Health Consequences of Aircraft Noise

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Abstract

Introduction

The ever-increasing level of air traffic means that any medical evaluation of its effects must be based on recent data.

Methods

Selective literature review of epidemiological studies from 2000 to 2007 regarding the illnesses, annoyance, and learning disorders resulting from aircraft noise.

Results

In residential areas, outdoor aircraft noise-induced equivalent noise levels of 60 dB(A) in the daytime and 45 dB(A) at night are associated with an increased incidence of hypertension. There is a dose-response relationship between aircraft noise and the occurrence of arterial hypertension. The prescription frequency of blood pressure-lowering medications is associated dose-dependently with aircraft noise from a level of about 45 dB(A). Around 25% of the population are greatly annoyed by exposure to noise of 55 dB(A) during the daytime. Exposure to 50 dB(A) in the daytime (outside) is associated with relevant learning difficulties in schoolchildren.

Discussion

Based on recent epidemiological studies, outdoor noise limits of 60 dB(A) in the daytime and 50 dB(A) at night can be recommended on grounds of health protection. Hence, maximum values of 55 dB(A) for the day and 45 dB(A) for the night should be aimed for in order to protect the more sensitive segments of the population such as children, the elderly, and the chronically ill. These values are 5 to 10 dB(A) lower than those specified by the German federal law on aircraft noise and in the report "synopsis" commissioned by the company that runs Frankfurt airport (Fraport).

Keywords: aircraft noise, noise exposure, hypertension, myocardial infarction, environmental pollution

Continually rising levels of air traffic are making it increasingly important to medically evaluate the effects of aircraft noise, with particular emphasis on organic diseases, annoyance, and functional disorders. Field studies under conditions of daily living are suitable instruments for this purpose. Laboratory tests are of only limited value because they fail to record phenomena such as habituation, sensitization, conditioning, and exhaustion. Sleep disorders in the form of awakening reactions (1) are also little suited for evaluation purposes since their avoidance is insufficient for the prevention of long-term health hazards (2).

Epidemiological research into the effects of noise has made significant strides in recent years. The availability of new studies therefore mandates a reassessment of the current situation. Many of the epidemiological studies published up to the year 2000 exhibit methodological deficiencies. In many cases, extreme groups were considered in a simplifying approach or the study population was classified as "exposed to stress" and "not exposed to stress" on the basis of a noise level criterion. These studies reveal only a trend towards increased health risks from continuous noise levels of 65 dB(A) upwards (3). New results are available especially as regards hypertension, annoyance, and learning difficulties (box 1).
Box 1

How loud are continuous sound levels?

Continuous sound levels are energy values averaged over a long assessment period and are inaudible. Only momentary sound events are perceptible. If the sound energy remains constant over the assessment period, however, the continuous sound level has the same value as the momentary sound level. The continuous sound level, with additions or deductions for the time of day, for example, is a single figure value intended to gauge only the long term effects of a noise situation. In Germany the established practice is to differentiate between the continuous daytime sound level (6 a.m. to 10 p.m.) and the continuous nocturnal sound level (10 p.m. to 6 a.m.). The unit of measurement is the dB(A), which takes into account that human hearing has variable sensitivity for different frequencies. The fact that aircraft noise is perceived as a greater annoyance than road and rail noise, however, is not factored in. In residential areas around civil airports, the continuous aircraft related noise level now reaches levels exceeding 65 dB(A). For example, about 200 000 residents in the area around Frankfurt Airport, some of whom live more than 20 km distant from the airport along the flight corridors, are exposed to a continuous daytime noise level of 55 dB(A) and above.

Method

A selective literature review of epidemiological studies from 2000 to March 2007 was performed in the DIMDI and PubMed databases using the search terms noise and epidemiol*** (German and English), supplemented by literature references from the authors’ own databases. Articles with the terms occupational, work, and tinnitus were excluded electronically. In a second step, articles obviously unrelated to the study topic, such as studies on the effects on hearing or language, were excluded. In the third step, 10 primary studies among 81 remaining publications were identified on the basis of study topic (for example day or night), design (information value), scope (avoidance of random errors), and the probability of systematic errors (bias) (table 1). Inclusion criteria were case numbers of above 1000 or more than 5000 individual measured values in the case of the time-series studies, address-based recording of aircraft noise exposure, and standardized recording of the effect endpoints or medical diagnoses of diseases elicited by questionnaire. Review articles and standard publications as well as studies with other effect endpoints were disregarded. The primary studies identified on this basis were evaluated in terms of diseases, noise annoyance, and learning difficulties.

