
Haines 2002 [68]	London-School-Performance Study Cross-section	Heathrow Airport vicinity	11,000 children (age 11)	Reduced reading ability, poorer performance in maths, (no control SES)
Hiramatsu 2003 [69]	Okinawa Study Cross-section	Okinawa AFB vicinity	2269 children (age 8-11)	Effect on long-term memory

SES = socio-economic status

A follow-up international study, carried out in England, Spain and the Netherlands, investigated the cognitive performance and the health of primary school children at schools exposed to aircraft noise (RANCH Study) [70]. A total of 2844 children aged 9 to 10 from 89 schools were investigated. The children were selected based on aircraft noise and road traffic noise exposure to their schools; in parallel, control schools of comparable socio-economic status (matched schools) were identified. Aircraft noise exposure to the schools varied from 30 to 77 dB(A), and road traffic noise exposure between 32 and 71 dB(A).

The results of the RANCH Study indicated a significant linear correlation between the intensity of chronic aircraft noise exposure on the one hand, and reading comprehension and recognition memory on the other, and also a significant non-linear correlation to noise related annoyance, statistically controlled for the education level of the mother, the socio-economic status of the parents, long-term illnesses of the children and the sound insulation of the classrooms (cf. Fig. 14). A 5% increase in aircraft noise exposure ($L_{eq,16h}$) corresponded to an average delay of two months in reading age in Great Britain, and of one month in the Netherlands [71].



Adjusted mean reading Z score (95% CI) for 5 dB bands of aircraft noise (adjusted for age, sex, and country)

Adjusted mean annoyance (95% CI) for 5 dB bands of aircraft noise (adjusted for age, sex, and country) and fitted curve

Fig. 14 (left panel) Increased aircraft noise leads to a linear drop in reading comprehension; (right panel) extent of subjective annoyance increases in nonlinear form. The correlations are significant after taking socio-economic data into account (according to [70]).

For road traffic noise, no connection with reading comprehension could be ascertained. In the RANCH Study, neither aircraft noise nor road traffic noise affected self-reported health or overall mental health.

1) Studies Conducted after 2006

The Dutch data from the RANCH Study was subjected to further assessment in order to ascertain the connection between aircraft noise exposure and the percentage share of children with a low level of reading comprehension [72]. The statement regarding an averaged reduction in learning ability (cf. results of the RANCH Study) is problematical, because children with writing, reading or speaking difficulties are considerably more strongly affected by noise than "normal" children (cf. e.g. [73,

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74]).

Since there were no guidelines showing which test results would correspond to a low level of reading understanding, van Kempen established her own guideline values at “control schools” [72]. Children whose schools were subjected to a low level of aircraft noise exposure were used as a reference group, and the low level of reading comprehension was established on the basis of the standardized distribution of the test results of these children. The percentiles 20%, 10% and 5% were selected as limits of low level reading comprehension in the control groups. In this way, van Kempen was able to assign good or poor reading comprehension status to each child.

The relationship between aircraft noise exposure at school (L_{Aeq} 7 AM-11 PM), and the probability of poor reading comprehension was determined in a multistage logistical regression. The calculation was carried out using both continual aircraft noise exposure and 2.5 dB level classes. The control variables were the same as in the RANCH Study.

An enhanced assessment of van Kempen shows that rising aircraft noise exposure to schools is significantly related with a higher share of children with lower reading comprehension (cf. Fig. 15).

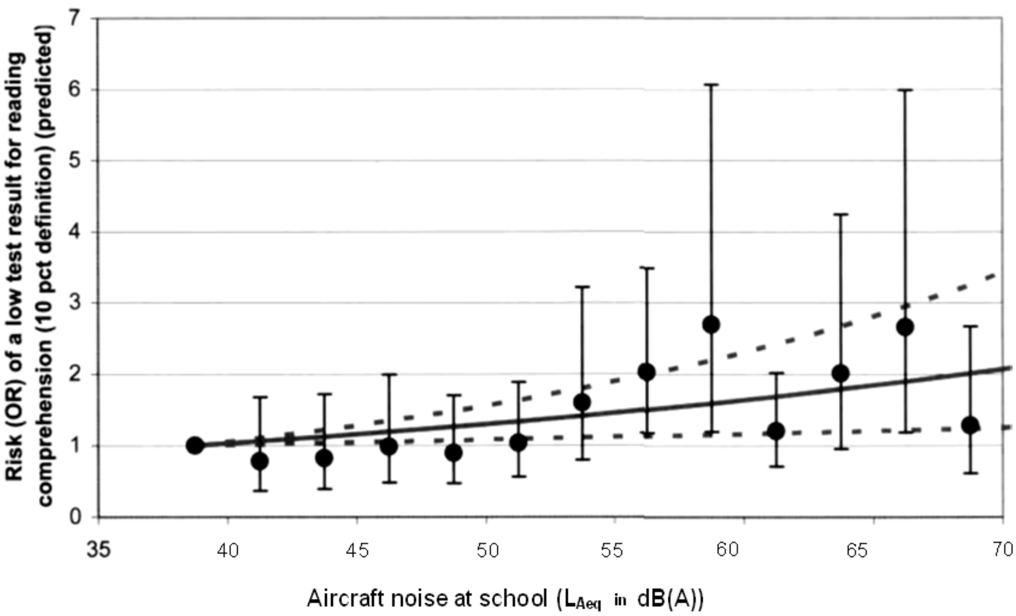

Fig. 15 Adjusted Odds Ratios and 95% CIs for the probability of low test results for reading comprehension, based on the 10% percentile, both for the continual variable and for the 2.5 dB sound pressure level classes [72].

