Environmental Research Consultancy Department

Aircraft Noise and Health Effects – a six monthly update

CAP 2963

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Chapter 1
Introduction

1.1 This report is an update on recent work and findings in the field of aircraft noise and health effects. It covers published research between September 2023 and March 2024 and also includes findings from the Internoise Congress held in August 2023, held in Chiba, Greater Tokyo.

1.2 The aim of the report is to provide a succinct overview of new work relating to aviation noise and health, and such updates are published on a six-monthly basis. This report has been published to provide the public and the aviation industry with a concise and accessible update on recent noise and health developments. It should be noted that the CAA has not validated any of the analysis reported at the conferences, nor takes any view on their applicability to UK policy making.

1.3 The findings in the following chapters are grouped by subject area and include those presented at Internoise and in academic journals in the past six months.

Chapter 2
Internoise 2023

Community Response and Annoyance

2.1 This section focuses on the findings from the Internoise 2023 Congress on community response to aircraft noise. The first paper was from **Scholten et al** which was a discussion on aviation noise in the United States and the current state of Federal Aviation Administration (FAA) research on community response.

2.2 The paper discusses how the Neighbourhood Environmental Survey (NES) by the FAA indicated that the exposure-response relationship between aircraft noise and annoyance has changed since the time of the Schultz curve, and that this is no longer an accurate representation of people's attitudes towards aircraft noise. The NES study, described in previous CAP reports, collected a nationally representative dataset of more than 10,000 responses on aircraft noise annoyance around 20 statistically representative airports across the U.S. and the aim was to obtain a contemporary update to the Schultz Curve.

2.3 Figure 1 shows the results from this study, which indicates that the NES results show a substantially higher percentage of people highly annoyed over the entire range of aircraft noise levels included in the study (50 – 75 dB DNL). NES results also show that annoyance at lower noise levels is proportionally higher than those observed from the Schultz Curve.

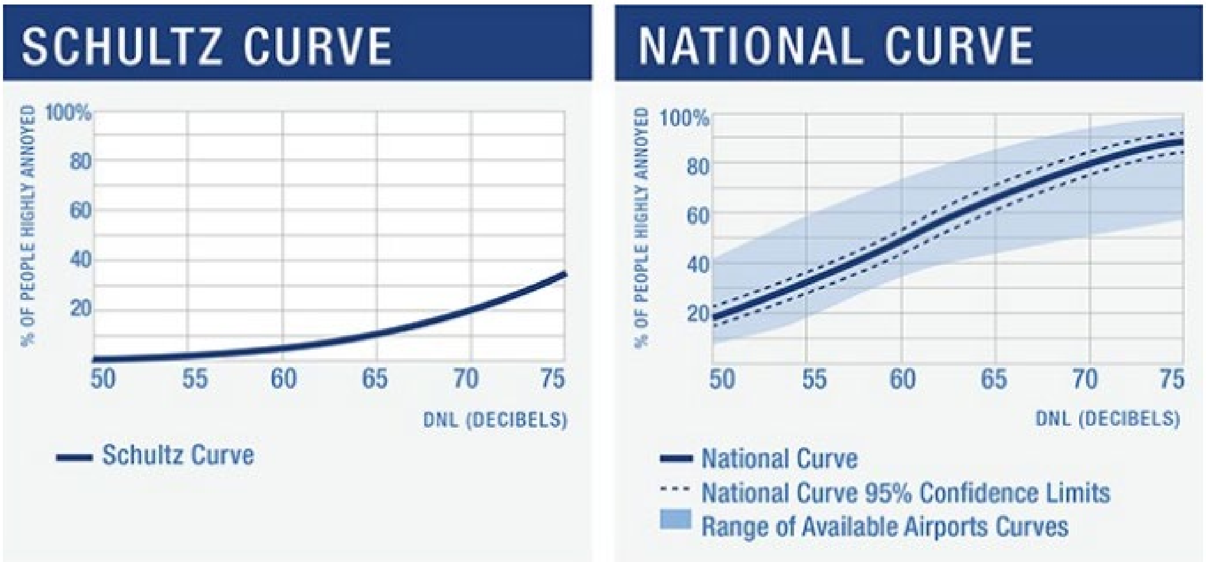

Figure 1: Comparison of Schultz Curve and the U.S. National Curve from the NES.

2.4 The FAA initiated follow-on studies to the NES, using data from the NES as well as additional data sources with the intent of using the findings to continue to help inform ongoing FAA research and policy priorities on aviation noise. The follow-on studies looked at noise metrics and significance thresholds of annoyance that will feed into a review report by the FAA on the foundational technical elements of its civil aviation noise policy. The review report will consider whether to retain or modify the FAA's system for considering aviation noise around airport communities, which currently comprises of the DNL metric, as well as consider whether to expand its system to allow for the expanded use of supplemental or alternative noise metrics for decision-making or disclosure purposes. The FAA will also determine whether a "significance threshold" for noise impacts should be retained or modified, and if so, how.

2.5 The follow-on studies examined the use of the Number Above (NA) metric, and whether this could improve upon modelling high annoyance compared to DNL's exposure-response relationship. The analysis examined seven thresholds of the NA metric, NA50 L_{max} - NA80 L_{max}, in 5 dB increments, using the 10,322 respondents from the NES. The authors explain that the results indicate a clear, increasing relationship between the number of events and high annoyance. Correlation coefficients between NA and DNL ranged from approximately 0.6 to 0.8 for the seven thresholds, with NA70 L_{max} being highest at 0.797.

2.6 When logistic regression was applied to the models, although the NA-only models were relatively good predictors of annoyance, the DNL models outperformed the NA-only models for 75 percent of the model types and fit/performance metrics. The conclusions stated were:

- Using NA in the high-annoyance dose-response modelling generally did not improve upon the DNL only model, and
- Replacing DNL with any (of the seven studied) NA L_{max} measures is unwarranted.

2.7 **Hauptvogel et al** presented a paper on the development and validation of the Aircraft Noise Related Fairness Inventory (fAIR-In). Perceived fairness is introduced as a concept that addresses factors such as the perceived fairness of the distribution of noise, and transparency from the airport in terms of decisions or developments. The authors explained that there has been a lack of a validated tool to measure such perceptions, and this led to the development of the fAIR-In.

2.8 Following the development process, 32 items were included in the fAIR-In and the survey was validated using additional scales for over 1300 respondents to answer. The fAIR-In included four elements of fairness: distributive, procedural, informational, and interpersonal. The results indicated that all fairness elements were negatively related to annoyance, ranging from moderate to strong. Fairness and acceptance of the airport and air traffic were positively related, ranging from moderate to strong. A negative correlation between willingness to protest and all fairness facets, ranging from weak to moderate was also observed.

2.9 The authors propose that this new, validated tool could be used to assess relationships between residents and airports, or other authorities. They suggest it could be a useful way of assessing the feeling of residents when considering any procedural changes, and it may provide an early opportunity to gauge any concerns and engage with residents in order to minimise a feeling of mistrust or lack of communication. This could also be applied to other noise sources, such as UAS and air taxis. This work was also published in the International Journal of Environmental Research and Public Health, and also at the 2023 ICBEN Congress.

2.10 **Gjestland** presented a discussion on factors influencing the results from social surveys. Typically, with transportation noise and community response such as annoyance, the results from social surveys are presented in an exposure-response curve, which allows for comparisons with other studies using the same methodology across communities. Gjestland states that the results from such surveys are not wholly dependent on noise exposure levels, and other factors are contributing to the annoyance response.

2.11 This paper was included in CAP 2587 as it was also presented at the 2023 ICBEN Congress. A more detailed description of the paper is provided in that report, but briefly, factors such as the use of annoyance response scales, mode of survey presentation, operational changes (high-rate change and low-rate change airports) and traffic volume are presented as factors that can influence social survey results.

