Environmental Research Consultancy Department

Aircraft Noise and Health Effects – a six monthly update

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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 from March – September 2023. The report will provide an overview of the most relevant findings that were published during this period, including the findings presented at the International Commission on Biological Effects of Noise (ICBEN) Congress, which was held in Belgrade in 2023.

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 ICBEN and in academic journals in the past six months.

Chapter 2

Overview of ICBEN

2.1 **Griefahn** presented a summary on the history and development of ICBEN over the past 50 years. ICBEN was founded in 1968 when the American Speech and Hearing Association organised a conference on Noise as a Public Health Hazard in Washington DC, to sum up the state of the art on the effects of noise ‘on hearing threshold, on speech intelligibility, the psychological and physiological state’. The four founders were psychologists, an engineer and a physicist, who collaborated to improve the knowledge base on the physiological and psychological effects of noise.

2.2 The founders focused on the effects of noise on health and identified 6 areas:

1. Noise-Induced Hearing Loss
2. Speech and Communication
3. Physiological Effects of Noise
4. Performance and Behaviour
5. Noise-induced Sleep Disturbances
6. Community response to Noise

2.3 ICBEN’s purpose is to produce regular conferences and publish proceedings of the findings. The total number of nations contributing to all ICBEN-congresses is now 65. Nearly two thirds are from Europe, a fifth from America, one eighth from Asia and 5% from Australia, New Zealand, and Africa. 80% of all contributions are from 20% of the countries. When related to the population of the respective countries Sweden, Norway and the Netherlands are most active, followed by Finland and Switzerland.

2.4 In terms of the future of ICBEN, Griefahn highlights some areas that should be addressed to secure a continuation of the Commission. The importance of attracting new scientists was stressed, and the re-establishment of International Noise Teams to ensure international collaboration across subject areas continues.

Chapter 3

Aircraft Noise and Annoyance

3.1 This chapter summarises the main findings on aircraft noise and annoyance that have been published during the past six months. The following findings were presented at the ICBEN Congress, held in June 2023.

3.2 **Kodji et al** published findings from the DEBATS study, in terms of the link between self-reported health status and annoyance. 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.

3.3 This paper presented results from the study which aimed to investigate noise annoyance as a mediator[1] in the association between noise and self-reported health 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}.

3.4 There was a total effect of aircraft noise levels on impaired self-reported health observed (OR=1.39, 95%CI: 1.06 to 2.12, for 50-54 dBA L_{den} versus < 50 dBA. About 48% of this total effect was mediated by aircraft noise annoyance (indirect effect: OR=1.17, 95%CI: 1.12 to 1.24). The effect of aircraft noise exposure on impaired self-reported health increased with increasing noise levels. The authors state that these findings support previous findings that annoyance is a mediating factor in the relationship between aircraft noise and self-reported health.

3.5 **Gjestland** presented a discussion on results comparisons from annoyance surveys and which factors may affect the results of a survey. The paper

[1] 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.

describes the variables that need to be considered in addition to the definition of 'Highly Annoyed' (HA) that is used for each study.

3.6 The first of these factors is response scales. The technical specification recommends that two standardised questions should be included in a survey. These ask about the long-term noise annoyance for a specific timeframe e.g., a 5-point verbal scale or the 11-point numerical scale. Highly annoyed is defined by the two upper categories of the verbal scale and the three upper categories of the numerical scale. These two scales do not result in identical answers in terms of highly annoyed response, and it is highlighted by Gjestland that it is therefore important to note how the quantity of 'highly annoyed' was derived. HA_V from the verbal scale and HA_N for the numerical scale. HA_V is normally the larger and the difference is equivalent to a 6 dB shift in noise exposure (Gjestland and Morinaga).

3.7 The second factor is the mode of survey presentation, such as face-to-face, telephone or postal. A recent comparison by Miller et al of the large-scale postal questionnaire survey conducted by the FAA found that people responding to a written questionnaire appear to be more annoyed than people responding to a telephone interview. The difference was found to be equivalent to a 5 dB shift in the noise exposure. Fidell also compared survey modes and found that mail surveys resulted in a higher prevalence of highly annoyed respondents with a difference equivalent to a 10 dB shift in the noise exposure.

3.8 Operational changes also need to be considered according to the authors. In terms of aircraft noise these have been well documented, with a difference found in exposure-response curves between 'high-rate change' (HRC) and 'low rate change' (LRC) airports. Gelderblom found that the average difference in the annoyance response between an LRC airport and an HRC airport was equal to a 9 dB shift in the Community Tolerance Level (CTL) value. People living near a high-rate change airport seem to tolerate 9 dB less noise in order to express the same degree of annoyance as residents of a low rate change airport community. Gjestland suggests that this may also be observed for other sources of transportation noise, such as the resurfacing of a road, or the introduction of a new road.

3.9 Traffic volume is another factor for consideration in annoyance studies. With an increase in traffic volume comes an increase in noise level and subsequent annoyance level. However, Gjestland states that the annoyance seems to increase at a faster rate than the equivalent level. The importance of the number of movements is discussed, with the author having previously reported the results from 32 aircraft noise surveys and concluded that for a given noise exposure level the percentage of highly annoyed people increased equivalent to a DNL increase of 1.8 dB per doubling of the number of aircraft movements.

3.10 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. This curve indicated a much higher prevalence of annoyance than the earlier FICON curve.

3.11 It is explained that the scoring of highly annoyed by Miedema and Vos for their exposure response relationship was based on a cut-off of 72 % on the annoyance scale. Miller et al. defined high annoyance as the two upper categories of a 5-point verbal scale, equivalent to a 60% cut-off. The individual verbal responses of the 20-airport study have been re-calculated as described in the standard ISO 15666:2021 with category 5 on the scale counted in full and category 4 given a weight 0.4. The difference between the two procedures for scoring prevalence of high annoyance resulted in the equivalent of a 5 dB shift in the noise exposure.

3.12 Gjestland suggests that the reported exposure-response curve for the US 20-airport study should be adjusted by 5 dB to account for postal versus face-to-face mode, and an additional 5 dB for the definition of high annoyance. The two curves are similar for exposure levels below 60 dB DNL (Figure 1).