Seabi et al. investigated 437 primary school children aged 9 – 14 subjected to major aircraft noise exposure at Durban International Airport in South Africa (52%) (test group), and 337 primary school children of the same age (48%) living in a quieter area (control group) [75, 76]. Of the children in the test group 151 children spoke English as mother tongue (first language [EFL]), and 162 spoke it as primary foreign language (second language [ESL]). In the control group, the breakdown was comparable (191 EFL to 156 ESL). As in the RANCH Study, reading comprehension was ascertained using the Suffolk Reading Scale Level 2. Continuous sound level measurements were carried out during the test period (8 AM - 10 AM). At the test group schools, a continuous sound level of 69 dB(A), with maximum levels of up to 95 dB(A) were measured; in the control schools continuous sound level of 40 dB(A) and maximum levels up to 54 dB(A) were measured.

Children in the test group had a significantly poorer reading comprehension compared to children in the control group. The difference was, however, smaller than expected (effect size 0.35).

Children with English as first language scored significantly better results in reading comprehension tests (effect size 0.46) than pupils with English as primary foreign language.

The significant interaction term showed the deterioration of reading comprehension in the presence of aircraft noise (effect size 0.87) only among EFL pupils. Here, it should be noted that reading comprehension at South African schools was significantly lower (mean 35.27) than reading comprehension at British schools in comparable studies (mean 98.2). Compared with British (European) pupils, the South African pupils had lower reading comprehension, regardless of noise levels [75].

The study by Clark et al. is a continuation of the RANCH project [77]. Six years after the RANCH Study (2001-2003), he investigated 461 pupils aged 15 to 16 who had attended one of the schools participating in the RANCH Study in 2001-2003 (response rate 45%). For the primary and secondary schools, the 16-hour outdoor continuous sound level (7 AM to 11 PM) was ascertained on the basis of postal codes. Reading comprehension was measured according to the Suffolk Reading Scale 2,

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Level 2, in the RANCH Study, and Level 3 in the follow-up study. The annoyance was measured using the five-stage ICBEN scale. The control variables were the same as in the RANCH Study.

Prior to adjustment for the effects of socio-demographic factors, the increase in aircraft noise exposure (1 dB) at primary school was associated with a significant reduction in reading comprehension (-0.008), and with a significant increase in annoyance (0.017). After the statistical control for socio-demographic factors, only the significant increase in annoyance connected to aircraft noise remained.

For cumulative aircraft noise exposure at primary and secondary schools, a significant reduction in reading comprehension (-0.014), and a significant increase in annoyance (0.030) were apparent prior to the statistical control for socio-demographic factors. Reduced reading comprehension was in a comparable order of magnitude to the reduction shown in the RANCH Study. After the statistical control for socio-demographic factors, here too, only the significant increase in annoyance related to aircraft noise remained.

The results show that children attending primary schools which were severely exposed to aircraft noise showed higher noise annoyance even after six years than children attending primary schools which were less exposed to aircraft noise.

As part of the NORAH study an investigation on the influence of air traffic noise on cognitive performance and quality of life of school children became available on the Internet [25]. The study was performed in 2012 and involved 85 second grade classes from 29 primary schools exposed to aircraft noise between 39 and 59 dB(A) in the vicinity of Frankfurt Airport, which included 1243 children, 1185 parents and 85 teachers.

An increase of 10 dB in aircraft noise was associated with decremented reading performance corresponding to one month delay. In addition, the authors noticed an unexpected distinct influence on quality of life and motivation for learning. Parents of children attending highly exposed schools reported sleeping disorders and an increase in medications prescribed by physicians.

Thus, the results of earlier studies were essentially confirmed. The question of long-term effects was not investigated. Therefore, as long as no other information is available a longer lasting deficiency must be assumed.

2) Conclusions on Learning Disorders due to Aircraft Noise

The findings regarding learning disorders confirmed the ubiquitous experience that full mental capacity requires quiet, and that noise diminishes it. For children, noise at school can have serious negative consequences. This appears to be particularly true for pupils with learning problems; moreover, it can be observed that the share of such children correlates with socio-economic status, according to which socio-economic status is a problematic control variable in epidemiological studies (over-controlling) [78]. The fact that the period of time in which deficits can be compensated is unknown – and whether they can be compensated at all – causes great concern [65, 77].

I. Studies Currently in Progress

1) The NORAH Study

The acronym NORAH stands for Noise Related Annoyance and Health. In this study, coordinated by the Environment and Neighbourhood House in Frankfurt, annoyance, sleep disturbance, learning disorders of children, blood pressure, behaviour and the occurrence of organic cardiovascular disease are investigated. The first results on learning disorders communicated in 2015 are described above.

2) The RaN Study

The acronym stands for Recurrence and Noise. It is designed to estimate the incidence of re-lapse after an episode of acute coronary syndrome. This question has considerable practical significance with regard to secondary prevention and has not yet been addressed. The data is gathered in cardiological centres in the vicinity of Frankfurt Airport, and exclusively involves patients whose diagnoses were confirmed by coronary angiography. The first results are expected in the end of 2016.

IV. EXPOSURE LIMIT VALUES FROM TODAY'S PERSPECTIVE

In this paper, we are stressing the necessity of adequate noise protection and noise reduction strategies for public health. According to the information presented, it is necessary to regulate aircraft noise exposure –ideally at source – and to reduce it. In order to achieve this goal, exposure limit values are indispensable.