2.12 Gjestland includes an example of a comparison of survey results and used the Miedema and Vos curve (face-to-face questionnaires) to compare with the 2021 20 US airports study (Miller et al, postal questionnaires) which was used to obtain a new US national average exposure-response curve. It is concluded that for accurate comparisons, new exposure-response curves must either be constructed on the same basis as Miedema and Vos (face-to-face questionnaires and using the 72% annoyance cut-off), or they should be adjusted accordingly.

2.13 **Akiyama et al** presented findings from a study on the effect of visual information of source image on aircraft noise annoyance. The rationale for this study is that although laboratory studies in anechoic chambers allow for specific noise stimuli to be presented and responses measured to just that sound, in the real-world people are exposed to the visual element of the noise source and other environmental factors.

2.14 Previous findings have suggested that annoyance to aircraft noise is less affected by visual stimuli compared to other transportation noise sources such as road traffic, boats, and railway noise). To study this further, this aim of this study was to explore the annoyance response to aircraft noise in addition to visual stimuli in an anechoic chamber. The average sound pressure level for aircraft noise used ranged from 61.8 to 71.4 dB $L_{Aeq,30s}$. For comparison with the previous study, stimuli of road traffic images and road traffic noise were also included.

2.15 Participants sat in the centre of the audio-visual simulation system and evaluated the annoyance of presented stimuli. 30 stimuli were presented randomly and repeated twice. Thirteen participants (8 males and 5 females, aged 22-25 years) were included. There were differences in the annoyance scores by visual stimuli. The differences for aircraft noise were smaller than those for road traffic noise. In the cases where $L_{Aeq,30s}$ was maximum (71.4 dB) and minimum (56.9 dB), there was a slight tendency for the difference of the annoyance response to increase. Some participants reported that the aircraft noises annoyed them at both low and high-frequency ranges.

2.16 To evaluate the effect of visual information more quantitatively on aircraft noise, the Magnitude Estimation (ME) method was adopted in the second part of the experiment. The effects of the visual information on annoyance were quantitatively evaluated by converting the differences of ME values to physical values of additional A-weighted sound pressure levels.

2.17 The results suggested that the annoyance reductions when presenting pictures of aircraft noise were about 0 to 3 dB. This tendency was similar to road traffic noise, but the effect seems to be smaller. The authors suggest that this may be due to participants not being as familiar with aircraft noise. It was also suggested that the gap between expected loudness based on the visual impression and actual loudness may affect the annoyance evaluation. The authors suggest future studies are needed to explore why the effects of visual information on the annoyance response are different based on the type of noise source.

2.18 **Brink and Wunderli** presented newly proposed Swiss transportation noise limits and compared them to the WHO recommendations. In December 2021, the Federal Noise Abatement Commission, an advisory committee of the Swiss government, proposed new noise limits for road, rail and air traffic that overall are considerably stronger than the values that are currently in force.

2.19 In the development of the new limits, subjective and objective effects were considered. Self-reported (”subjective”) effects like annoyance and self-reported sleep disturbances, and (”objective”) cardiometabolic effects for which the evidence was considered scientifically sound enough, namely ischaemic heart disease (IHD), diabetes, and cardiovascular mortality. In order to define acceptable risks for these outcomes, Disability Weights (DW)[1] were considered. In addition, based on the sleeping habits of the population, the duration of the night period was extended to nine hours, starting at 22:00 and ending at 07:00.

2.20 The adopted 'acceptable risks' (level at which a noise exposure value must be regarded as non-protective anymore (i.e., harmful or annoying in the sense of the Swiss legislation)) were defined and the resulting values calculated:

- **Self-reported effects**
  - Annoyance: 25% HA
  - Sleep Disturbance: 15% HSD
- **Objective disease effects**
  - Cardiovascular Disease Mortality: 2.5%
  - Ischemic Heart Disease IHD incidence: 5%
  - Diabetes incidence: 20%

2.21 The authors used exposure-response relationships for annoyance (%HA) (including the Swiss SiRENE survey) and studies on cardiovascular (CVD) mortality, ischemic heart disease (IHD) incidence and diabetes incidence, including both data from Switzerland and from the WHO evidence review on cardiovascular and metabolic effects for the calculation of the limit values for the L_{den} metric. Self-reported sleep disturbance studies, using both Swiss data and data from the WHO evidence review on noise effects on sleep were used for the determination of the L_{night} limit value. The authors explain that exposure-response functions for cardiometabolic and mortality endpoints were also included for L_{night} so that this value was not solely based on self-reported sleep disturbance data.

2.22 Table 1 shows the new limit values set for L_{den} and L_{night}. The authors explain that for the day period, the new limits for road traffic noise are about the same as the previous ones. In the case of railway and aircraft noise, they are about 6 dB stronger (i.e., lower) than in the current legislation. For the night-time, the recommended values are about 1 to 3 dB stronger than before.

[1] A DW is a weight factor that reflects the severity of a disease or condition on a scale from 0 (perfect health) to 1 (equivalent to death).

Table 1: Newly recommended limit values by the FNAC, given as L_{den} and L_{night} (dBA) [A] Limit value set due to self-reported effects. [B] Limit value set due to somatic-disease effects.

Source	Lden	Lnight
Road traffic noise	62 [B]	52 [B]
Railway noise	65 [A≈B]	56 [A=B]
Aircraft noise	55 [A≈B]	43 [A]

2.23 A comparison with the WHO recommendations is provided by the authors, and the observation that the new limits set by FNAC are considerably higher than those given by WHO. This is shown in Table 2. The authors suggest that this discrepancy is due to the WHO recommendations working on a lowest-observed-adverse-effect (LOAL) principle, and the FNAC limits are based on the Swiss Environmental Protection Act which states that limit values should (only) protect against "significant" disturbances of well-being and can therefore be set higher.

Table 2: Recommended limit values for L_{den} and L_{night} by the FNAC and the WHO (dBA), and their differences. The '+' indicates that the FNAC recommendation is less strong than the respective WHO Guideline value.

	FNAC Lden	WHO Lden	FNAC Lnight	WHO Lnight	Diff. Lden	Diff. Lnight
Road traffic	62	53	52	45	+ 9 dB	+ 7 dB
Railways	65	54	56	44	+ 11 dB	+ 12 dB
Aircraft	55	45	43	40	+ 10 dB	+ 3 dB

2.24 Three papers were presented that examined aircraft noise effects in the Far East. The first, by **Lertsawat et al** investigated characteristics of community responses to airport noise around Bangkok International Airport. The study collected survey data ten years after the opening of the airport in 2006, and prior to planned expansion to enable more air traffic movements and passenger capacity. The survey data was collected between June and August in 2015 and included annoyance questions, and a quality-of-life questionnaire designed by the WHO (WHOQOL).

2.25 A preliminary study was conducted in 2014, which involved paper-based surveys and web surveys. The researchers found that using the web-based questionnaire form involved difficulties in handling field work smoothly, for example, internet connection problems, test takers unfamiliar with web-based forms, etc.

Therefore, for the 2015 full study, it was decided to use paper-based questionnaires only. 1,633 questionnaires were distributed, and 1,289 households were randomly surveyed in the full-scale study in 2015.

2.26 Figure 2 illustrates the responses relating to aircraft noise sources, on an 11-scale answer questionnaire (QB6) about aircraft noise disturbance during the 12-month period that the respondents lived in the community prior to being involved in the survey. The results found that 44 out of 147 respondents, 59 out of 146 respondents, and 208 out of 1,289 respondents answered that they were most affected by aircraft noise and gave a rating of 10 for the 2014 paper-based, 2014 web-based, and 2015 paper-based, respectively.