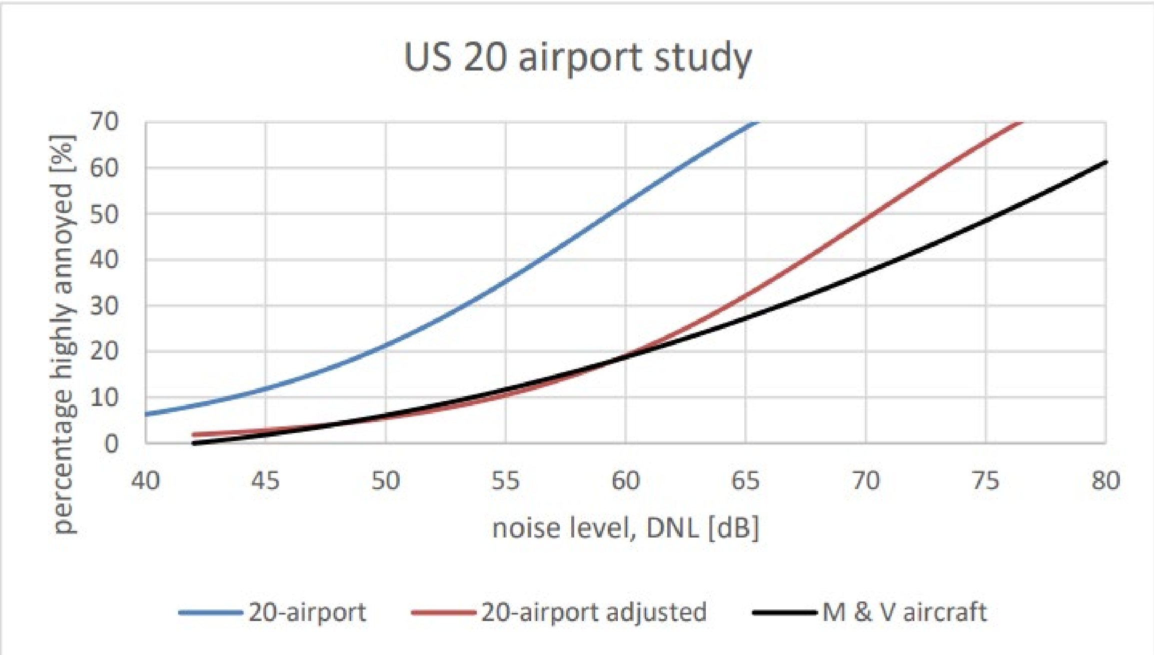

Figure 1: Exposure-response curves for the US 20 airport study

3.13 Gjestland concludes 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.

3.14 **Reedijk et al** presented findings on exposure-response relationships for air traffic noise annoyance and sleep disturbance in the Netherlands. The aim of this study was to investigate the association between aircraft noise exposure and the probability of being highly annoyed or sleep disturbed among residents living in the vicinity of 14 airports in the Netherlands. Survey data from over 250,000 respondents in the Municipal Public Health Service Health Monitor 2020 was included in the study.

3.15 Annoyance and sleep disturbance were measured using the 11-point numerical scales. Aircraft noise levels were monitored at a grid level closest to the participants' homes. In addition to logistic regression analysis, the authors used a natural cubic spline (a statistical method for forming a line between data points) in the data, to account for any possible non-linear effects. The obtained relationships were airport-specific, and the results indicated that in 2020 more residents were highly annoyed and sleep disturbed at the same noise levels than in 2002 (Amsterdam Schiphol Airport). An important consideration is that this study was conducted during the Covid-19 pandemic, during which more people would have worked from home. The authors conclude that airport-specific and non-linear exposure-response relationships are recommended.

3.16 **Welch et al** presented findings on the influence of number and sound level of noise events and task engagement on perceived loudness and annoyance. The study compared perceived loudness, annoyance and the ability to perform a cognitive task when exposed to aircraft noise.

3.17 Participants were exposed to recordings of aircraft noise, presented either as a single 15-second overflight at a sound-level of 80 dB $L_{Aeq15seconds}$ or four 15-second overflights at 60 dB $L_{Aeq15seconds}$. They were also required to perform a mental arithmetic task during some sessions. Participants rated their perception of loudness and annoyance, and physiological markers of stress were recorded. The results indicated that the single 80 dB stimulus was perceived as louder and more annoying than the four 60 dB flights. The difference in loudness and annoyance decreased when performing the task. Noise exposure did not impact the task performance. The authors reported that the physiological markers reflected task engagement, and the single high-sound level stimulus was found to be more stressful than the four lower ones. They suggest that this relationship between sound level, number of overflights and task engagement could be explored further in future.

Other published findings on annoyance

3.18 Annoyance due to transportation noise was the main outcome studied in the paper by **Starke et al**, who analysed data from the German LIFE-adult study. Road, railway and aircraft noise were studied in relation to annoyance in the city of Leipzig, and the findings were compared to those from Guski et al, which featured in the 2018 WHO Guidelines.

3.19 The LIFE-Adult study is a large population-based longitudinal study of a representative sample of the adult residents (40-79 years) of Leipzig. The baseline study was conducted in 2014, with a follow-up between 2017 and 2012. From the 10,000 participants at baseline, 5670 participants took part in the follow-up survey. The follow-up study, which was part of the NORAH study, contained survey questions on annoyance due to transportation noise. The 5-point ICBEN verbal scale was used, with the top two categories being used as the Highly Annoyed cut-off point. For aircraft noise, in addition to L_{den}, L_{max} and Number Above Threshold (NAT) metrics were used.

3.20 The results indicated that approximately 8.6% of participants were highly annoyed from road traffic noise, 3.7% from rail traffic noise, and 3.7% from aircraft noise. More men were highly annoyed from aircraft traffic noise than women (4.5% versus 3.0%). Participants in the lowest socioeconomic group displayed the highest proportion of annoyance for all traffic noise sources.

3.21 For all three noise sources, an increased risk of high annoyance with increasing noise levels (L_{den} and L_{night}) was observed. For aircraft noise, all associations were statistically significant, per 10 dB OR = 12.7 (95%CI 9.37–17.10) (L_{den}) and OR = 19.71 (95% CI 11.65–33.35) (L_{night}). Figure 2 illustrates the exposure-response relationships for annoyance and the three transportation noise sources in the LIFE study, compared with those found by Guski. None of the participants in the LIFE study were exposed to aircraft noise above 60 dB L_{den}.

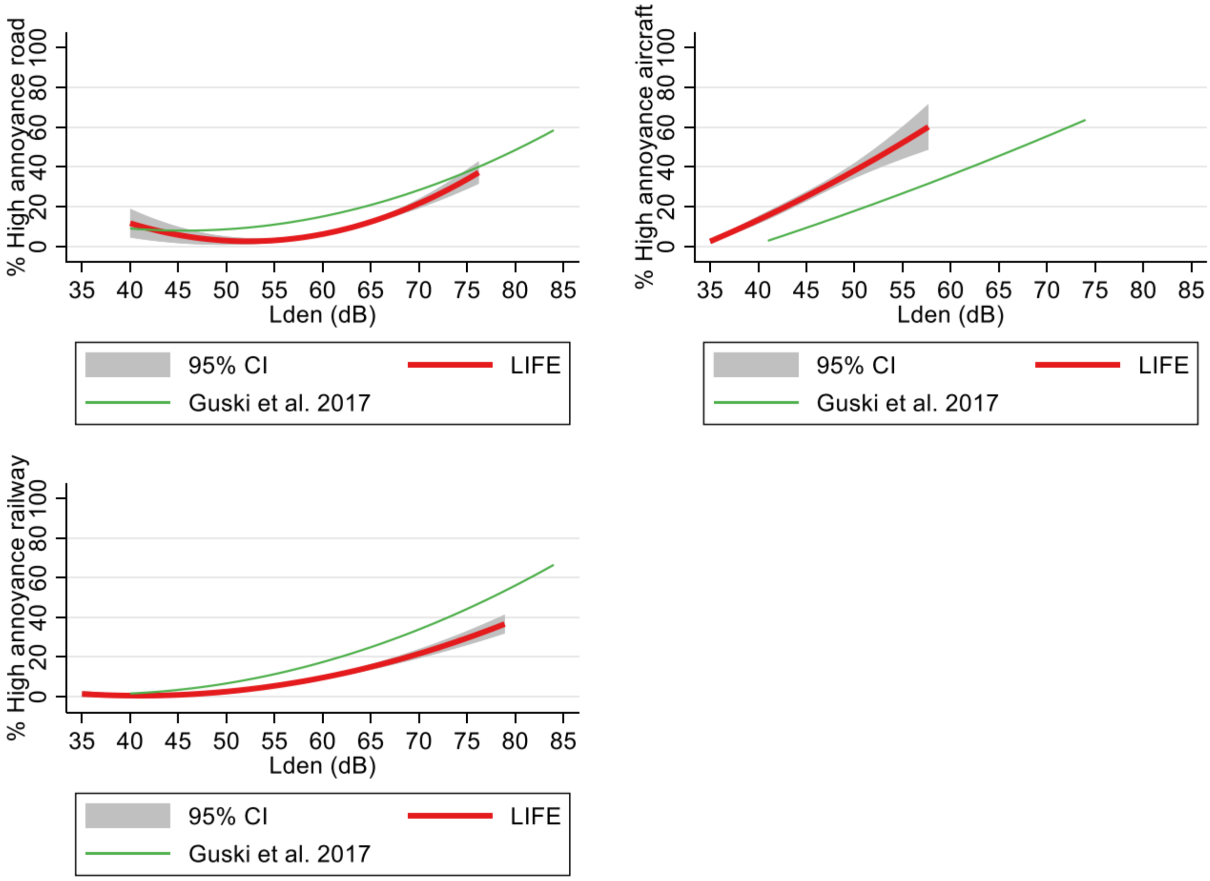

Figure 2: Comparison of % High Annoyance (HA) for road, railway, and aircraft noise between the LIFE-Adult study and the WHO review by Guski et al., 2017.