In case these values are exceeded, damage to health cannot be excluded. This implies a duty to examine existing noise situations and to introduce measures to reduce exposure.

When deriving exposure limit values, it should be noted that it is not only aircraft noise that impacts on the cardiovascular system. Study results show that ever-present particulate matter is also connected with the occurrence of cardiovascular illness.

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A. The Particulate Matter Issue

Road traffic induced noise exposure is generally accompanied by exposure to small and very small particulate matter. Chronic or acute exposure to very small particles, particularly dust with a particle size of less than 2.5µm, can lead to increased cardiovascular health risks [79, 80, 81]. The diagnoses regarding cardiovascular illness to some extent overlap with noise induced illnesses. In studies on health hazards of noise, the simultaneous exposure to particulate matter must therefore be taken into account. In epidemiological studies on road traffic noise, the simultaneous exposure to particulate matter is very difficult to separate from pure noise exposure, even if simultaneous measurements of particulate matter exposure are carried out.

In air traffic, by contrast, particulate matter emissions occur at relatively great heights. Here, particles are dispersed over a wide area by air currents, and particulate exposure and noise exposure no longer co-vary systematically at the receiver's side. In epidemiological studies on aircraft noise, the effect of particulate matter as a simultaneous health hazard along with aircraft noise is therefore less probable. For this reason it is not necessary to assume that the study results discussed above are distorted by the presence of particulate matter.

B. Aircraft Noise Exposure Limit Values

Although in most epidemiological investigations reported, risks generally become significant only in the higher or highest exposure categories, compared with non-exposed or little-exposed population groups (e.g. [33, 42]), this does not necessarily mean that at lower exposure, risks drop to nil“ [82]. The assumption of an effect threshold of this nature may be an artefact of statistical evaluation. In the derivation of the following limit values, an effect threshold was assumed.

In 2015 exposure limit values, have changed in two respects during the past ten years.

The scientific proof that aircraft noise can lead to health hazards has been so firmly supported that not only the increased occurrence of hypertension disease, but also of cardiac infarction and strokes attracts little controversy. Night-time aircraft noise is considered to be the most dangerous form of noise exposure.

The noise level at which 25% of the exposed population feels highly annoyed has dropped by almost 10 dB(A) in the last 10 years. According to an assessment of recent studies, it is at an average of 56 dB(A) for the day-evening-night level (L_{den}), and an average of 54 dB(A) for the 16-hour continuous sound level (6 AM to 10 PM). If only recent studies from Europe are taken into account, the level for each is 1 dB lower. The reduction applies to aircraft noise but not for road traffic noise. Accordingly, in order to avoid significant annoyance levels, the exposure limit values of an L_{den} of 55 dB(A) and an L_{eq} of 53 dB(A) for the 16-hour continuous sound level would have to apply in Europe.

The stipulation of exposure limit values for the increased risk of chronic hypertension due to aircraft noise is difficult, since the studies vary in quality (e.g. study design, random sampling size, response rates, control variables), and some studies were carried out only with men [41], or yielded significant results only for men [36, 22]. There are even a few national studies which have shown no increased risk [43, 83].

From the internationally accepted HYENA Study, a limit of the day-evening-night level (L_{den}) of 54-55 dB(A), for a night-time flight share of 4-5% can be taken [42]. This corresponds with the results of Rosenlund [35] and Eriksson [22, 41], who found a clear risk increase related to an L_{den} of 50-55 dB(A). At this level, there is also a significant increase in the prescription of medications. Hypertension risk is increased by 10-20% [22, 35, 36, 41]. In order to avoid illness, the lower limit of the range must be used.

According to the present state of knowledge, an L_{den} of 50 dB(A) over the course of a 24-hour day must be seen as the exposure limit value needed to avoid increased hypertension risk (vgl. [84]). Night-time aircraft noise should not exceed L_{night} = 45 dB(A) (cf. [42]; also [85]). For the medium-term goal of protecting residents, an 8-hour night-time sleeping period with no aircraft noise between 10 PM and 6 AM must be the goal (cf. [86], see recital 190).

For the 16-hour day level, no reliable exposure limit value can be derived from the studies which use the L_{den} or the L_{eq}, 24h as acoustic parameter, since the risk increase ascertained for the 24-hour day always contains the night-time [85, 87, 88]. The stress of noise during night-time can strongly affect coping with noise during the day-time. Noise during the day-time can also influence the coping capacity in the night. In the HYENA Study, which examines the 16-hour day level, a slight risk increase depending on $L_{Aeq,16h}$ was ascertained, but not statistically confirmed [42]. The consumption of anti-hypertension medication showed an increase in the 16-hour day level (except in Italy), with a significant increase only in England [45]. In the Okinawa Study [89, 90]) the effect of aircraft noise on the risk of hypertension be derived entirely from 16-hour day time was assessed. In that study, 28,781 persons in the vicinity of three air force bases in Okinawa were investigated (military aircraft noise). Night-time flights were rare, with only a low level of aircraft operations during off-peak hours. The lowest level class at which a significant increase in hypertension risk was ascertained was an L_{dn} of 60-65 dB(A); hypertension risk in this level range increased by approximately 10%. In civil aviation with aircraft movement peaks in the off-peak hours, a buffer below the lower level class must be maintained in order to avoid damage to health (cf. [91]). According to the information available today, an $L_{eq,16h}$ of 55-60 dB(A) should be seen as the limit value for today’s usual day-time flight allocations at civilian airports. The 24-hour assessment using the EU day-evening-night level (L_{den}) is preferable to a separate assessment of

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the day-time hours.