Table 1

Overview of selected primary studies

As regards myocardial infarction, one road traffic noise study is also mentioned (4) because no aircraft noise studies are available on this topic. One study from 1995 (16) is devoted to learning difficulties; there are no new longitudinal observations on this subject (table 1).

Results

The most informative new studies relate to hypertension, annoyance, and learning difficulties. As far as may be deduced from the findings, absolute changes in risk were reported. A study of road traffic noise annoyance and a meta-analysis showed a significant noise-related increase in myocardial infarctions from continuous daytime noise levels of 60 dB(A) upwards (4, 5). No studies exploring a relationship with aircraft noise are available. This association is therefore not examined more closely. There is no
Hypertensive disease

In pathophysiological terms, the development of noise-related hypertension is regarded as the consequence of impaired recovery processes. Noise-related stress persisting over long periods can lead to the exhaustion of compensatory mechanisms and a decrease in the body’s regulatory capacity. In many cases, therefore, health effects of chronic noise-related stress only begin to appear after 5 to 15 years (6). Chronic arterial hypertension affects a large segment of the population and is a major risk factor for myocardial infarction and stroke. At least every third adult has blood pressure values above the optimal range and an increase from "optimal" to still normal blood pressure values doubles the risk of stroke or myocardial infarction (7).

In 2001, Rosenlund evaluated aircraft noise exposure for 2959 adults based on an address-specific search and found an association between the increase in raised blood pressure and a continuous 24 h aircraft noise level (FBN) above 55 dB(A) and at maximum levels above 72 dB(A) (8).

Eriksson et al. studied 2037 men in the 40 to 60 year age group over a 10 year period (9). The continuous noise levels (FBN) were determined for exact addresses using a geo-information system (GIS technology). The presence of hypertension was documented by repeated medical examinations including blood pressure measurements and a questionnaire about cardiovascular treatments and risk factors. Exposure to aircraft noise above 50 dB(A) (FBN) was associated with a significant 20% increase in the risk of hypertension (table 2).

| Table 2 |
| Relationship between aircraft noise annoyance and number of hypertension sufferers (HT) |

The special significance of nocturnal noise exposure for the development of hypertension is demonstrated by the HYENA study (10), which studied 4861 adults aged 45 to 70 years living in the close vicinity of 6 European airports. The continuous noise levels were determined to an accuracy of 1 dB for exact addresses, separately for the day and night. The presence of hypertension was determined by repeated blood pressure measurements and a questionnaire about cardiovascular treatments. The prevalence of hypertension adjusted for age and gender was between 49% and 57% in the countries concerned. A 10 dB increase in the continuous night-time noise level was found to be significantly associated with a 14% increase in the probability of being diagnosed with hypertension. The first significant level class was 40 to 44 dB(A). The chance of becoming ill also increased slightly with continuous daytime noise levels, but was not statistically significant.

A Swedish study (11) demonstrated a close association between noise level, hypertension, and use of blood pressure lowering medications (figure 1). 1953 volunteers aged between 18 and 75 years from a random sample were studied. The feedback rate was 71%. All volunteers were exposed to a traffic induced continuous noise level (road, rail, air traffic) of at least 45 dB(A) over 24 h. The noise exposure was determined for exact addresses (GIS technology) and compared with medical diagnoses of hypertension elicited by a questionnaire (figure 1).
Increased medication consumption associated with aircraft noise exposure was also revealed by a Dutch study with 11,812 participants. In this case, however, exposure was only recorded approximately by means of zip codes (12). In this case the clearest increase in consumption was associated with evening noise, which could be due to the legal restrictions on night flight activity in Amsterdam.

The largest study of medication use was performed in the vicinity of Cologne/Bonn Airport (Germany). Individual prescription data of 809,379 persons insured with statutory health insurance companies were linked to address-specific aircraft and road traffic noise exposure data (GIS technology) (13, e4). The study revealed significant relationships between the intensity of aircraft noise and the number of antihypertensive medications prescribed per patient. The increase in prescription prevalence correlated most clearly with night-time aircraft noise between 3 and 5 a.m., since the highest nocturnal aircraft noise exposure occurs at Cologne/Bonn Airport during this period. For this time window, antihypertensive medications for women were already prescribed 27% significantly more often at a continuous aircraft noise level of 40 to 45 dB(A) and 66% significantly more often at 46 to 61 dB(A). For men, the significant increase in prescription prevalence was 24% at continuous noise levels of 46 to 61 dB(A).

Significant exposure dose-effect associations were detected, i.e. the more noise, the more medications were prescribed (figure 2).