3.22 The results in Figure 2 indicate that for road noise in the LIFE study the exposure-response relationship shows an increase in %HA starting at 55 dB L_{den}, at 50 dB L_{den} for railway noise, and below 40 dB L_{den} for aircraft noise. For road traffic noise, the curve based on the LIFE study was lower than the WHO review (Guski et al., 2017) starting at 45 dB L_{den} and both were comparable at 75 dB L_{den}. For rail traffic noise, the proportion of highly annoyed was generally lower for the LIFE study compared to the WHO review. For aircraft noise, the proportion of highly annoyed participants was consistently higher than the WHO review by Guski et al., 2017).

3.23 A positive association between high annoyance and all three transportation noise sources was found in the LIFE study. Aircraft noise was found to have the strongest association with annoyance (OR = 12.7; 95% CI: 9.37–17.10 per 10 dB L_{den}), and this was strongest for L_{night} compared to L_{den} (OR = 19.71; 95% CI: 11.65–33.35 per 10 dB L_{night}). The authors suggest some reasons for the discrepancy between the aircraft noise exposure response curves in this study, and that from Guski. The WHO curve used the upper 28% of the scale responses to define HA, compared to the upper 40% in the LIFE study.

3.24 It is also suggested that the Leipzig/Halle airport might be considered a "high-rate change airport". The number of annual flight movements at Leipzig/Halle airport increased from approximately 60,000 in 2010 to about 80,000 in 2019, and it has been suggested that these kinds of changes in movements elicit a higher annoyance response for a given exposure level, than more steady state airports. The authors also explain that approximately half of the flight movements in the Leipzig/Halle airport occur between 10 p.m. and 6 a.m. and consist mainly of freight flight. Therefore, unlike most of the studies in the WHO review, there is no night-time flight ban in place, so the authors propose that the 10 dB penalty for night time in the L_{den} equation may be underestimating the effect of aircraft noise on HA.

Chapter 4
Aircraft Noise and Cardiovascular Disease

ICBEN findings

4.1 Several papers were presented at ICBEN that examined the effects of aircraft noise on cardiovascular health and these will be discussed in this chapter.

4.2 As part of the DEBATS study, aircraft noise and blood pressure were investigated, and an association was found between aircraft noise and both systolic and diastolic blood pressure. **Giorgis-Allemand et al** presented the findings from a further element of this study, which examined the moderating[2] role of air pollution in this relationship. The air pollution exposure was estimated for the month prior to each blood pressure reading, using data from nearby air quality stations. The results indicated that systolic and diastolic blood pressure were associated with increased NO_2 levels, and that there was no association between blood pressure and PM_{10}.

4.3 The association between aircraft noise and blood pressure remained statistically significant after adjustment for NO_2. The authors explain that the interaction between aircraft noise and NO_2 was not statistically significant, however the association between aircraft noise and blood pressure was strongest in the lowest NO_2 third of the population, suggesting a moderating effect of air pollution. They propose that air pollution as a moderator between aircraft noise and blood pressure warrants further investigation, with particular attention given towards those pollutants related to air traffic. Further findings presented at ICBEN from the DEBATS study were related to obesity markers. **Evrard et al** investigated aircraft noise and obesity (BMI) and central obesity (waist circumference) in this longitudinal study. No significant association was found between exposure to aircraft noise and the risk of obesity as defined by BMI. The authors did find a positive and significant association was found between aircraft noise and the risk of central obesity.

4.4 **Molitor et al** presented findings on aircraft noise, inflammation, and cardiac function after myocardial infarction (MI) (heart attack). The results were obtained from mice in a MI model, and in humans with incident MI. Mice were exposed to aircraft noise levels of average sound pressure level of 72 dB (peak level 85 dB) which resulted in pro-inflammatory aortic gene expression in the myeloid cell adhesion pathways. A myeloid cell is a type of blood cell that originates in the bone marrow. Myeloid cells move from the bone marrow to tissue sites via the

[2] A moderator variable changes the strength or direction of an effect between two variables x and y.

blood and need to cross endothelial barriers to gain access to tissues. The authors found that aircraft noise alone promoted adhesion and infiltration of inflammatory myeloid cells in vascular/cardiac tissue, along with other inflammatory responses in the blood, and worsening of cardiac function. Following MI, stronger endothelial dysfunction and increased inflammation occurred in those mice who were pre-exposed to aircraft noise.

4.5 The human element of this study examined participants included in the population-based Gutenberg Health Cohort Study (median follow-up:11.4 years) with incident MI, which revealed elevated C-Reactive Protein (a predictor of having subsequent cardiac issues) at baseline and worse Left Ventricular Ejection Fraction (LVEF), which is the central measure of left ventricular systolic function, after MI in those people who had a history of aircraft noise exposure, and subsequent annoyance development.

4.6 The authors conclude that aircraft noise exposure before MI substantially increases subsequent cardiovascular inflammation and aggravates ischemic heart failure, facilitated by an increase in pro-inflammatory vascular responses. They suggest that the reduction of environmental noise exposure would benefit the clinical outcome of those people experiencing MI. These findings were also published in the journal *Cardiovascular Research*.

4.7 **Peters et al** examined the relationship between long-term aircraft night noise exposure and self-reported hypertension in a national cohort of female nurses in the US called the Nurses' Health Study (NHS) and Nurses' Health Study II (NHSII) study populations. Annual night-time average aircraft sound levels (L_{night}) surrounding 90 airports for the years 1995-2015 (in 5-year intervals) were modelled using the Aviation Environmental Design Tool and assigned to participants' addresses. The risk of incident hypertension was estimated using hazard models at levels above and below 45 dB L_{night}, and adjustment was made for factors such as socio-economic status, air pollution and individual risk factors.

4.8 The authors found that there were 63,600 NHS and 98,938 NHSII participants free of hypertension at the study baseline (1994/1995). They observed 14,391 and 12,144 new hypertension cases by 2013, respectively. Less than 2% of participants were exposed to L_{night} ≥45 dBA. In NHS, they observed an adjusted hazard ratio (HR) of 1.10 (95% CI: 0.95, 1.27), and for NHSII, an adjusted HR of 1.13 (95% CI: 0.99, 1.30) comparing exposure to L_{night} ≥ 45 versus < 45 dBA. In a meta-analysis of the data the findings indicated a HR of 1.12 (95% CI: 1.01, 1.23). The authors conclude that these findings support a positive association between night-time aircraft noise and hypertension risk across the NHS/NHSII cohorts, and this may further support the evidence base for the effect of sleep disturbance and burden of disease due to environmental noise.

4.9 **Hahad et al** reported findings from their study into noise annoyance and the risk of hypertension with a focus on sex-specific analysis. The rationale for this study was that the link between noise-induced cardiovascular outcomes and sex is not clear from the existing literature, nor indeed if there are any sex-specific differences between men and women in terms of cardiovascular risk due to noise exposure. The aims of this study were:

- to determine whether noise annoyance due to different sources is associated with prevalent and incident atrial fibrillation in a large population-based cohort of men and women and if so
- whether there are sex-specific differences in noise annoyance-induced risk of atrial fibrillation[3].

4.10 The study utilised data from the Gutenberg Health Study (GHS) which included over 15,000 participants between 2007 and 2012. Interviews and clinical examinations were used to obtain baseline data and then the follow-up study occurred between 2012 to 2017. Self-reported annoyance was measured on a 5-point scale and asked about daytime annoyance and disturbance to sleep. Noise sources included road, railway, aircraft industrial and neighbourhood noise. Source-specific overall noise annoyance was defined as highest source-specific annoyance rating regardless of whether it affected daytime or sleep.