C. Noise levels indoors

When converting forecast free-field outdoor sound levels to indoor levels for aircraft noise, the simplified method is to assume a typical outdoor-indoor sound level difference. Particularly important is the sound level difference for tilted-open windows, which is supposed to be 15 dB. This approach is used for example in the German Aircraft Noise Law, in spatial planning procedures, and in the professional literature [92]. In order to justify the sound level difference of 15 dB, German authorities refer to the guideline of the Association of German Engineers VDI 2719, No. 10.2, which states that “Windows in the ajar position achieve only a weighted sound reduction index of approx. R_w = 15 dB…”. In this statement, it should be noted that this VDI guideline does not refer to a tilted position of the window, but rather to an ajar position, and that moreover there is no reference to a level difference of 15 dB(A), but rather to a weighted sound reduction index of R_w = 15 dB. The sound level difference of a tilted-open window is calculable. In Fig. 16, the standard outdoor-indoor sound level difference (L_o -L_i) over the open gap at the top of the window is shown. The figure shows that a sound level difference of 15 dB occurs only with very narrow opening gaps.

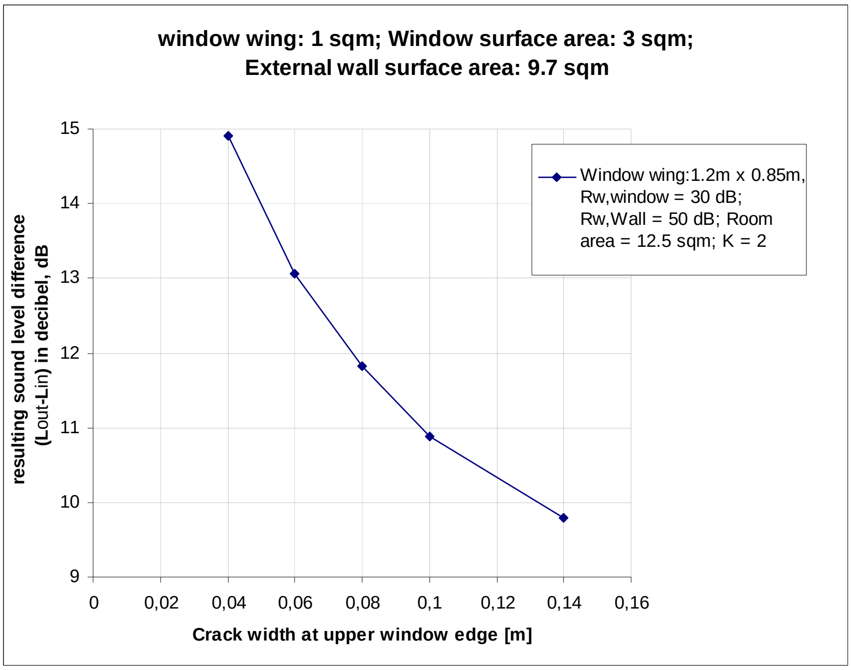

Fig. 16 The relationship between the resulting standard outdoor-indoor sound level difference and the opening gap at the top of an ajar-open window wing of 1 sqm, calculated as per the VDI Guideline 2719, in association with Supplemental Sheet 1 of DIN 4109-2, Sect. 11 ($R'_{w,Wall}$ = 50 dB; $R'_{w,window\ surface}$ = 30 dB, Window surface share 30%; room surface 12.5 sqm; K=2 [93]).

A Monte-Carlo simulation, in which all parameters of the free-field sound level difference were evaluated by means of random selection from suitable value combinations, yielded a distribution with an average value of 12 dB after running 50,000 variants, with a roughly equal distribution of variations of the parameters and a usual window gap of 110 mm [94]. This was also confirmed by measurements [95]. Moreover, a protective concept cannot be based on the mean value of a normal distribution, since approximately 50% of all cases are below the mean value, and would hence be insufficiently protected. In order to ensure that the noise level difference will be achieved in 90% to 95% of all cases, an indoor-outdoor sound level difference of 10 dB with the window tipped open must be assumed.

However, an exclusive orientation toward indoor sound levels is not useful. Aircraft noise exposure outdoors must be incorporated into the health-related assessment of noise levels as well, because long-time effects of noise have mostly been documented based on outdoor noise exposure of the residential environment.

D. Conclusion

In order to protect residents in the vicinity of airports, legally standardized exposure limit values for aircraft noise exposure must be provided. This has been demanded, among others, by:

− the WHO (Night Noise Guidelines for Europe [6])

− the German Medical Association [96] and

− the German Advisory Council on the Environment (Reduce Aircraft Noise: The Need for Reform in the Planning of Airports and Air Routes. ([86] see recital 189).

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From the available studies an upper limit of 50 dB(A) for L_{den} as a 24 h value and 45 dB(A) for L_{night} are to be derived to avoid excessive annoyance, cognitive constrictions and health impairments. To avoid sleeping disorders at night an 8 hours period without noise is required.

V. DISCUSSION OF RESULTS WITH RESPECT TO EU LEGISLATION CONCERNING NOISE PROTECTION

The findings of the synopsis above call for sound protection mechanisms in order to avoid noise related negative impacts. This section analyses the European legislative framework referring to noise.