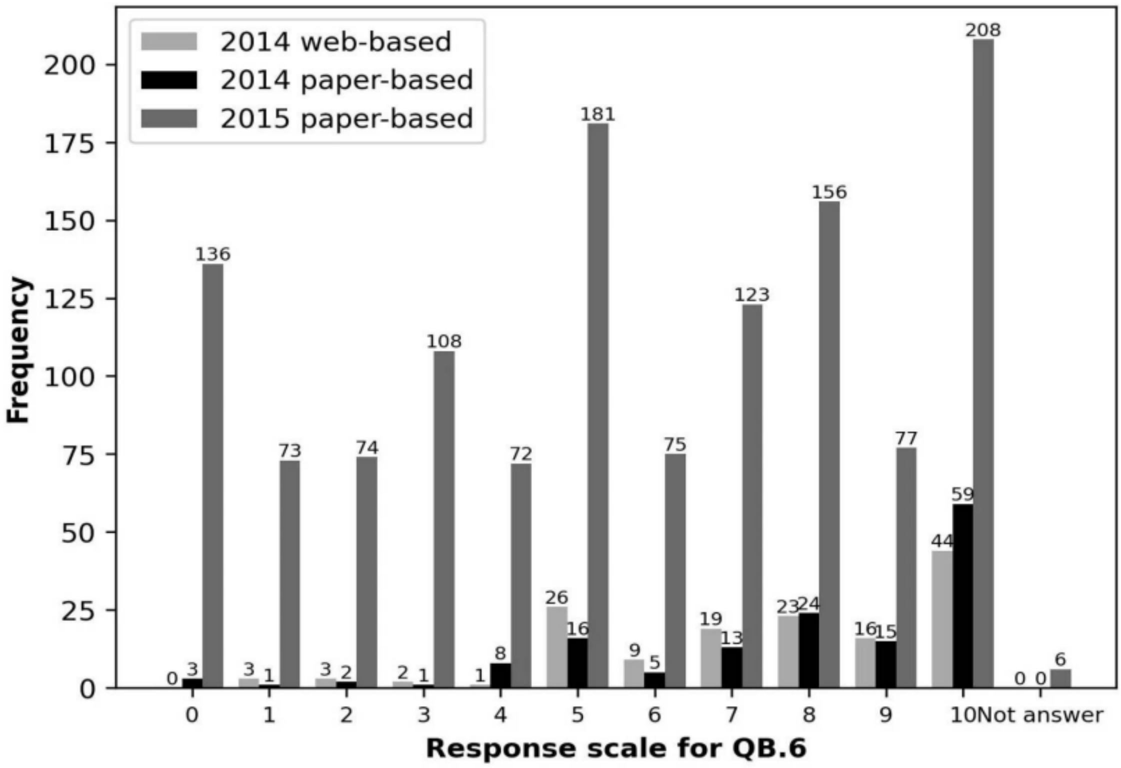

Figure 2: Noise annoyance responses as answered on an eleven-point scale for aircraft noise (QB6)

2.27 The authors explain that the study will provide a useful baseline for data on annoyance from aircraft noise prior to the planned expansion of the airport. The researchers plan to conduct a cross-analysis of the dataset with noise exposure levels from the predicted noise exposure map using the noise prediction model. The exposure-response relationship will be calculated to illustrate annoyance to aircraft noise for operations during the first phase of Suvarnaphumi Airport service in Thailand.

2.28 **Nguyen et al** presented findings from a study investigating the long-term effects of aircraft noise on the residents living around Long Thanh Airport before its opening. Long Thanh Airport (LT) is a new airport that is due to open in 2025 and will be the largest aviation hub in Vietnam. This purpose of this study was to obtain baseline measurements for health conditions and annoyance in the residents living around this area, so comparisons can be made once the airport is operational.

2.29 To date, the main source of environmental noise for these residents has been from road noise, with the 24-hour A-weighted equivalent continuous sound level (L_{Aeq}) at a representative house in each area ranging from 51 to 72 dB. The study will focus on evaluating the health of residents in ten residential areas situated along the planned flight paths of LT. The study surveyed over 640 people in 2022 and gathered data on health conditions. Noise sensitivity, mobility patterns, and attitudes towards different modes of transportation were also investigated.

2.30 The results indicated that satisfaction with the information provided about the airport was high, with only 2 respondents expressing dissatisfaction. Most respondents (90%) supported the proposal. In terms of anticipated changes once the airport is operational, 57% of respondents believed that noise levels would worsen. In residential areas, 85% of respondents expected improvement, while 15% anticipated a decline. 86% of respondents anticipated an enhanced quality of life once the airport is operational. Most (90%) of respondents did not oppose the opening of the new airport, with only a small number expressing opposition.

2.31 The percentage of highly annoyed (%HA) respondents across the ten selected sites ranged from 0.0% to 5.1%, Insomnia levels ranged from 0.0% to 5.0%. The percentage of respondents with low sleep quality ranged from 5.2% to 15.0%. No distinct correlation was found between noise levels and low sleep quality, as both higher and lower noise levels were associated with varying percentages of respondents experiencing this issue.

2.32 Figure 3 illustrates the relationships between $L_{Aeq,24h}$ and the percentage of highly annoyed (%HA) for aircraft, road traffic, and general environmental noise based on data from 641 respondents across ten selected sites. The logistic regression model indicated that at the same noise level, the proportion of people annoyed is higher for road traffic noise compared to environmental noise. This may be explained by road traffic being the predominant noise source at this stage.

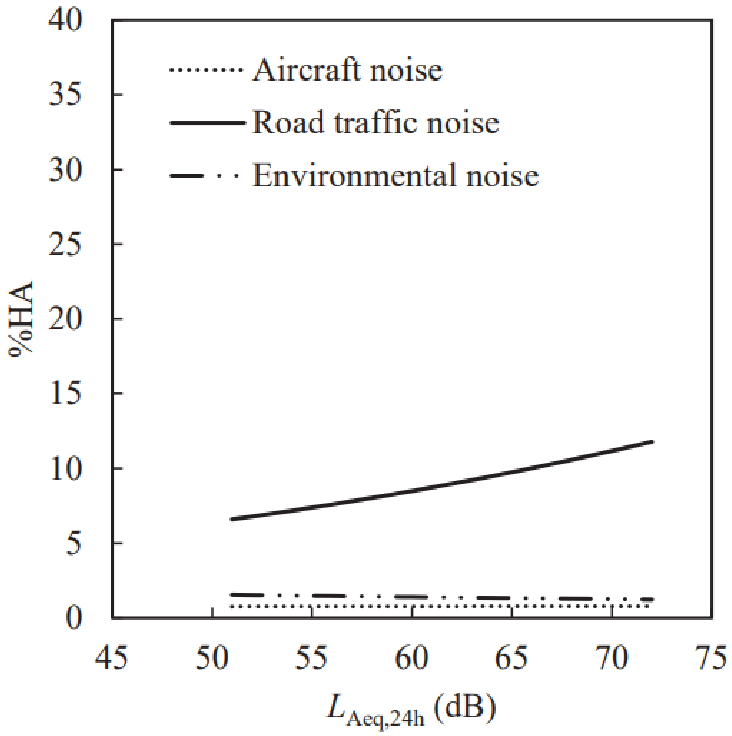

Figure 3: $L_{Aeq,24h}$, %HA for aircraft, road traffic, and general environmental noise relationships

2.33 It is explained that the regression model also considers contextual factors, noise exposure, and other factors impacting health, and analysis indicated that the health of the residents is associated with non-acoustic factors beyond noise exposure, such as sensitivity and attitude towards transport modes. The authors refer to another study in Vietnam, Noi Bai Airport (described in CAP 2587) where a significant change in annoyance was observed following the opening of a new terminal building in 2014. It is suggested that the same response will occur for LT airport, but it is stressed that in high noise environments where there is a lot of road traffic background noise, it is not always possible for residents to identify the noise source and people are generally more annoyed by noise when they can easily identify its source. The study found that traffic noise was the most frequently cited environmental nuisance among the surveyed participants in the vicinity of the newly-planned airport. The authors explain that community response to noise in extremely noisy urban environments, like Ho Chi Minh City, has very specific characteristics. The high levels of background noise from heavy motor vehicles mean that residents are unable to identify a particular noise source that they are exposed to, leading them to potentially underestimate the impact of specific noise sources.