4.11 Prevalent and incident atrial fibrillation was defined as either self-reported previous physician diagnosis of atrial fibrillation and/or diagnosis of atrial fibrillation on the study electrocardiogram during the baseline and follow-up examinations at the study centre. The baseline data revealed that in this population, men were older, had higher socioeconomic status, consumed more alcohol above the recommended limit, and no differences were observed regarding physical activity compared to women. Although women had in general lower cardiovascular risk factors and medication profiles, the prevalence of atrial fibrillation was higher in women (22.6%) compared to men (13.3%).

4.12 With respect to noise annoyance during the day, aircraft noise was the most prominent source affecting 60.7% of men and 56.0% of women. At night, aircraft noise was the largest source of annoyance with 32.9% of men being affected and 30.1% of women. There was an increase in the prevalence of atrial fibrillation in relation to the degree of overall noise annoyance during the day and sleep in both men and women.

4.13 When observing the source-specific data, the authors found consistent positive associations between annoyance due to different noise sources and an increased risk of prevalent (self-reported physician diagnosed) atrial fibrillation in both men and women. The highest effect estimate in men was observed in

[3] Atrial fibrillation is a heart condition that causes an irregular and often abnormally fast heart rate.

response to industrial noise annoyance with an OR of 1.21 (95% CI 1.09-1.34), and neighbourhood noise in women (OR 1.22, 95% CI 1.15-1.29).

4.14 In terms of incident (as measured on the study electrocardiogram during the baseline and follow-up examinations at the study centre) atrial fibrillation, in men, a 25% (OR 1.25, 95% CI 1.07-1.44) higher risk of incident atrial fibrillation in response to industrial noise annoyance was observed.

4.15 Road traffic (OR 1.14, 95% CI 1.01-1.28) and neighbourhood noise annoyance (OR 1.19, 95% CI 1.05-1.34) independently increased the risk of incident atrial fibrillation in men. In contrast, effect estimates in women were weaker and of lower magnitude.

4.16 When examining overall noise annoyance and prevalent and incident atrial fibrillation, the authors found that in men, overall noise annoyance as well as overall noise annoyance during the day and night was consistently and positively associated with higher risk of prevalent incident atrial fibrillation ranging from 11 to 18%, whereas in women prevalent risk of atrial fibrillation was consistently increased but not incident risk.

4.17 The authors discuss the strengths and limitations of the study. One of the strengths is the large sample size and the inclusion of multiple noise sources and the examination of both prevalent and incident atrial fibrillation within the same study population. One of the limitations was that the study did not access objective noise exposure and considered noise annoyance to be a valid indicator of adverse noise-induced effects. The authors did not control for whether participants had moved house in the follow-up study, and a further limitation is the lack of any confounding data on air pollution, which is a risk factor for atrial fibrillation. However, the authors do state that previous studies have indicated that air pollution and noise exposure may act independently to increase risk of atrial fibrillation.

4.18 The authors conclude that this study provides evidence that noise annoyance is related to atrial fibrillation in both men and women, while stronger effects were observed in men, especially when it comes to the incident risk of atrial fibrillation. They highlight research gaps, including a lack of longitudinal studies and types of cardiovascular outcomes such as the one examined in this study.

4.19 **Dzhambov et al** presented findings on transportation noise and the prevalence of hypertension and diabetes in Sofia, Bulgaria. Between July-September 2022 a population-based cross-sectional survey was conducted on over 900 participants who had lived at the same address in Sofia for the previous five years. Hypertension and diabetes were self-reported of based on medication use. Residential road, air, and rail traffic day–evening–night noise levels were available from the strategic noise maps of Sofia from 2017.

4.20 The results indicated that only aircraft L_{den} was consistently positively associated with higher prevalence of hypertension across different statistical model adjustments, although statistical significance was not reached. None of the noise sources were associated with the prevalence of diabetes in this study.

Other published findings on cardiovascular outcomes

4.21 In addition to the findings presented at ICBEN, several papers have been published on the effects of aircraft noise on cardiovascular outcomes. This section of the report describes these.

4.22 **Itzkowitz** et al published findings on aircraft noise and cardiovascular morbidity and mortality around Heathrow Airport. This study examined the effects of short-term aircraft noise exposure from the previous day, and cardiovascular events in over six million people living near to Heathrow. The authors state how the previous research has largely focussed on long-term exposure to aircraft noise, with the exception of a 2000-2015 study in Zurich by Saucy et al that found acute increases in cardiovascular mortality associated with night-time aircraft noise around Zurich airport. For night-time deaths, exposure levels in the 2 hours preceding death were significantly associated with mortality for all causes of CVD [OR = 1.44 (1.03–2.04) for the highest exposure group (L_{Aeq} > 50 dB versus <20 dB)]. Most consistent associations were observed for ischaemic heart diseases, myocardial infarction, heart failure, and arrhythmia.

4.23 The study aimed to examine the short-term effects of aircraft noise at different times of the night and day on short-term cardiovascular morbidity and mortality. Air pollution and temperature were adjusted for within the design. All hospital admissions and deaths due to primary cardiovascular disease in the study area from January 2014 to December 2018 were included. Data were obtained for all events with primary cause of admission or death due to stroke, coronary heart disease, and other cardiovascular disease and linked to postcode-level noise estimates.

4.24 The authors performed conditional logistic regression to estimate the odds ratio and 95% confidence intervals per 10 dB increase for the metrics L_{day}, L_{eve}, L_{night} L_{den} and L_{Aeq24} as well as for the eight pre-defined distinct time periods throughout the 24-hour period. The results indicated that there was no association between aircraft noise and deaths due to cardiovascular disease. For hospital admissions the authors found evidence of a small increase in risk for a 10 dB increment in noise during the previous evening (L_{eve} OR = 1.007, 95% CI 0.999–1.015), particularly from 22:00–23:00 h (OR = 1.007, 95% CI 1.000–1.013), and the early morning (04:30–06:00 h OR = 1.012, 95% CI 1.002–1.021) for all cardiovascular disease admissions. They also found evidence of an increase in risk associated with noise during the previous night for admissions due to stroke (24:00–04:40 h OR = 1.133, 95% CI 1.007–1.276). This is shown in Figure 3.

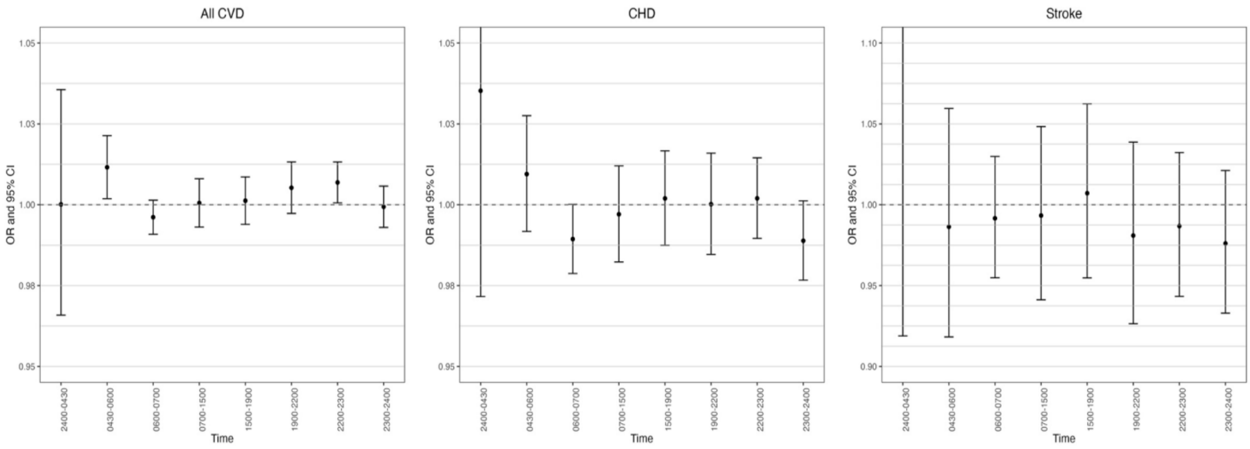

Figure 3: Odds ratios and 95% confidence intervals for hospitalisations due to all CVD, CHD and Stroke per 10 dB L_{Aeq} increase at defined time points throughout the day, evening, and night. Estimates adjusted for NO2 concentration, mean temperature and holiday effect.