As regards the prodromal stages of chronic hypertensive disease, a time-series study performed in the vicinity of Frankfurt Airport in Germany showed that a relationship between the day-to-day variations in aircraft noise and morning blood pressure is also present in the physiological range. Two groups exposed to a continuous nocturnal outdoor air traffic noise level of 50 dB(A) were compared for three months: the West group was exposed for 75% of the time, the East group for 25% of the time. The evaluation of altogether 8266 blood pressure measurements in 53 persons showed that blood pressure was statistically significantly higher by a mean 10/8 mmHg in the West group compared to the East group. The West group was also found to have a reduced relaxation ability insofar as the "less noisy" periods were no longer perceived as such as a consequence of the noise related stress (14).

There are no epidemiological studies with results that contradict an increase in hypertension due to aircraft noise.

**Learning difficulties**

Noise can impair human mental performance without detectable organic damage. Stansfeld et al. studied 2844 children aged 9 to 10 years in 89 schools. These children showed a significant relationship between the deterioration in silent reading comprehension and certain memory performances and increasing aircraft noise exposure at schools (15). Reading comprehension showed a linear decrease with increasing noise (figure 3 a), while the subjective annoyance showed a logarithmic increase (figure 3 b).
An earlier longitudinal study in 9- to 13-year-olds in Munich, Germany, produced similar results (16, e5, e6), while a study in 11-year-olds from 2002 (e7) showed that socioeconomic factors could be responsible for the learning impairments. In the Stansfeld study, the relationships demonstrated remained statistically significant after adjustment for mother’s education, socioeconomic status, longstanding illness, and extent of classroom insulation against noise (15). Children had a one- to two-month reading delay per 5 dB(A) increase in aircraft noise (15, e8–e10). There are no studies that contradict these findings.

Annoyance

Aircraft noise annoyance is evaluated in Europe mainly by means of meta-analyses of the kind submitted by Miedema et al. (17, e11). The studies on which they are based, however, are more than 25 years old in relation to the year 2007.

The air traffic investigated in these studies and the types of aircraft operating at that time are hardly comparable with the present day situation at passenger airports. A new study performed in the vicinity of Frankfurt Airport revealed that 64% of the survey sample felt themselves exposed to moderate to extreme aircraft noise annoyance, compared to only 23% in the rest of the state of Hesse. The survey sample classified aircraft noise as the most objectionable source of noise (18, 19, e12): the higher the aircraft noise level, the greater was the annoyance (figure 4).

At a continuous daytime outdoor noise level of 53 dB(A), 25% of local residents considered themselves exposed to a serious noise annoyance. In the relevant legislation, this percentage is defined as the beginning of considerable annoyance (e13). A comparison of the 25% annoyance curve of Frankfurt with that of other European airports shows that the Frankfurt values are in the mid-range of more recent studies. It may therefore be assumed that the noise associated with the anticipated extension is not greatly overestimated (figure 5). The aircraft noise was perceived as a particular nuisance in the night and in the off-peak hours, i.e., in the morning and evening. In addition, aircraft noise was perceived as a much greater annoyance at the weekends than during the week (19) (figure 5).
The boundary to considerable annoyance is now established at much lower continuous aircraft noise levels than in previous studies. Guski et al. already mentioned in 2004 that between 1960 and 1995 the continuous noise level decreased by about 8 dB(A) with the same level of annoyance (20). Today the boundary at which 25% of the average population feel seriously affected is approximately another 8 dB(A) lower. High mobility figures, sensitization by years of stress and the refined study methodologies are under discussion as reasons for this decrease.

Nocturnal noise

In the HYENA study, an increase in blood pressure requiring treatment was significantly associated with a continuous nocturnal aircraft noise level of 40 to 44 dB(A), compared to an exposure below 35 dB(A). In the Eriksson study (9) in the 40 to 60 year age group of volunteers, a risk increase was associated with a nocturnal aircraft noise level from about 40 dB(A) upwards, assuming an 8% night air traffic and 20% evening air traffic distribution. The Cologne medication study yielded similar threshold values. In this case, a significant increase in prescriptions for antihypertensive medications was already associated with nocturnal exposure, between 3 and 5 a.m., in the range of 40 to 45 dB(A) in women and of 46 to 61 dB(A) in men. Health is therefore impaired at the latest by a continuous nocturnal aircraft noise level of 50 dB(A). From this level onwards, organic diseases and functional disorders with a positive exposure-effect relationship are to be expected. As with other injurious environmental factors, a certain distance from this level must be maintained. In 2001, a night-time level of 45 dB(A) was recommended as a prophylactic value by the great majority of German noise researchers (21). Recent epidemiological studies confirm this estimate.