Noise protection, particularly against aircraft noise, has been incorporated into European law in various forms. First of all, regard will be had to EU primary law (Section 5.1). After that the provisions of the Environmental Noise Directive (2002/49/EC, END) will be discussed, with reference to the obligations of Member States (6.2), as well as duties conferred on the European Commission (6.3). Taking into account the statements of the 7th Environmental Action Programme (6.4) conclusions from the noise related health findings will be drawn (6.5), both *de lege lata* and *de lege ferenda*.

A. EU primary law

According to EU primary law, protection and improvement of human health are important goals of the European Union. EU actions should primarily be designed to support, coordinate and supplement measures of the Member States (Art. 6 Subp. a, Treaty on the Functioning of the European Union [TFEU]). Noise protection, as a component of EU environmental policy (compare Art. 191 Para. 1 TFEU), is designed to preserve and protect the environment, to improve its quality, as well as to protect human health. According to Art. 191 Para. 2 TFEU, EU environmental policy is based "on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay."

As laid down in Art. 3 Para. 1 of the Charter of Fundamental Rights of the European Union, every person has the right to "respect for his or her physical and mental integrity". At the same time, protection of health, in terms of physical and mental integrity, is a fundamental right of each EU citizen as well.[3] Moreover, Art. 8 Para. 1 of the European Convention on Human Rights (ECHR) includes noise protection as an element of the right to respect for privacy and family life.[4] The ECHR is an international treaty to which the EU has acceded (compare Art. 6 Para. 2 of the Treaty of the European Union (TEU)). Thus, its guarantees are general principles of EU law (Art. 6 Para. 3 TEU).

B. The Environmental Noise Directive (END)

Since the European Community's 5th Environmental Action Programme of 1992 (OJEC no. 138 of May 17, 1993: pp. 1 ff), noise protection has been recognised as a discrete goal of the European Union. The ensuing green paper, called "Future Noise Policy" (COM [1996] 540 final, OJEC no. C 200, June 30, 1997), has essentially outlined the primarily source-based efforts of the Community. It was considered the beginning of an action programme, which, first of all, was supposed to provide a firm picture of the noise situation by comprehensive data collection, and likewise to include potential noise reduction measures. Art. 7 of the 6th Environmental Action Programme of the Community aims at substantially reducing the number of persons regularly affected by long-term average levels of noise, in particular from traffic which, according to scientific studies, cause detrimental effects on human health[5].

1) Targets for Member States

Directive 2002/49/EC (END)[6] has established binding rules for Member States to draft "strategic noise maps" gathering noise exposure data (Art. 7). Furthermore the Directive imposes the duty to draw up "action plans" to manage noise issues and effects, including noise reduction (Art. 8).

Contrary to the former legal situation in most Member States, the END is based on a holistic perspective on noise: All types of noise are to be considered according to uniform assessment criteria to generate a comprehensive picture of noise exposure, which can be applied to assessments using comparable methods. For this purpose, "data about environmental noise levels should […] be collected, collated or reported in accordance with comparable criteria. This implies the use of harmonised indicators and evaluation methods, as well as criteria for the alignment of noise-mapping." (END, recital (7)).

This data collection process is based on the term "environmental noise", defined in Art. 3 Subp. a END as "unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air

[3] ECJ, ECR. 1999, I-5251 – Lucaccioni; ECR. 1996, I-5501 ff. – Royale belge SA vs. Commission.

[4] ECHR, Judgement of Oct. 2, 2001, Hatton et al. vs. UK, No. 36022/97); in ÖJZ 2003, 72; restrictive ECHR (Grand Chamber), Judgement of July 8, 2003, Hatton et al. vs. UK, No. 36022/97); in NVwZ 2004, 1465.

[5] Decision no. 1600/2002/EC of the European Parliament and the Council of July 22, 2002 regarding the 6th Environmental Action Programme of the European Communities, OJEC L 242, p. 1

[6] Directive 2002/49/EC of June 25, 2002 Relating to the Assessment and Management of Environmental Noise (OCEC No. L 189: pp. 12 ff. – the so-called Environmental Noise Directive (END).

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traffic, and from sites of industrial activity."[7]

Art. 1 Para. 1 Clause 1 END aims at defining "a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise." Actions on noise mapping, public information on environmental noise and its effects, as well as the adoption of action plans by Member States based on noise maps (Art. 1 Subp. 1 Clause 2 END) should therefore be considered as an initial approach to further develop a European strategy for reducing environmental noise.

Noise action plans work towards both the prevention and reduction of environmental noise, especially in cases of deleterious effects, and the maintenance of satisfactory noise situations. Nevertheless, Art. 1, Para. 2

END indicates that, first of all, a general foundation for noise reducing measures regarding major noise sources should be created. Member States are obliged to gather information and report it to the Commission (Art. 10 END). Subsequently, the Commission may propose additional legislative actions or implementation strategies(Art. 11 END).

The END is only the beginning of the EU's endeavours. So far, there is no extensively conceived and binding noise protection policy, which would accomplish the objectives and principles of EU primary law. In fact, it is merely a first step, but further moves are predetermined in the END (see Section 12.2).

Consequently, the END does not provide for pan-European uniform noise limit values. Art. 5 END rather mandates Member States to autonomously determine noise limits based on uniform assessment methods (so-called "noise indicators").