4.25 The authors found that following stratifying by age and sex, the effect of aircraft noise on cardiovascular admissions was statistically significant in men over the age of 65 during the previous evening (L_{eve} OR = 1.021, 95% CI 1.006–1.036), specifically during 19:00–22:00 h (OR = 1.016, 95% CI 1.001–1.031) and 22:00–23:00 h (OR = 1.014, 95% CI 1.002–1.025). After stratifying by ethnicity, an association with early morning hours (04:30-06:00) (OR = 1.054, 95% CI 1.014–1.095) was seen in cases who reported Black ethnicity and for other ethnicity (not South Asian or Black) with previous evening noise during the hour of 22:00–23:00 (OR = 1.008, 95% CI 1.001–1.017) for hospitalisations due to all cardiovascular disease. There was also a significant increase in risk of CHD hospitalisation among cases who reported Black ethnicity associated with noise in early morning hours 04:30–06:00 h (OR = 1.111, 95% CI 1.011–1.220) and during the midday hours of 07:00–15:00 (OR = 1.085, 95% CI 1.022–1.153).

4.26 The effect of aircraft noise on CVD hospital admissions was strongest in the winter months, both in the early morning hours (04:30–06:00 h OR = 1.013, 95% CI 0.999–1.029) and evening hours (15:00–19:00 h OR = 1.011, 95% CI 1.000–1.022; 19:00–22:00 h OR = 1.022, 95% CI 1.008–1.035; 22:00–23:00 h OR = 1.016, 95% CI 1.007–1.026). The authors also found that noise variability was a modifying factor in the relationship between noise exposure and cardiovascular hospital admissions. Aircraft noise during early morning hours was more impactful in areas of high variability and high mean noise while night-time noise had a greater effect in areas of low variability, and high variability with low mean noise.

4.27 The authors concluded that small associations between aircraft noise and cardiovascular disease admissions were found, mainly relating to late evening and early night-time exposures, particularly in men over the age of 65, and for people identifying as black ethnicity. This is consistent with the suggested pathway of short-term effects of aircraft noise at night leading to sleep disturbance, increases in blood pressure and stress hormones, and impact on endothelial function. There was no association between aircraft noise and deaths observed, contradicting the findings by Saucy et al, though the authors suggest this may be due to a much smaller number of deaths compared to the number of hospital admissions in this study. They suggest further research into respite measures and behavioural interventions is warranted to translate these findings into practical measures.

4.28 **Grady et al** published further findings from the US Nurses' Health Study (NHS) with over 57,000 participants, and the Nurses' Health Study II (NHSII), with over 60,000 participants. The methodology for this study was described earlier in this chapter. This element of the study investigated long-term aircraft noise, cardiovascular disease (CDV), and mortality in the cohorts of female nurses between 1994 and 2014. During this time there were 4529 CVD cases and 14,930 deaths. Approximately 7% (n = 317) of CVD cases were exposed to DNL ≥50 dBA. Following statistical analysis, the authors did not find associations between aircraft noise and cardiovascular disease incidence, cardiovascular mortality, or all-cause mortality in this sample. The authors stressed that even in large cohorts such as these, there were limitations due to the small numbers of exposed cases.

4.29 **Pyko et al** published findings on a pooled analysis of nine Scandinavian countries, examining long-term exposure to transportation noise and Ischemic Heart Disease (IHD). Pooled analyses were performed on nine cohorts from Denmark and Sweden, including 132,801 participants. Over 22,400 incident cases of IHD were identified during follow-up from national patient and mortality registers, including 7,682 cases of myocardial infarction. The authors found statistically increased risk of IHD associated with long-term exposure to road traffic and railway noise in the five years prior to the study. Associations were also observed for aircraft noise but without a clear exposure-response relationship.

4.30 Several papers were published recently that have investigated aircraft noise and endothelial function. The endothelium is a thin membrane that lines the inside of the heart and blood vessels. Endothelial cells release substances that control vascular relaxation and contraction as well as enzymes that control blood clotting, immune function, and platelet adhesion. Endothelial dysfunction has been shown to be of significance in predicting stroke and heart attacks due to the inability of the arteries to dilate fully. The dysfunction may be a result of high blood pressure, diabetes, high cholesterol, and smoking.

4.31 Endothelial dysfunction precedes the development of artherosclerosis, a chronic disease characterised by abnormal thickening and hardening of the arterial walls with resulting loss of elasticity. Artherosclerosis may cause a stroke or heart attack.

4.32 **Jiminez et al** have investigated the effects of stopping aircraft noise on blood pressure, endothelial function, and inflammation in mice, with the aim of assessing how long the adverse effects of aircraft noise may persist once the noise source has been removed. The mice were assigned to one of five groups: a control group with no aircraft noise, a noise group with four days noise exposure, and one of three noise cessation groups which consisted of four days of aircraft noise exposure, followed by a cessation of noise for one, two or four days.

4.33 The results indicated that after one day without aircraft noise exposure, the endothelial dysfunction of the aorta was normalised, and vascular oxidative stress[4] and increased blood pressure were partially corrected, while markers of inflammation showed a normalisation within four days of stopping the noise exposure. In contrast, the authors found that endothelial dysfunction, oxidative stress, and inflammation of the cerebral micro-vessels of noise-exposed mice did not improve at all even after four days of no aircraft noise exposure.

4.34 The authors explain that these results may provide evidence for differences in the longevity of noise effects between the cardiovascular and brain tissues, with the cardiovascular system recovering from the impacts of noise exposure and the brain exhibiting greater sensitivity to aircraft noise and not recovering at the same rate. The authors suggest this may explain the presence of diseases such as dementia being linked to transportation noise exposure, and they propose to study this further, using longer periods of noise cessation.

4.35 **Kvandová** and other authors from the above study also looked at the possibility of mitigating the effects of aircraft noise-induced vascular dysfunction and oxidative stress by the means of exercise, intermittent fasting and a drug that activates the α1AMPK[5] in mice. The authors investigated mice that were exposed to aircraft noise-induced vascular dysfunction, and the the potential protective role of α1AMPK activated via exercise, intermittent fasting, and pharmacological treatment. The mice were exposed to aircraft noise (maximum sound pressure level of 85 dBA, average sound pressure level of 72 dBA) for four days which resulted in endothelial dysfunction, oxidative stress as described above. The authors found that with activation of the α1AMPK with these three

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4 Oxidative stress is an imbalance of free radicals and antioxidants in the body, which can lead to cell and tissue damage. Long-term oxidative stress contributes to the development in a range of chronic conditions such as cancer, diabetes, and heart disease.

5 The adenosine monophosphate-activated protein kinase (AMPK) is an important regulatory protein for cellular energy balance and is considered a master switch of glucose and lipid metabolism in various organs.

approaches prevented endothelial dysfunction and vascular oxidative stress, suggesting that these methods mitigate noise-induced cardiovascular damage. They suggest that future research on human populations is required to clinically prove the concept of exercise/fasting-mediated mitigation of transportation noise-associated disease.