2.34 **Shiotani et al** presented a discussion on the comparison between the WHO Environmental Noise Guidelines (ENG) (2018) and Japanese environmental quality standards for road, railway, and aircraft noise. They also compared the incidence of Ischemic Heart Disease (IHD) between Europe and Japan. For the Japanese environmental quality standards for noise, the equivalent value of L_{den} was estimated, and compared with the Guidelines (2018).

2.35 For aircraft noise, the recommendation is 45 dB L_{den}, and the Japanese environmental quality standards are 57–62 dB, the difference between the two being between +12 and +17 dB. When examining the incidence of IHD, the authors found that there was a lower incidence (approximately 60%) in Japan compared to that observed in Western Europe. It is explained that in the literature it is suggested that the difference in mortality rates and prevalence of IHD between Japan and European populations is caused by a combination of differences in lifestyle, including dietary habits, and racial differences (genetic factors).

2.36 The authors explain that the recommendations in the ENG (2018), which are based on study data from Europe, are difficult to apply in Japan due to differences in physical characteristics and lifestyle habits. Currently, only a few cross-sectional studies have been conducted in Japan. They suggest further study into the relationship between noise and cardiovascular disease in Japan to further understand the exposure-response relationship for this specific region.

Chapter 3

Aircraft Noise and Cardiovascular Disease

3.1 This chapter includes findings published from the past six months on aircraft noise and cardiovascular effects. The first paper by **Hadad et al** examined the pooled effects of traffic noise and cardiovascular effects and sleep disturbance. The analysis focused on field studies and included four randomised crossover studies (published between 2013 to 2021 and conducted at the University Medical Centre Mainz, Germany).

3.2 275 subjects (40.4% women, mean age 43.03 years) were each exposed to one control scenario (regular background noise) and at least to one traffic noise scenario (60 aircraft or train noise events) in their homes during night-time. Three of the four studies reviewed were by Schmidt et al, and looked at aircraft noise, and one by Herzog et al which focused on train noise. After each night, the subjects visited the study centre for comprehensive cardiovascular function assessment, including the measurement of endothelial function and sleep-related variables.

3.3 The primary outcome measured was flow-mediated dilation of the brachial artery. Flow-mediated dilation (FMD) refers to dilation (widening) of an artery when blood flow increases in that artery. The primary cause of FMD is release of nitric oxide by endothelial cells. FMD is a non-invasive measure of blood vessel health (endothelial dysfunction) which (when low) is at least as predictive of cardiovascular disease as traditional risk factors. Major cardiovascular disease associated with low FMD include cardiac death, myocardial infarction, and stroke. The results of the pooled analysis revealed a significant mean difference between the control scenario and noise scenario with 60 events, indicating worsened endothelial function upon noise exposure. There was no effect of sex and age on the mean difference in FMD.

3.4 In terms of the secondary outcomes (mean arterial pressure, how participants felt the following morning after the study, restfulness, and sleep quality) results from the pooled analysis revealed significant mean/median differences in higher mean arterial pressure, disturbed feeling in the morning, sleep quality, and restfulness due to noise exposure. A positive association between higher age and an increased disturbed feeling in the morning and sleep quality was found following noise exposure.

3.5 The authors concluded that the results of the pooled analysis indicated that acute exposure to simulated nocturnal traffic noise (aircraft or railway) is associated with impaired endothelial function, higher mean arterial pressure, and disturbed sleep quality. Further results suggested that feeling in the morning and restfulness of sleep were significantly disturbed after noise exposure during the night. These results remained stable when excluding the only study in which train noise instead of aircraft noise was present, indicating this effect is accurate for aircraft noise alone. The authors did not find evidence of noise-induced changes in heart rate, stress hormones, inflammation, and pulse transit time.

3.6 **Olbrich et al** published findings from a study into the risk from aircraft noise of recurrent cardiovascular events after acute coronary syndrome. The authors explain the rationale for this study as no previous study has looked at the risk of future cardiovascular recurrences linked to aircraft noise. The study design was a prospective patient cohort of over 700 people in cardiac centres in the Rhine-Maine region of Germany, around Frankfurt Airport. The patients had been previously diagnosed with coronary syndrome between 2013 and 2018. At the time of inclusion, participants filled in a baseline questionnaire about co-morbidities and relevant socioeconomic and lifestyle factors. Yearly follow-up data were obtained by study nurses and study doctors using questionnaires, telephone contact, and hospital records. The follow-up period ended in April 2021.

3.7 Individual aircraft noise exposure at the homes of patients was calculated, and exposure to road traffic and railway noise was obtained from noise maps. The protocol defined the combined endpoint as recurrences of cardiovascular events including cardiovascular death, myocardial infarction, stroke, bypass surgery or coronary intervention with stent implantation. All-cause mortality was defined as a further endpoint. 737 patients were included at baseline, and follow-up information was obtained from 663 patients. The mean follow-up period was 42 months, ranging from 1 to 80 months.

3.8 Overall, 663 patients were followed after hospital release and 621 patients (84.2%) could be followed for at least one year. In addition, 532 and 401 and 148 patients (72.2%, 54.4% and 20.1%, respectively) were followed for two, three and five years, respectively. During the follow-up period, 137 of 663 patients experienced a recurrence of a cardiovascular disease and 28 patients died. About half of the recurrences occurred within the first year of follow-up (12%). Cumulative incidences of recurrent events using death as a competing event were 16.1% (after 2 years), 19.8% (3 years), 21.9% (4 years) and 24.6 (5 years).

3.9 At baseline, 24 (3.3%) participants had a modelled $L_{Aeq,day}$ aircraft noise exposure level below 35 dB, which was censored at this cut point for further analysis, resulting in an average daytime level of 45.3 dB. For night-time aircraft noise exposure ($L_{Aeq,night}$) 41 patients (5.6%) were found to be exposed <30 dB, the censoring level, resulting in an average $L_{Aeq, night}$ of 39.5 dB. The average 24h L_{den} level was 48.1 dB.

3.10 The results indicated that adjusted hazard ratio (HR) for recurrence was 1.24 (95%-CI: 0.97–1.58) per 10 dB increase in L_{den} aircraft noise exposure. A combined analysis of recurrence and all-cause mortality yielded a HR of 1.31 (95%-CI: 1.03–1.66). Similar HRs were found for L_{day} and L_{night} aircraft noise exposure.

3.11 The authors explain that the results indicate an increased risk for recurrences in relation to all outdoor aircraft noise exposure metrics in an exposure dependent manner. This reached statistical significance for daytime and 24-hour aircraft noise exposure levels. The effect was also found to be stronger for patients without noise-proof windows in their home. They concluded that people with pre-existing cardiovascular disease are particularly vulnerable to effects from transportation noise and would benefit from a reduction in aircraft noise levels. The effects for road and rail noise were less and did not reach significance.