2) Noise Mapping based on Defined Noise Indicators

According to Art. 5, Para. 1 END, the noise indicators L den and L night as per Annex I are to be used for noise mapping. The L den is defined as a day-evening-night noise indicator for overall annoyance (Art. 3 Subp. F END); the L night is a noise indicator for sleep disturbance (Art. 3 Subp. I END). Both cases are further defined in Annex I. Additionally, optional indicators are a noise indicator for annoyance during the day period, and a noise indicator for annoyance during the evening period (Art. 3 Subps. g and h; Art. 5 Paras. 1 and 4 END). According to Annex I, the day is twelve hours, the evening four hours and the night eight hours; the evening period may be shortened by a maximum of two hours for the benefit of either day or night, provided that this choice is the same for all the sources. Therefore, several Member States, including Germany, have to introduce an evening period not yet provided in their legal regimes, whose specific protective nature has still to be shaped by EU law.

3) Noise Assessment

The assessment of noise indicators, meaning any method used to calculate, predict, estimate or measure the value of a noise indicator or the related harmful effects (Art. 3 Subp. e END), is prescribed for measurement and computation in Annex II (Art. 6 Para. 1 END). However, deviations based on different measurement or computation methods in different Member States are permitted under the preconditions of Art. 6 Para. 2 END, until common assessment methods are established according to Art. 13 END. As far as the estimates of concrete noise values are concerned, and therefore the issue of assessing the health relevance of certain noise levels, Art. 6 Para. 2 END in conjunction with Annex III on assessment of noise effects on populations recommend applying exposure-response relationships at least for the relation between annoyance and L den , as well as sleep disturbance and L night for road, rail and air traffic noise, and for industrial noise.

It is not explained which concrete noise values require the drafting of an action plan.[8] This decision is at the Member States' discretion; in Germany, aside from the 34th Federal Noise Protection Regulation (34. BImSchV) on Noise Mapping, no further regulations have been made in conjunction with Art. 8 Para. 1 END.

According to Art. 8 Para. 1 Subp. 2 END, "the measures within the plans are at the discretion of the competent authorities." It can be concluded that exposure values are only relevant for the obligation to draft an action plan, if a decision must be made (i) about which measures in the context of an action plan should primarily be taken or (ii) in which areas particularly rapid action is required due to critical noise situations (as commented by Cancik 2008). Only the identification of "places near major roads" and other infrastructure in terms of Art. 7 Paras. 1 and 2 END, respectively, require threshold values [97]. Other authors assume that the duty to draw up action plans only exists if noise problems and noise effects require regulation. This shall be the case if national limit values are exceeded.[9]

In any case, there is a certain level of uncertainty among Member States regarding the application of Art. 8 END. The European Commission has stated that only 20 Member States have submitted action plans, only five of them within the timeframe provided, as of January 18, 2009. Moreover the data submitted was very diverse and difficult to compare

[7] Activities as per Appendix I of Directive 96/61/EC of the Council of September 24, 1996 concerning Integrated Pollution Prevention and Control (OCEC L 257 of Oct. 10,1996, p. 26, now Directive 2010/75/EU of the European Parliament and the Council of November 24, 2010 regarding industrial emissions OCEU343, p. 17).

[8] Hansmann in Landmann/Rohmer, Umweltrecht [environmental law], vol. III, Federal Immissions Protection Law (BImSchG), § 47d Rn. 4; Jarass, BImSchG, § 47d Rn. 4, with further substantiation which refer to national law with respect to the issue of limit values.

[9] Hansmann, ibid, Rn. 8-9; Jarass, ibid.

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(COM/2011/0321 final; No. 4.3.4, p. 7).

C. Implementation of the END at the EU level

The END not only contains stipulations for Member States, but also assigns tasks to the European Commission (compare Art. 6 Paras. 2 and 10-12). The Commission has to determine common assessment methods; check existing Community measures related to environmental noise sources; and submit a report regarding the previous implementation of the Directive, including the issue of whether there is a "need for further Community actions on environmental noise" (Art. 11 Para. 2 END). As early as March 10, 2004, the Commission reported to the European Parliament and the Council including a review of existing Community measures relating to sources of environmental noise (Art. 10 Para. 1 END).[10]

1) The CNOSSOS-EU Project

In 2008, the European Commission began to fulfil its mandate of establishing common assessment methods for noise levels, as stipulated in Art. 6 Para. 2 END. For this purpose, the project "Common Noise Assessment Methods in Europe" (CNOSSOS-EU) was initiated under the aegis of the Joint Research Centre (JRC). The project aims at establishing technical foundations for the revision of Annex II to the Directive, thus ensuring that noise mapping in Europe is carried out in accordance with a uniform methodology, and achieving comparability. The report published in 2012, certifies ECAC.Doc. 29 as the basis on which to calculate aircraft noise, supplemented by elements of the German Instruction on the Calculation of Noise Protection Areas (AzB 2008) (cf. [98]). The introduction of uniform calculation bases at EU level could contribute to harmonizing the assessment of aircraft noise, which would facilitate a uniform assessment process.

2) Report of the Commission (COM/2011/0321)

In 2011, the European Commission submitted the first report based on Art. 11 END to the European Parliament.[11] This report (COM/2011/0321 final, p. 1) assesses the need for further Community actions on environmental noise (Art. 11 Para. 2 END), and reviews the acoustic environment quality in the EU based on the data submitted by Member States (Art. 11 Para. 3 END).

In the course of its evaluation, the Commission has established, with regard to noise indications and limit values, that 22 Member States have established legally binding noise limit values (of which three are still in progress), and only four Member States have only provided benchmark values. It is frequently noted that standardized noise protection values are exceeded, without carrying out sufficient remediation measures. The report states that in some countries the implementation of such measures was not linked to whether a value is binding or not.