4.36 **Sudevan** authored an invited editorial in the European Journal of Preventive Cardiology and commented on these studies on mice and the potential for translation of the results to human studies. They stress that the studies are important for the understanding of how to potentially mitigate the impacts of aircraft noise on cardiovascular disease, but state that: "*there is a long way to go forward from an animal model-based 'proof of concept' to reach a clinically efficacious drug intervention for tackling noise-related vascular dysfunction. This idea needs to be explored in detail, and the related efficacy should be tested appropriately in the future via human clinical trials before reaching a final conclusion.*"

4.37 **Münzel et al** published a review paper on environmental stressors and the endothelium. The review examined the mechanisms leading to endothelial dysfunction in response to traditional and novel cardiovascular risk factors noise and air pollution, with a particular focus on oxidative stress and inflammation. The authors describe the pathways by which noise can influence cardiovascular health through the 'direct' and 'indirect' pathway. The direct pathway influences the cardiovascular system through sleep disturbance and fragmentation. The indirect pathway causes an emotional response and stress reaction, which leads to the release of stress hormones, which can negatively influence the cardiovascular system.

4.38 The review highlights studies on different transportation noise sources and the impact on endothelial function and cardiovascular disease and provides a review of the research on air pollution and the same outcomes. Although there are pharmacological approaches that may mitigate the impacts of noise and air pollution, the authors conclude that reductions of PM2.5 concentrations in air quality, and significant reductions in transportation noise in the day and night remain the most efficient way of lessening the stress on the cardiovascular system.

4.39 **Münzel et al** also authored a review article on transportation noise and cardiovascular disease. The review focuses on the non-auditory effects of noise on the cardiovascular system, which are suggested to be the pre-cursors to future cardiovascular disease. The authors explain twenty-two million adults live in Europe in agglomerations or near primary noise sources with levels starting at 55 dBA L_{den} are highly annoyed by noise from road traffic, railways, aircraft, and industry. It is estimated that 6.5 million adults suffer severe sleep disturbance because of night noise levels ≥ 50 dBA. Sleep disturbance is a significant risk factor for future cardiovascular events. According to The European Environment Agency in their 2020 report, exposure to environmental noise from road traffic, railways, aircraft, and industry are estimated to contribute every year to approximately 48,000 new cases of ischemic heart disease and 12,000 premature deaths.

4.40 The authors describe the noise as a stressor model, proposed by Babisch, and the two pathways for noise exposure to impact the body. The direct pathway, where high noise levels cause damage to the ear, and the indirect pathway, whereby lower noise levels cause sleep disturbance, and disrupt activities and communication. The stress response elicited includes annoyance, or anger, and it is proposed that over time this leads to cardiovascular risk factors such as hypertension, increased glucose and cholesterol levels, or an increase in blood viscosity. This is illustrated in Figure 4.

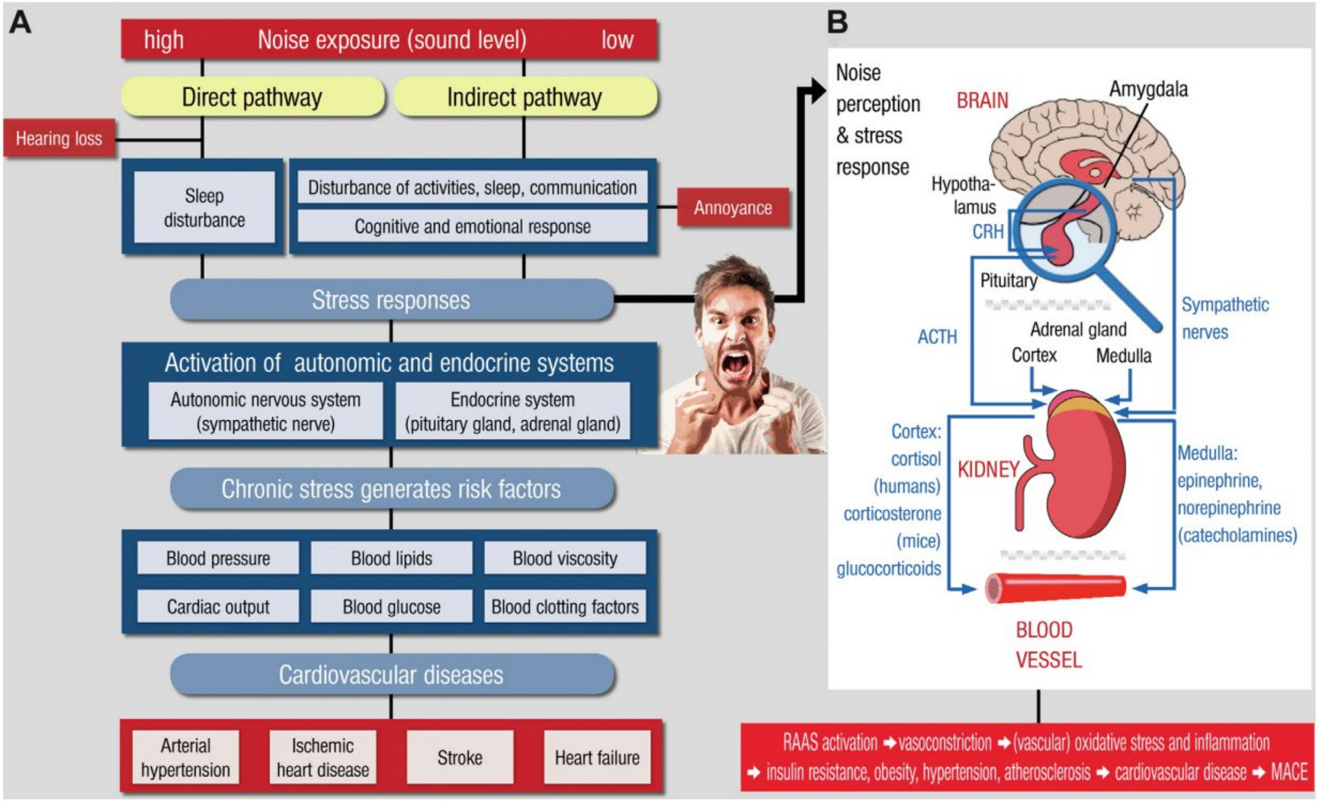

Figure 4: A – pathways by which noise exposure leads to cardiovascular disease risk factors. B – Neurohormonal activation as a result of noise exposure. Taken from Munzel et al (2023) reproduced without permission.

4.41 Stress responses to noise over longer periods of time ultimately lead to CVD, hypertension, atherosclerosis, stroke, heart failure and arrhythmia. The authors provide an overview of diabetes, obesity, and annoyance in relation to noise exposure, as well as mental health outcomes such as depression and anxiety and dementia.

4.42 A detailed discussion of the findings relating to noise exposure and IHD, heart failure and stroke was included in the review, and a section on noise and changes to endothelial function being a pre-cursor to more serious cardiovascular endpoints, as previously outlined in this report. The experimental findings on the effects of noise on circadian clock dysregulation in mice were also provided.

4.43 The review concluded with a discussion of the types of noise mitigation strategies that may be implemented. The authors suggest the importance of differentiating between ‘active’ and ‘passive’ measures. ‘Active’ measures in relation to aircraft noise, (which means a reduction of noise at its source), include the continuous descent approach, flying higher, landing at a steeper angle, or a GPS-guided approach, flight paths that avoid flying over residential areas or the use of newer engines. Night flight bans are also cited as highly effective mitigation measures. ‘Passive’ measures include structural changes such as installing soundproof windows or insulation.

Chapter 5
Aircraft Noise and Sleep Disturbance

5.1 The relationship between aircraft noise and sleep disturbance was investigated in a number of studies, the findings of which were presented at the ICBEN congress. **Smith and Evandt** from Team 5: Noise and Sleep presented a review of research in this area between 2021 and 2023. The review covered other noise sources such as wind turbine noise, occupational noise, neighbourhood noise, hospital noise exposure and other noise exposures as well as transportation noise, including aircraft noise.