3.12 **Hadad et al** published findings on a 10-year follow-up study into noise annoyance due to various sources, and cardiovascular disease (CVD) risk. The authors examined the relationship between noise annoyance and CVD risk in a large population-based cohort study. Cross-sectional (N= 15,010, aged 35–74 years, baseline investigation period 2007–2012) and prospective data (5- and 10-year follow-up from 2012 to 2022) from the Gutenberg Health Study were used to examine the relationship between noise annoyance due to different sources and the risk of prevalent[2] and incident[3] CVD. Outcomes included atrial fibrillation, coronary artery disease, myocardial infarction, stroke, chronic heart failure, peripheral artery disease, and venous thromboembolism.

3.13 The various hypotheses concerning the relationship between noise annoyance and its influence on CVD risk are discussed in the paper. It is suggested that multi factors probably feed into the pathway between annoyance and CVD.

3.14 The results suggested that simulated night-time aircraft noise caused adrenaline release and led to impairment of the endothelial function partly due to oxidative stress in healthy adults and a more pronounced vascular dysfunction in subjects with already established CVD. The negative vascular effects of night-time aircraft noise were found to be independent from annoyance and attitude towards noise. The authors stress that this may contribute to short sleep duration, fragmented sleep, reduced slow-wave sleep, psychological stress, and insomnia. Aircraft noise as well as railway noise annoyance during sleep was associated with an 8% and 15% risk elevation of prevalent CVD.

3.15 In cross-sectional analyses, noise annoyance was an independent risk factor for prevalent CVD, with the strongest associations seen for noise annoyance during

[2] Incidence = the rate of new cases of a disease occurring in a specific population over a particular period of time.

[3] Prevalence = the number of cases of a disease in a specific population at a particular timepoint or over a specified period of time.

sleep (e.g., neighbourhood noise annoyance: odds ratio 1.20, 95% confidence interval 1.13–1.27, $p < 0.0001$).

3.16 In the 10-year follow-up, mostly positive associations (although not significant) between noise annoyance and incident CVD were observed, no indication of increased CVD risk was observed after 5 years of follow-up. Noise annoyance due to different sources was associated with prevalent CVD, whereas only weak associations with incident CVD were found.

Chapter 4

Aircraft Noise and Sleep Disturbance

4.1 This chapter outlines the main findings on aircraft noise and sleep disturbance from the six months between September 2023 to March 2024. The first paper is authored by **Basner et al** and describes the FAA's national sleep study protocol.

4.2 The most recent US sleep study was conducted in 1996 by Fidell et al. Since then, aircraft movements have increased and the noise from aircraft has reduced, thereby calling for an update to this study and new results for sleep disturbance due to aircraft noise in the US. The objective of the proposed National Sleep Study (NSS) is to collect nationally representative information on the effects of aircraft noise on sleep to derive exposure–response relationships between the $L_{AS,max}$ of single aircraft noise events (ANEs), expressed in decibels (dB), and the likelihood of waking up, expressed as a percent chance (0–100%). The authors explain that other measures of sleep disturbance and related health effects will also be analysed as secondary endpoints.

4.3 The proposed methodology is for a postal/web survey to be used to gather data on eligibility and to recruit participants for a 5-night in-home field study. For survey respondents interested in and eligible for participation in the field study, sound recording and electrocardiography (ECG)/actigraphy equipment will be shipped to them for objective measurements of noise-induced awakenings. At the end of the 5-night measurement period, equipment and surveys are shipped back by study participants for analysis by the researchers.

4.4 Seventy-seven U.S. airports with relevant night-time air traffic from 39 states are included in the sampling frame. Based on simulation-based power calculations, the field study aims to recruit 400 participants from four noise strata and record an electrocardiogram (ECG), body movement, and sound pressure levels in the bedroom for five consecutive nights. The primary outcome of the study is an exposure–response function between the instantaneous, maximum A-weighted sound pressure levels (dBA) of individual aircraft measured in the bedroom and awakening probability inferred from changes in heart rate and body movement.

4.5 Self-reported sleep disturbance due to aircraft noise is the secondary outcome that will be associated with long-term average noise exposure metrics such as the Day–Night Average Sound Level (DNL) and the Night-time Equivalent Sound Level (L_{night}). When the paper was written in 2023, the study had successfully collected field study data from 385 participants. Data acquisition was expected to be completed by the end of October 2023. The data acquisition period will be followed by a two-year period of data analysis. A final report for the study is expected in 2025.

4.6 The FAA's National Sleep Study is designed to provide large-scale, objective, physiological data on the effects of aircraft noise on sleep in the United States, which can be used by the FAA to inform the effectiveness of current noise regulation. The authors stress that the study is unprecedented in scope and size and will be a landmark study for the understanding of the effects of aircraft noise on sleep.

4.7 In his recent editorial piece on the long-term health consequences of noise exposure and the effects on sleep, **Basner** explains that in animal studies, intermittent noise exposure during the night is thought to be the reason for the pathophysiological changes that predispose them to negative health consequences. He cites oxidative stress-induced vascular and brain damage, uncoupling of endothelial and neuronal nitric oxide synthase, vascular/brain infiltration with inflammatory cells, and changes in circadian rhythms as biologic plausibility for the associations observed in epidemiological studies. Endothelial dysfunction was also found in human participants after a single night of noise exposure, with stronger effects in patients with pre-existing cardiovascular conditions. He also explains that aircraft noise can also trigger acute cardiac events during sleep which constitutes another mechanism of how noise exposure can contribute to cardiovascular mortality.

4.8 Basner stresses the importance of the environment for sleep quality. He explains that there is a critical need for studies that inform health impact assessments, but also further work on the understanding of whether noise mitigation strategies work. Although reducing noise exposure at the source is clearly the most effective way of addressing noise effects, it is sometimes either technically infeasible or too expensive. Basner stresses the need to understand whether simpler and less expensive noise mitigation measures (e.g., sound insulation, white noise, and earplugs) are effective in reducing the effects of noise on sleep.

4.9 **Elmenhorst et al** published findings from observational field studies around Frankfurt airport before 2011 and after 2012 the implementation of a night-time ban on flights between 23:00-05:00. The aim was to assess whether exposure to reduced night-time flight traffic protects airport residents from sleep fragmentation. The work formed part of the Noise-Related Annoyance, Cognition, and Health (NORAH, 2011–2015) study, which has been described in previous reports.

4.10 In 2011, 49 participants were included, and 42 of those also participated in the 2012 data collection. In 2012 a further 41 participants deemed as late sleepers (bedtime and rise time between 23:00–23:30 and 7:00–7:30, respectively) were recruited, as they were exposed to aircraft noise in the morning part only. Due to their later rising time which for them would occur well beyond the end of the curfew, late sleepers may benefit less from the current night flight ban.

4.11 Polysomnography and acoustic measures were recorded in participants' homes, the first was a familiarisation night and then this was followed at a later stage by nights 2-4 for three consecutive weekday nights. Figure 4 shows the Aircraft noise events and number and duration of awakenings during participants' time in bed.