The Commission faced a broad spectrum of limit, trigger and guideline values, and only five member states "specifically indicated that they had used health-based assessments or drew on WHO health-based assessments in establishing noise limit values" (COM/2011/0321 final, p. 4).

Despite these disparities, the European Commission, in 2011, rejected the adoption of mandatory noise limit values or noise target values at EU level, on the basis of the principle of subsidiarity. If that were done, national and local authorities would have limited flexibility to adapt the level of protection and the action plans/measures to their specific situations. On the other hand, the establishment of EU noise trigger values, minimum requirements, or EU recommendations were expressly considered. In the Commission's view such approaches are advantageous, since they could serve as minimum thresholds to trigger action on noise but would not prevent Member States from setting stricter requirements, where necessary (COM/2011/0321 final, p. 11).

D. The 7^th^ EU Environmental Action Programme

According to the 7th EU Environmental Action Programme[12], (EAP), noise protection as per Art. 2 Para. 1 Subp. c is the priority objective within the general objective to safeguard the Union's citizens from environment-related pressures and risks to health and well-being.

In a total of 106 points, the Programme presents an environmental strategy for Europe until 2020. With regard to noise, point 49 states that available data on long-term average exposure show that 65% of Europeans living in major urban areas are exposed to high noise levels, and more than 20% to night time noise levels at which adverse health effects occur frequently. A "high noise level" is defined as one above 55 dB during day-time (L_{den}) and 50 dB at night (L_{night}).

Thus, the 7th EAP states that noise related "adverse health effects" do occur in the EU. Accordingly, the 7th EAP should ensure that "noise exposure in the Union has significantly decreased [by 2020], moving closer to WHO recommended levels

[10] COM/2004/0160, accessible at http://eur-lex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:52004DC0160&from=EN
[11] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0321:FIN:EN:PDF.
[12] Art. 1 of Decision no. 1386/2013/EU of the European Parliament and the Council of November 20, 2013 on a general Environmental Action Programme for the EU for the period of time through 2020 titled "Living well within the limits of our planet", established the 7th EU Environmental Action Programme, which will be valid until December 31, 2020 (accessible under http://bookshop.europa.eu/en/general-unionenvironment-action-programme-to-2020-pbKH0113833/).

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(point 54 (b))”. In order to achieve this goal, point 54 (ii) requires implementing an updated Union noise policy aligned with the latest scientific knowledge, and measures to reduce noise at source, including improvements in city design (7th EAP: pp. 48 and 51).

E. Legal conclusions from the results of the present synopsis

It follows from the above that EU efforts are evidently geared to realizing a European noise protection level aligned with the latest scientific knowledge, and, in the long term, conforming to WHO recommendations. The present synopsis shows that the rationale for noise effect research supports the correctness of the holistic approach of the European noise protection policy (firstly, comprehensively codified in the Environmental Noise Directive) in many aspects. At the same time, there is need for further improvement. An amendment of the END should entail instruments to ensure the intended level of protection and to fulfil the primary law provisions. However, “adverse health effects”, as identified by EU bodies, also underpin the imperative to act at national and local level.

1) Noise Indications for Health and Considerable Annoyance

First of all, this involves using a noise indicator for a 24-hour day instead of subdividing it into a day-time level and a night-time level. The present synopsis has particularly shown that health related effects of noise exposure, such as hypertension, cannot easily be presented in terms of a 16-hour day level, since health – or a healthy human being – cannot be subdivided into day-time and night-time segments. Rather, dealing with day-time noise exposure is inextricably linked with the night-time challenges for mind and body. The same applies to considerable annoyance. Therefore, a noise indicator merely covering a 16-hour time period is only suitable to describe a threshold for health risks in the case of airports without night-time operations. Since many civilian airports in Europe also operate at night, the noise indicator with a day-evening-night level, introduced by the END, is the preferred parameter from the viewpoint of noise effect research. Due to the special health-related relevance of night-time noise exposure, the additional use of the L night level is indispensable.

Therefore, noise indicators should be codified not only for the assessment of noise exposure, but also as a basis for an assessment of health effects, amending the existing Art. 6 Para. 3 END.

2) Updating the EU‘s Exposure-response Relationships

The present synopsis has also shown that the Commission’s exposure-response relationships no longer appropriately reflect today’s aircraft noise exposure. In order to improve comparability of noise assessment and the achievement of Art 6 Para. 3 and Annex III END, recommendations for the application of exposure-response relationships should be developed based on an evaluation of the investigations discussed in the present synopsis.

For this purpose, European studies since 2000 should be assessed, as Janssen et al. already did in 2009 for recent European studies (e.g. Switzerland, Germany and the Netherlands) carried out between 1991 and 2006 [31]. The assessment should also cover results of the ongoing NORAH-Study.

3) More Comprehensive Noise Mapping

With reference to noise mapping, the noise indicators L_{den} and L_{night} are already binding minimum levels in terms of noise values. It is the sole example of “binding” noise values in the END. Annex VI Nos. 1.5, 1.6 as well as 2.5, and the 2006 END provide for mandatory mapping at an L_{den} of 55 dB(A) and an L_{night} of 50 dB(A); for the night-time value, an additional mapping procedure as from 45 dB(A) is optional.