5.2 Of the 80 studies included in the review, three studies on aircraft noise and sleep were included. Two of the studies used survey methods to measure sleep disturbance. One study by Al Harthy et al was conducted in Oman and examined noise levels around an airport and insomnia and sleep disturbance, with 41% of respondents reporting insomnia symptoms. Trieu et al investigated community responses to aircraft noise in around Tan Son Nhat airport using survey methods in 2008 and 2019. Despite an increase in the number of aircraft movements and passengers in that time, the authors found relatively small changes in self-reported sleep quality. Wang et al investigated how changes in flight routes around LaGuardia airport impacted sleep in two neighbourhoods close to the airport. In all age groups the authors found an impact of aircraft noise on sleep disturbance, with the most significant finding in the age group of 5-17 years.

5.3 Smith and Evandt reported that in general there has been an increased interest in the study of younger population groups across noise sources, and combined exposures such as noise and air pollution is a growing area of research. Mitigation measures have been explored with regard to other noise sources.

5.4 **Gong et al** examined the evidence of the relationship between aircraft noise and sleep disturbance around four airports (Heathrow, Gatwick, Manchester and Birmingham) within the UK. One of the research gaps previously highlighted is the lack of large-scale objective sleep data with respect to disturbance from aircraft noise. The use of polysomnography[6] is considered to be the most accurate methodology for obtaining objective physiological data that can allow for changes in sleep stages and awakenings to be observed, however this is expensive and time-consuming. The use of actimetry[7] has previously been used

[6] Polysomnography records brain waves, the oxygen level in blood, and heart rate and breathing during sleep. It also measures eye and leg movements.

[7] Actimetry/Actigraphy is a non-invasive method of monitoring human rest/activity cycles. A small actigraph unit, also called an actimetry sensor, is a small wristwatch-like device worn on the wrist.

in sleep studies as a proxy for sleep-wake activity, and although not as accurate as polysomnography because it measures rest-activity patterns rather than brain activity, this method is less expensive and allows for a larger sample size of data to be collected. There is a limited data on the use of actimetry in large-scale aircraft noise and sleep disturbance studies, and this study aimed to address this.

5.5 The authors used data obtained from the UK Biobank, a population-based biomedical database. Over 105,700 participants aged 40-69 years living near four major airports in England were included, and self-reported and actimetric methods were used to investigate the association between aircraft noise exposure and sleep disturbance. A further element to this study is that circadian rhythm (24-hour rhythm) was used as a sleep outcome, which has not previously been widely studied in this context. Data from 2006-2010 was used as the baseline, and follow-up data was obtained from 2012-2013.

5.6 Self-reported sleep disturbance was measured by asking questions on sleeplessness/insomnia, daytime sleeping or dozing, and sleep duration. Sleep duration was categorised into less than 6 hours, between 6 and 8 hours, and more than 8 hours. In terms of actimetry data, valid physical activity data from 96,600 participants (93.3%) were obtained, of whom 24,050 (sleep duration) and 22,102 (other actimetric measures) participants were living near the 4 major airports in this study.

5.7 The overall time spent asleep was calculated, alongside three outcomes that related to circadian rhythms: *"Relative amplitude (RA), intra-daily variability (IV), and inter-daily stability (IS). RA measures the contrast in activity levels between the most active 10 hours and the least active 5 hours within a 24-hour period. A higher RA value indicates greater activity during the day and reduced activity during sleep. IV measures the fragmentation of the 24-hour rest-activity rhythm, and a high IV suggests a more fragmented rhythm indicative of circadian dysfunction. IS measures the stability of the rest-activity rhythm, and a higher IS score indicates a strong alignment with light and other environmental cues that regulate the biological clock."*

5.8 The authors also used the average acceleration during the least active continuous 8-hour, 6-hour, and 5-hour periods within a 24-hour period. These were used to measure participants' movement or arousals during the least active periods, with a low level of movement suggesting a more peaceful rest during those times. Participants were categorised into three noise exposure categories of <45 dB, >=45 dB and <50 dB, and >=50 dB L_{night}.

5.9 The results indicated non-significant associations between night-time aircraft noise and self-reported sleeplessness and sleep duration. Participants exposed to aircraft noise levels above 55 dB L_{night} experienced a 1.25 odds ratio (95% CI 1.09-1.42; N=85,624) for reporting daytime dozing. The actimetry data results indicated that individuals exposed to night-time aircraft noise above 50 dB L_{night} experienced a significantly higher average acceleration during the least active continuous 8-hour of 0.13 mg (95% CI 0.04–0.21), and 0.07mg (95% CI 0.02–0.11). No significant differences were observed in the least active continuous 6-hour average accelerations.

5.10 No significant association between night-time aircraft noise and time spent asleep was found. The circadian rhythm outcomes (N=18,481), revealed significant associations between night-time aircraft noise and relative amplitude (coefficient: -0.004, 95% CI (-0.01– -0.00)), inter-daily stability (coefficient: -0.01, 95% CI -0.01– -0.00))), and intra-daily variability (coefficient 0.01, 95% CI (0.00–0.02).

5.11 The authors highlight that the association between L_{night} and daytime dozing could be an indication of sleep disturbance due to aircraft noise. There is also evidence suggesting that night-time aircraft noise may be related to disrupted circadian rhythms, with individuals exposed to noise levels above 50 dB L_{night} showing lower relative amplitude and inter-daily stability as well as higher intra-daily variability. The authors suggest that these outcomes imply that participants experienced increased restlessness during the night, an inconsistent rest-activity pattern, and fragmented rhythm. Limitations of the study include the possibility of misclassification and bias from the use of self-reported and actimetric data.

5.12 The need to collect accurate, accessible, and widespread data on noise and sleep disturbance has resulted in Belgian researchers **Dekoninck et al** to develop a new methodology for collecting indoor and outdoor noise levels, motility, and heart rate. This protocol was presented at ICBEN and briefly comprises an indoor and outdoor microphone, which allow noise data to be transferred and processed over wi-fi. The physical impact of noise on human sleep is assessed by ECG (Electrocardiogram) and accelerometry. This device is easy to install, collects a full ECG, provides motion data though the accelerometer and measures heart rate variability. Automated processes merge the noise, ECG and motility data.

5.13 The authors have completed a pilot study with this protocol, with the aim to roll it out to a large (300-400 participant) study within the Flemish Human Biomonitoring Program, with teenagers as the target participants. They claim the protocol to be relatively low-cost, easy to set up and accurate, with the first pilot suggesting that heart rate and motility can successfully be linked to noise events.

5.14 **Bartels et al** presented findings on the effects of aircraft noise on sleep quality, sleepiness and annoyance in people sleeping at night-time and daytime. The effects of aircraft noise and sleep during night-time in healthy populations are usually studied, but there is comparatively little known about the effects on sleep of vulnerable groups such as shift workers. The requirement of shift workers to be awake during the night and sleep during the day means their circadian phase is opposite to the normal pattern, which in itself can cause an impact on health and sleep quality. The authors state that in Germany 15% of the workforce are shift workers who are required to sleep during the day. There are no previous studies examining the effects of aircraft on daytime noise, and the aim of this was to examine objective and subjective quality, sleepiness and annoyance in both daytime and night-time sleep.

5.15 Thirty-three participants slept in the laboratory for two visits of two consecutive nights and were randomly assigned a to be a ‘day sleeper’ or ‘night sleeper’. During one of the visits participants were exposed to aircraft noise during both sleep episodes. Noise from 81 aircraft flyovers from eight different aircraft types were played back in the bedrooms with an average sound pressure level of 46.8 L_{eq}. The authors explain this level represents a common indoor aircraft noise exposure near Cologne/Bonn Airport.

5.16 Polysomnography was used to measure various sleep parameters and self-reported sleep quality was measured via a six-item questionnaire, and sleepiness via another standardised scale. Annoyance was measured with the ICBEN 5-point verbal scale.