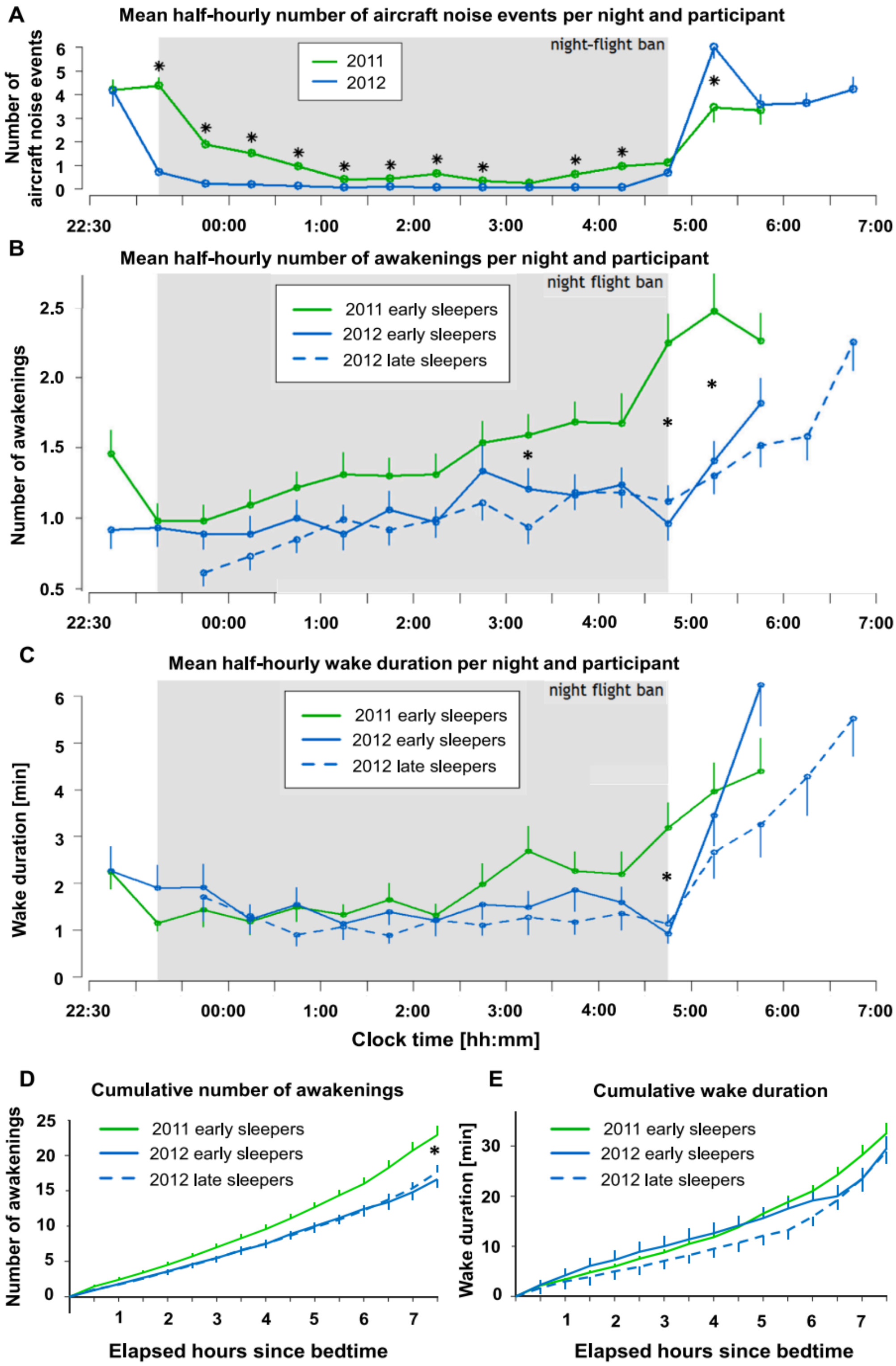

Figure 4: Aircraft noise events and number and duration of awakenings during participants' time in bed. A, Average number of aircraft noise events when no noise from a different source was present, B, number of awakenings (irrespective of the cause), C, wake durations, D, cumulative number of awakenings, and E, cumulative wake durations at half-hourly intervals per night and participant. A-C: between before (green) and after (blue) the implementation of the night-flight ban at Frankfurt Airport.

4.12 The Night-flight ban implementation in 2012 reduced air traffic volume during the curfew. When looking at half-hourly intervals throughout the night (Fig. 4 A), the number of aircraft noise events was decreased in 2012 in 10 out of 11 intervals between 23:00 and 4:30 (all $p < 0.05$). The nightly number of awakenings and wake duration per participant were lower in 2012 than in 2011. The number of awakenings was significantly reduced within the 3:00–3:30 and 4:30–5:30 intervals, and wake duration within the 4:30–5:00 interval (all $p < 0.05$, Fig. 4 B-C). The cumulated sum of nightly awakenings after 7.5 hours elapsed sleep time was lower in 2012 compared to 2011 (early sleepers 2012 versus 2011: $p < 0.0001$; late sleepers 2012 versus early sleepers 2011: $p = 0.003$), whereas no such effect was observed for the cumulated wake duration ($p > 0.05$; Fig. 4 D-E).

4.13 Figure 5 displays the awakening probability as a result of aircraft noise. A, Exposure-response relationship between maximum sound pressure level ($L_{AS,max}$) of single aircraft noise events and awakening probability before (green) and after (blue) the night-flight ban. The calculated awakening probability at a given $L_{AS,max}$ remained unchanged by the night-flight ban (unadjusted model $p = 0.8$, fully adjusted model $p = 0.3$).

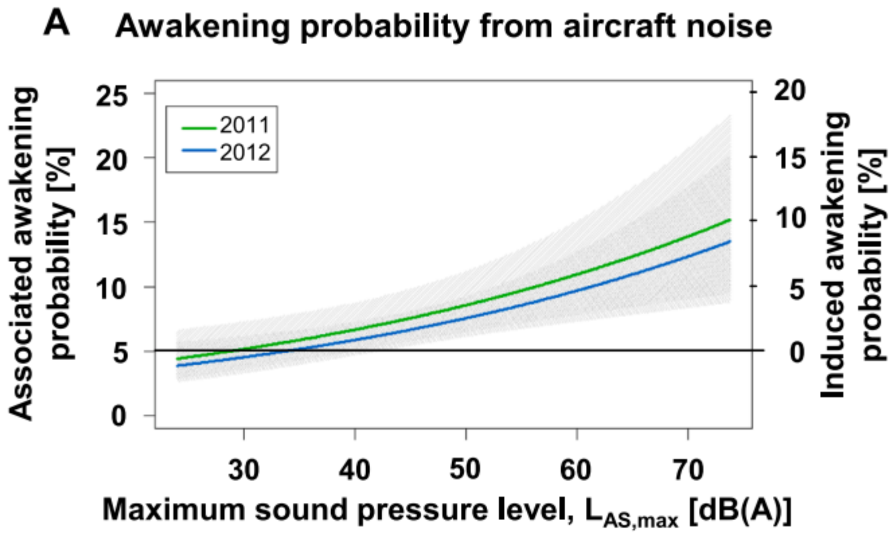

Figure 5 A: Awakening probability due to aircraft noise. A, Exposure-response relationship between maximum sound pressure level ($L_{AS,max}$) of single aircraft noise events and awakening probability before (green) and after (blue) the night-flight ban (Table 1) with 95% confidence

interval. Left ordinate: noise-associated awakening probability, right ordinate: noise-induced awakening probability.

4.14 Figure 5 B illustrates the predicted associated awakenings between 2011 and 2012 early and late sleepers.

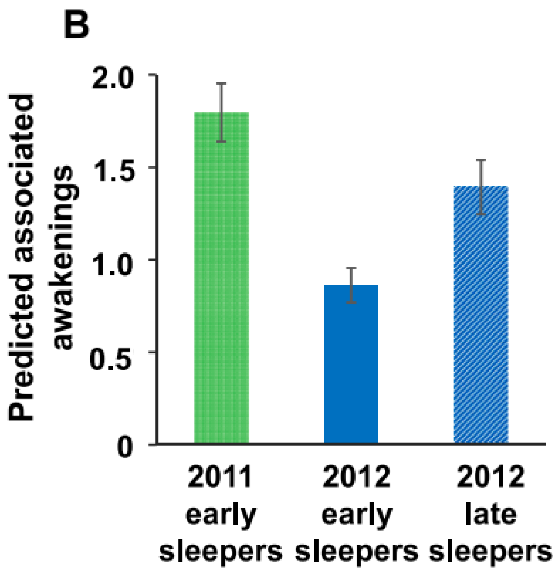

Figure 5B: Number of predicted aircraft noise-associated awakenings across groups and years from noise-associated awakening probabilities.