The present synopsis shows that according to today’s level of knowledge, an L_{den} of 50 dB(A) in a 24-hour day should be regarded as the emmission limit value for aircraft noise in order to avoid the risk of hypertension; night-time aircraft noise should not exceed an L_{night} of 45 dB(A). Hence, seen from the perspective of health protection, it is necessary to stipulate mandatory noise mapping already at these noise values to embrace noise hazardous to human health. Therefore, noise mapping starting at L_{den} = 50 dB(A) and L_{night} = 45 dB(A) is necessary. So revision of the END is required.

Considering the precautionary principle, Annex VI should provide for embracing and designating noise exposure at a level reduced by 5 dB(A) while noise maps are drafted. Aircraft noise should therefore be mapped at an L_{den} of 45 dB(A) and an L_{night} of 40 dB(A).

No major additional cost would be associated with this, since the incorporation of additional certifiable noise level ranges would be possible by means of a few additional calculations. At the same time, investments in a yet incomplete monitoring network would enable the ascertainment of data in quiet areas, and hence, as provided by

Art. 8 Para. 1 of the Directive, their incorporation into action plans. Such an expansion of the mapping requirement has already been considered by the European Commission in its report under Art. 11 END(cf.COM/2011/0321 final, No. 15).

4) European Noise Limits

With regard to the question of whether binding European noise limits can or should be established, the term “limit” itself is essential. On the one hand, limits can be considered values which are strictly binding, and may hence not be exceeded. In the

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context of aircraft noise, these "real" limits are sporadic. Generally, the term "limit" means a value which requires certain measures if it is exceeded: either the elimination or reduction of the noise source itself, or protective measures with regard to the affected objective of protection.

However, in the Commission's view, binding noise limit values or noise target values[13] (to be understood as targeted reduction goals) are, because of the principle of subsidiarity, not a suitable tool for future noise protection policy in the European Union. Likewise, the Commission fears that coping with country-specific noise situations could be hampered by introducing binding limits.

This could certainly be true to the extent that, at this juncture, the implementation of binding European noise limits could demand too much of those countries where few noise protection measures have been realized to date, since significant rehabilitation costs may arise. This could cause a considerable competitive disadvantage for airports which are regularly affected by such a burden of cost. A specific duty for Member States to maintain quiet areas, as well as a fundamental general ban on a deterioration of the noise situation, would prevent noise standards already achieved from being further eroded. At the same time, all Member States should be given the possibility to catch up on noise protection. Therefore, binding noise limits at EU level appear to be inadvisable, given the currently limited level of harmonization.

Considering the great importance of noise protection in the EU bodies' view, and taking into account the economic and social costs, efforts of Member States in noise abatement planning should already be oriented towards a noise reduction goal defined as "target value", especially due to the new objectives of the 7th EU Environmental Action Programme (contrary to the European Commission's view).

5) European Trigger Values and Alarm Thresholds for Noise Action Planning

Member States should be obligated to establish noise action plans in cases where noise values, whose transgression causes adverse health effects, are exceeded, and to adopt noise reduction measures at source or at receiver's side, by way of specifying the stipulations of Art. 8 END. Here, trigger values and alarm thresholds should be established.

Trigger values causing the obligation to establish a noise action plan should, according to the information gained by the present synopsis, be determined for an L_{den} of 50 dB(A) and an L_{night} of 45 dB(A), in order to avoid annoyance, adverse health effects as well as cognitive impairment, thus embracing all legally protected goals of the END.

Alarm thresholds, to be understood as values from which it is envisaged that measures in a noise action plan aiming at reducing noise values or the exposure at the receiving point should be taken, should be set at an L_{den} of 55 dB(A) and an L_{night} of 50 dB(A). Noise action plans could thus be more closely oriented towards "clean air" action plans.[13]

6) Enforcement of Member States' Obligations under the END

As the European Commission has ascertained, to date the Directive has no clear enforcement provisions under which limit value transgressions in action plans could be directly connected to possible reduction measures. This is explicitly true also for those Member States which have established legally binding limits at national level. Consequently, according to the European Commission, there often seems to be the possibility of exceeding limit values without legal consequences. Therefore, the Commission is considering the establishment of clear targets, contents and the implementation of action plans (COM/2011/0321 final, No. 16).

Since noise action plans aim at contributing to the protection of human health, and the reduction of significant annoyance, concrete possibilities for noise reduction should be provided as part of noise action plans. Furthermore, the obligation to set precise time limits for the achievement of certain reduction goals, accompanied by stipulations to monitor the results, would be a suitable means for improving the practical effectiveness of noise action plans. Member States should likewise be obliged to appropriately ensure that measures provided in noise action plans are not counteracted by plans of other planning authorities. In Germany, measures stipulated in noise action plans are viewed as simple balance-of-interests considerations by other decision-makers, which they merely have to consider; they therefore have relatively slight force in practice.

Moreover, owing to the direct relevance for fundamental Union rights, it should be ensured that individuals can invoke trigger values and alarm thresholds. The recent development of environmental law has shown that particularly the recognition of individual EU citizens' rights generates considerable implementation pressure upon Member States. Hence it is appropriate to promote EU noise protection in this respect. Members of the public who are affected by environmental noise as well as environmental associations should therefore have the right to demand both the establishment of noise action plans and the implementation of concrete noise reduction measures through the courts of their respective countries.

[13] The "Clean Air for Europe" Directive 2008/50/EC defines in Art. 2 Subp. 9 "target value' shall mean a level fixed with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole, to be attained where possible over a given period"

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VI. REFERENCE

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