Whereas a nocturnal health hazard was formerly evaluated on the basis of awakening reactions, principal emphasis is now placed on the increased incidence of cardiovascular diseases associated with night-time noise (2). Assessing the hazard solely on the basis of awakening reactions is not acceptable because long-term health impairments cannot be ruled out when using this approach (2).

Daytime noise

Associations are also detectable for daytime noise annoyance. Increased use of antihypertensive medications was significant in the level class $L_{eq}$, 16 h at approx. 57.5 to 61.5 dB(A) during the daytime (11). Impairment of cognitive abilities of schoolchildren was exposure related and began at continuous outdoor aircraft noise levels above 45 dB(A) (16). Aircraft noise levels causing serious annoyance for 25% of the average population are classified in Germany as the upper limit of acceptable noise annoyance. In the Frankfurt study on noise annoyance, the boundary to considerable annoyance was defined as a continuous daytime noise level of 53 dB(A). The risk of health impairments therefore begins at the latest at continuous daytime noise levels of 60 dB(A). In terms of sensitivity, off-peak times during the day are to be classified as between the daytime and night-time value.

Discussion

The guide values determined are consistent with the findings and recommendations of German and international noise research (2, 21). The authors consider a publication bias unlikely because the large studies are usually already known while they are in progress and before results have been determined. Major deviations are revealed by the "synopsis" report commissioned by the company that runs Frankfurt Airport (22, 23). Since this summarizing assessment is frequently considered judicially to represent the current state of knowledge, a comparison with recent epidemiological findings is provided in table 3.
The "synopsis" report is based on the following definitions, among others:

- A critical tolerance value states that health hazards or impairments can no longer be ruled out.
- A preventive guide value defines when health hazards are largely ruled out (table 3).

In their publication of 2007, the authors of the Frankfurt "synopsis" see no reason to depart from the previous conclusions (23).

The higher values of still acceptable noise exposure can be explained to a great extent by the fact that the less suitable and in most cases old laboratory studies and the occurrence of night-time awakening reactions continue to be regarded as authoritative in the report. According to the new epidemiological studies, continuous daytime outdoor noise levels of 60 dB(A) and night-time levels of 50 dB(A) should not be exceeded in residential areas in order to extensively rule out damage to health. Vulnerable groups, especially children, the elderly, and the chronically ill may already be affected at levels below those tolerated by average persons. On medical criteria, a prophylactic outdoor value of 55 dB(A) (daytime) and 45 dB(A) (night-time) is therefore considered desirable. At about 55 dB(A) during the day it is to be assumed that 25% of persons will feel exposed to a serious noise annoyance.

Annoyance for awake persons can only be prevented by reducing aircraft noise (18, 19). The same presumably applies for the prevention of organic diseases and learning difficulties. Passive noise protection measures such as soundproof windows are not sufficient. Sleeping with closed, soundproof windows must also be regarded as hygienically questionable (24). Air change rates tend towards zero with closed windows. The DIN 1946-2 and DIN 1946-6 standards specify 0.15 percent by volume (1500 ppm) as the upper limit for CO₂ concentrations in living spaces (e₁₄–e₁₆). This value is already exceeded after the first hours of sleep when windows are closed (box 2).

### Box 2

**Noise protection areas**

The German Aircraft Noise Protection Act in the version of 30 October 2007 defines noise protection zones (NPZ) on the basis of continuous sound levels and maximum night-time level criteria. For new or substantially altered airports, the daytime protection areas begin at a continuous sound level of 60 dB(A). This represents NPZ 1. At night, the protection zone begins at a continuous sound level of 53 dB(A), from 2011 of 50 dB(A). From this level onwards, claims for damages for passive noise protection are possible. It is not yet clear what consequences the recently adopted Aircraft Noise Act has for persons living in the airport vicinity in terms of entitlement to active noise protection. Ekardt and Seidel take the view that the limits defined in the Act are only minimum standards that do not rule out the introduction of stricter requirements for planning purposes (25).

Based on these considerations and considering that the protection of health is guaranteed by the Basic Law, these results are of major relevance. The Aircraft Noise Act is to a great extent based on the state of scientific knowledge existing in the year 1999 when the first draft of the Amending Act was prepared.

Health hazards caused by aircraft noise can be most reliably identified from epidemiological field studies. The investigations conducted in recent years show distinctly lower guide values for health hazards, learning difficulties, and annoyance than previous assumptions on which the German Aircraft Noise Act is also based. Against this background, a warning must be issued from the medical viewpoint regarding a further increase in the widespread disease of hypertension associated with exposure to noise.

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### Footnotes
Conflict of interest statement

The authors declare that no conflict of interest exists according to the guidelines of the International Committee of Medical Journal Editors.

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Review Article

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