4.15 The number of predicted noise-associated awakenings (Fig. 5 B) based on the model were lowest in early sleepers in 2012 as a result of the low number of overflights during time in bed.

4.16 The authors concluded that a 6-hour night-flight ban was effective in reducing sleep fragmentation in residents around Frankfurt airport. The timing of the flight ban relative to an individual's sleep timing is important for the benefit for sleep.

Chapter 5

Aircraft Noise, Cognition and Mental Health

5.1 This chapter describes the research conducted on cognition and mental health with respect to aircraft noise in the past six months.

Cognition

5.2 **Wu et al** examined long-term exposure to transportation noise and global impairment and cognitive decline. This was a Swedish longitudinal study and based on 2594 dementia-free participants aged 60 + years from the Swedish National study on Aging and Care in Kungsholmen (SNAC-K). The authors aimed to investigate whether older adults exposed to source-specific transportation noise over a prolonged period experienced faster cognitive decline or increased cognitive impairment incidence. They also analysed the potential confounding effects of air pollution and greenness.

5.3 Trained nurses and doctors, following a standard procedure, conducted in-person interviews and physical check-ups to collect information on demographics, lifestyle, clinical history, blood samples, and medication history. Psychologists administered a comprehensive psychological test battery. Residential noise exposure data was obtained for road, railway and aircraft. The global cognition score was assessed with tests including episodic memory (free recall and recognition), semantic memory, perceptual speed and language (category and letter fluency).

5.4 Global cognition score and CIND (cognitive impairment, no dementia) were assessed with a comprehensive neuropsychological battery at baseline and up to 16 years. Residential transportation noise resulting from road traffic, railway, and aircraft were estimated at the most exposed façade and the time-weighted average exposure was assessed.

5.5 The results indicated that Global cognition score decreased at an average rate of − 0.041 (95 %CI − 0.043, − 0.039) per year. Aircraft noise was associated with a 0.007 (per 10 dB L_{den}; 95 %CI − 0.012, − 0.001) faster annual rate of decline. The Global cognition score appeared to not be affected by road traffic and railway noise. During the follow-up, 422 (21 %) participants developed CIND. A 10-dB L_{den} difference in exposure to aircraft and railway noise was associated with a 16 % (HR 1.16, 95 %CI 0.91, 1.49) and 26 % (HR 1.26, 95 %CI 1.01, 1.56) increased hazard of CIND in the multi-pollutant model, respectively. No association was found for road traffic (HR 1.00, 95 %CI 0.83, 1.21).

5.6 The authors concluded that the results suggest long-term exposure to aircraft and railway noise was associated with a higher risk of negative cognitive outcomes among older adults. There was no evidence of an association between road traffic noise and cognitive decline. The authors explain that more studies should be conducted to further investigate long-term exposure to source-specific transportation noise and cognition among older people, and their associated biological mechanisms.

Mental Health

5.7 **Hadad et al** published a review article on the impacts of noise on mental health, and examined evidence, possible mechanisms, and consequences. The review discusses how annoyance and sleep disturbance are proposed as key drivers of noise-associated non-communicable disease (NCD) onset and progression including both physical and mental health conditions. Although the physical impacts of noise have been well documented and are studied widely, the implications for mental health are not well mapped or understood. It is argued that this is of concern as mental health disorders may contribute substantially to the burden of disease in the noise-exposed populations.

5.8 Babisch's two pathway mechanism for the impacts of noise exposure on health is discussed in relation to mental health. The direct pathway impacts hearing and can cause ear damage, with exposure to high noise levels. The indirect pathway relates to the exposure to lower decibel levels in the range of 50–70 dBA that impairs daily activities, sleep, and communication. Sleep disturbance is strongly linked to mental health problems, including anxiety and depression. Figure 6 provides a visual representation of the two-pathway model in relation to mental health effects from noise.

5.9 The authors state that noise induces the stress response through either direct (hearing loss and inner ear damage) pathway or indirect (annoyance and sleep disturbance) pathway. The stress response results in the activation of the hypothalamic–pituitary–adrenal (HPA) axis and an increase in systemic inflammation that becomes neuroinflammation, resulting in the fear and anxiety response. Prolonged exposure to a high stress response leads to maladaptive coping strategies, such as smoking or alcohol consumption. The abbreviations in Figure 6 correspond to: CRH (corticotropin-releasing hormone), ACTH (adrenocorticotropic hormone), NF-κB (nuclear factor kappa-light-chain-enhancer of activated B cells), SNS (sympathetic nervous system), dAAC (dorsal anterior cingulate cortex), mPFC (medial prefrontal cortex), TNFα (tumor necrosis factor alpha), IL-6/1β (interleukin 6/1β).

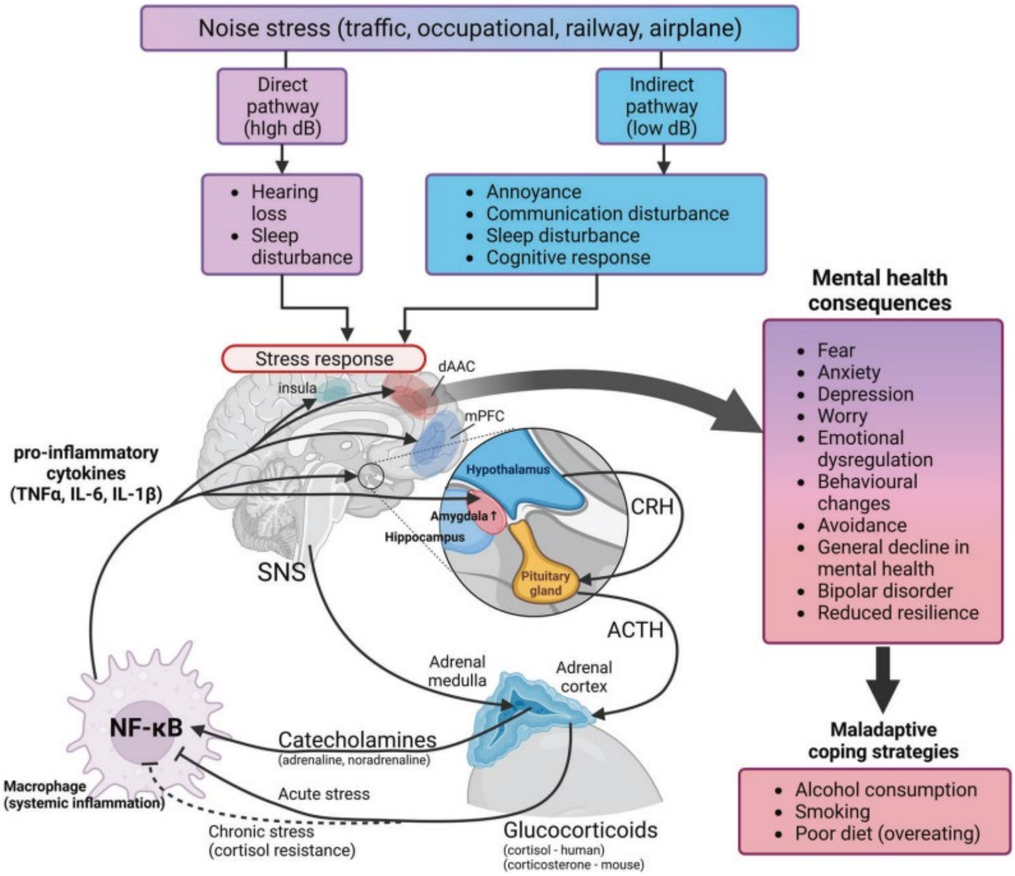

Figure 6: The noise/stress concept and the associated adverse mental health consequences

5.10 The review describes the main findings relating to mental health and transportation noise (road, railway and aircraft), in relation to depression and anxiety, suicide and behavioural issues in children, which have been reported previously. It also addresses the current gaps in the research, including the need for pre-clinical noise research that can enhance the understanding and mechanism of the impacts of noise on mental health, allowing for drug-based interventions where appropriate. In addition, biomarkers of noise-triggered mental health harms could be identified using validated animal models in order to allow early diagnosis of vulnerable groups at higher risk of noise-inflicted mental disease.

5.11 The authors suggest clinical noise research should further extend the evidence base of exposure-mediated mental health effects and also investigate non-pharmacological mitigation strategies (e.g., coping mechanisms for improved resilience) such as exercise, meditation, green space availability, co-exposures, and mental health training.

5.12 **Wicki et al** examined the acute effects of military aircraft noise on sedative and analgesic drug administrations in psychiatric patients. The rationale for this study was that sudden noise can prove to be disturbing to psychiatric patients who are often noise sensitive. Such sudden and loud noise exposure can increase the risk in such patients for an increase in mental health events such as agitation, aggression and self-harm, hospitalisation, and suicide. As a vulnerable group of people, the authors aimed to investigate short-term associations between fighter jet noise and on-demand sedative and analgesic drug administrations in a psychiatric clinic located close to a military airfield in Switzerland. The study was conducted from June 2016 to December 2021 including adults only for stays that were longer than three days. A total of 23,486 flights occurred during the study period. A case-time series analysis was used with an hourly time resolution, and noise exposure was modelled using flight plans and noise footprint data.

5.13 The authors found that higher fighter jet noise levels were associated with an increased probability for as-needed administration of sedatives and analgesics. In addition, larger effects were observed in patients with psychiatric multi-morbidity, supporting previous evidence that poorer mental health is associated with an increased sensitivity to noise. 5,968 clinical stays with a median length of 41 days were recorded. The odds ratio (OR) for medication administration over the lag period of 3 hours after noise exposure was 1.016 (95 %CI: 1.006, 1.026) per 10 dB L_{Aeq} for sedatives and 1.032 (95 %CI: 1.016, 1.048) per 10 dB for analgesics.

5.14 The authors explain that this is an under-studied group of noise sensitive individuals and that psychiatric patients are a vulnerable group who are at risk of noise-induced symptom increases.

Chapter 6
Other Findings

6.1 This chapter of the report contains other findings relating to aircraft noise and health effects published in the past six months. Subject areas include noise sensitivity, and results from a quasi-experiment around Heathrow airport.

6.2 **Kodji et al** published findings from the DEBATS study, in terms of the link between noise annoyance and noise sensitivity and their roles as moderators or mediators. To recap, DEBATS is a research program (2011-2016) including residents around three French airports: Paris-Charles de Gaulle, Toulouse-Blagnac, and Lyon Saint-Exupery. It includes an ecological study based on drug prescriptions, and on non-prescription drug sales, as well as a longitudinal field study following up approximately 1,200 of these residents for four years. The study investigated aircraft noise exposure (measured or calculated) and the measurements of different parameters related to health. Annoyance and health status (current and past) were assessed by questionnaires, and physiological variables such as blood-pressure or salivary cortisol.

6.3 This paper presented results from the study which aimed to investigate noise annoyance and sensitivity as a moderator[4] or mediator[5] in the association between noise and Self-Reported Health Status (SRHS) in a longitudinal study. In 2013, the study included 1,244 participants aged over 18 years and living around the three French airports. These participants were followed up in 2015 and 2017. They answered questions on self-reported perceived health status, aircraft noise annoyance, and noise sensitivity during the three visits. Noise maps were used to estimate outdoor aircraft noise levels in four zones: < 50, 50-54, 55-59 and ≥ 60 dBA in L_{den}.

6.4 The results indicated that aircraft noise levels were associated with severe annoyance. Severe annoyance tended to be associated with impaired SRHS. Aircraft noise levels were associated with impaired SRHS only in men (odds ratio [OR]=1.47, 95% confidence interval [CI]=[1.02, 2.11], for a 10-dBA L_{den} increase in aircraft noise levels) with a weaker association adjusted for annoyance (OR= 1.36, 95% CI=[0.94, 1.98]). The association was found to be stronger in men

4 In statistics and regression analysis, moderation (also known as effect modification) occurs when the relationship between two variables depends on a third variable.

5 A mediator variable serves to clarify the nature of the relationship between the independent and dependent variables. In other words, mediating relationships occur when a third variable plays an important role in governing the relationship between the other two variables.

who reported high noise sensitivity (OR=1.84, 95% CI=[0.92, 3.70], versus OR=1.39, 95% CI= [0.90, 2.14], for men who were not highly sensitive to noise).

6.5 The authors concluded that this study confirms the mediating role of aircraft noise annoyance and the moderating role of noise sensitivity in the relationship between aircraft noise levels and impaired SRHS.

6.6 **Beghelli et al** used changes in flight paths around Heathrow Airport to examine the health benefits of reducing pollution from aircraft. The early morning arrivals trial (EMAT) in 2012 and 2013 was introduced over five months to provide noise respite to specific communities affected by landings at Heathrow Airport. The main feature of the trial was the identification of four pairs of exclusion zones (two to the east and two to the west of Heathrow), which were designed to be free of aircraft movements during the night and early morning in alternate weeks for the duration of the trial, redirecting the night flights to other areas. The trial implemented a weekly switch between these two sets of exclusion zones, which were termed ‘odd’ and ‘even’ weeks.

6.7 The paper explains that night quota restrictions reduce landings at Heathrow between 23:30 and 06:00. However, airlines, responding to travellers’ preferences for early morning landings, allocate nearly all those landing slots between 04:30 am and 6:00 am. This pattern translates into one aircraft landing every 4 to 10 min during those hours when it is likely that sleep may be disturbed. Health effects were measured through changes in medication prescribing by GP practices.

6.8 The results indicated a statistically significant response for monthly medication spending on central nervous and respiratory system conditions and some less significant effects for cardiovascular conditions. The authors found stronger significant reductions in prescription spending on central nervous and respiratory conditions in the regions that experience a drop in air traffic during the trial. Residents in regions more overflown during the trial increased their medicine intake, but the effects are weaker.

6.9 It is explained that this study also illustrates the benefits of using publicly available data to estimate some of the direct costs from environmental exposure sources. The authors suggest that the results show a sizeable direct impact on GP spending in the areas affected. These estimates do not include the reduced costs of avoided GP visits, the gain in patients’ well-being, and impacts on individual worker productivity through absenteeism or increased productivity in the workplace. They suggest that these findings indicate that small variations in air traffic exposure during critical hours affects health, and this could inform environmental policy.

Chapter 7

Summary

7.1 This update report has summarised the main findings in the field of aircraft noise and health effects research over the six-month period September 2023 – March 2024. The chapters have included those findings presented at the Internoise congress 2023, and in peer-reviewed academic journals in the areas of cardiovascular disease, sleep disturbance, effects on cognition, mental health and other findings.

7.2 The findings from Internoise largely centred around community response to aircraft noise. There have been new findings published on the longitudinal impacts of aircraft noise on cardiovascular disease, and the understanding of the noise – cardiovascular pathway seems to be increasing. The new FAA National Sleep Study will provide new large-scale data with the aim of updating the exposure-response relationship between aircraft noise and sleep disturbance in the US. The impact of transportation noise on mental health effects is a growing area and is gaining momentum.

7.3 The aim of this report was to provide an overview of the recently published findings on aircraft noise and health effects, and the next report is due in September 2024 with findings included from relevant congresses and publications.

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