5.17 The results indicated a significant effect of aircraft noise on subjective sleep quality and annoyance after getting up in both groups of sleepers. The authors averaged sleepiness across assessment times (after getting up, after 10/11 hours awake, prior to the next sleep episode) and found that this was significantly increased after sleep under aircraft noise exposure in day sleepers, but not in night sleepers. There was no effect of aircraft noise on sleep efficiency for either group. Time spent in the lighter sleep stages 1 and 2 was higher when exposed to aircraft for day sleepers, but not for night sleepers. Likewise, the number of awakenings was increased during noise exposure in day sleepers, but not in night sleepers.

5.18 Slow wave sleep (deep, restorative stages of sleep) was reduced in the first episode of aircraft noise-induced sleep in day sleepers, but not the second sleep episode. There was a trend towards an interaction between noise exposure and the sleep episode for the number of awakenings in day sleepers. Whilst the number of awakenings was higher in the first sleep episode with noise exposure, it was not in the second one. Annoyance in day sleepers was increased and self-rated sleep quality was decreased in the first noise-exposed sleep episode whilst noise exposure showed no effect in the subsequent sleep episode.

5.19 The authors suggest that perhaps a type of compensatory response occurs between the first and second noise-exposed sleep episodes in day sleepers. They propose that the sleep in day sleepers is more fragile and therefore more vulnerable to the effects of transportation noise, and this area warrants further research, particularly over longer study periods.

5.20 **Clark et al** presented the methodology for a new UK study funded by the DfT on night noise from aircraft noise and health effects. The Aviation Night Noise Effects (ANNE) study aims to examine the different time periods of the night and how they impact sleep disturbance and annoyance in 4000 participants living near eight airports within the UK. The study will also include an objective sleep disturbance study of 200 participants, where physiological assessments of sleep disturbance will be linked to aircraft noise exposure at the participant's home.

5.21 The ANNE study, expected to be concluded in 2025, will derive exposure-response functions between night-time aviation noise metrics and sleep and annoyance outcomes. Metrics such as $L_{Aeq,8h}$, $L_{Aeq,1h}$, and N60 will be explored in relation to sleep disturbance and annoyance, and ultimately the results will feed into the UK government's night noise policy for aviation. In addition, the study will examine whether a relationship between objective sleep disturbance can be estimated for metrics such as LAmax and Sound Exposure Level (SEL). Investigations into certain sub-population groups will also be explored.

Other published findings on sleep disturbance

5.22 **Bozigar et al** published findings from the US Nurses' Health Study, on aircraft noise exposure and self-reported sleep duration and quality. The methodology for this large cohort study was described earlier in this report, and for this element of the larger study aircraft L_{night} and DNL levels were modelled around 90 US airports from 1995 to 2015 in five-year intervals. Categories of noise exposure for both metrics were compared to levels below 45 dB. From the study questionnaires, the authors obtained data on self-reported short sleep duration (less than 7 hours per night) in 2000, 2002, 2008, 2012, and 2014. Data on poor sleep quality (frequent trouble falling/staying asleep) was collected in 2000.

5.23 The results in over 35,000 participants (average age 66 years at baseline) indicated that short sleep duration was associated with both L_{night} and DNL, and the L_{night} association varied by individual, area, and airport characteristics, including region, living near a major cargo airport, living near a water-adjacent airport, and by self-reported level of hearing loss. Aircraft noise exposure was not associated with self-reported sleep quality in this study. The authors also found evidence for a relationship between increasing levels of aircraft noise (both metrics) and short sleep duration.

5.24 The authors outlined the limitations of the study, including a lack of males due to the selected cohort, a lack of younger participants, no measurement of annoyance or noise sensitivity and a lack of control for sleep medication use.

Chapter 6

Aircraft noise and Children

6.1 Two papers were presented at ICBEN that focussed on the effects of noise on children and adolescents. **Engelmann et al** presented the outcomes from an umbrella+ review of transportation noise on children and adolescents in Europe. The review focussed on outcomes such as cognitive functioning, behaviour, annoyance, sleep disturbance, cardiovascular outcomes, metabolic effects and adverse birth outcomes. An Umbrella+ review includes most recent systematic reviews and pooled analyses as well as recent original studies not yet included in these reviews.

6.2 The paper details the inclusion criteria and methodology for reviewing the relevant findings, such as only including participants under 18 years, reviews in English since 2015 and consideration of the main three transportation noise sources – road, railway, and air traffic. The authors evaluated the evidence for an association between transportation noise sources and physical and mental health outcomes using the same criteria as in the WHO noise guidelines. They concluded that there was only a limited number of reviews that met the criteria, yet they propose they are still relevant for health impact assessments and should be considered in future studies.

6.3 **Kuhlmann et al** explained the methodology for obtaining views from 15 European countries on the environmental noise impact on children's and adolescents' health and cognitive development as part of the EU Horizon 2020 project Equal-Life (Early Environmental quality and life-course mental health effects). The paper describes the aims of the interviews within the framework of the broader study, but the stakeholders' views about the role of environmental noise for children's and adolescents' well-being and development have not yet been published.

Other published findings on noise and children

6.4 **Graafland et al** reported on a study investigating exposure to outdoor residential noise during pregnancy and size of the embryo, foetal growth, and birth outcomes. The rationale for this study was that there have not been any previous studies that have explored the association of environmental noise exposure during pregnancy with embryonic size and foetal growth parameters. It is explained that changes in embryonic and foetal growth rates are indicators of the foetal response to an adverse environment both in and out of the uterus. In addition, previous research has suggested that embryonic and foetal growth and development are determinants for health and disease in later life.

6.5 This study examined the association between exposure to outdoor residential total noise (comprising road traffic, railway, aircraft and industry), road traffic noise, and railway noise exposure during pregnancy and embryonic size and foetal growth parameters and birth outcomes in a large population-based prospective cohort of nearly 8000 participants. Embryonic size and foetal growth parameters (head circumference, femur length, and estimated foetal weight) were measured by ultrasound at several gestational ages. Information on neonatal anthropometrics at birth (head circumference, length, and weight) and adverse birth outcomes (pre-term birth, low birth weight, and small for gestational age) were retrieved from medical records.

6.6 The results indicated that exposure to outdoor residential total noise, and road traffic noise during pregnancy resulted in larger embryonic size in early pregnancy. It is suggested this may be due to maternal stress and the embryo growing rapidly as a survival mechanism in early pregnancy, to adapt to adverse conditions in the uterus. There was no modifying effect of traffic-related air pollution. There was no evidence of an association between total noise or road traffic noise exposure during pregnancy and foetal growth or birth outcomes, nor between railway noise exposure during pregnancy and any of the outcomes.

Chapter 7
Other findings

Non-acoustic factors

7.1 The influence of non-acoustic factors continues to gain momentum in the area of aircraft noise and health effects. **Fenech** presented an update on the development of an ISO Technical Specification to standardise the characterisation and use of non-acoustic factors for both noise and soundscapes assessments. **Van Kempen et al** gave an overview on the recent research to include non-acoustic factors across various noise sources since 2021 with a focus on cardiovascular and metabolic outcomes, mental health, and dementia. Eight systematic reviews were included for cardiovascular and metabolic outcomes, with six of these investigating aircraft noise. 38 original studies were included in the review, with 13 involving aircraft noise. For mental health and dementia outcomes, 14 reviews were included and 22 original studies, of which three included aircraft noise.

7.2 Non-acoustic factors can include perceptions of people towards the noise source, a sense of control over the situation, coping strategies and individual attitudes towards air traffic. **Hauptvogel et al** presented findings on perceived fairness as a concept that addresses such factors, for example 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 Aircraft Noise related Fairness Inventory (fAIR-In).

7.3 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.

7.4 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 more detail this year in the International Journal of Environmental research and Public Health.

7.5 **Paunović** presented a keynote lecture on individual differences in how humans react to noise. The presentation discussed how individual differences may impact the effects of noise on annoyance, sleep disturbance, and cardiovascular outcomes such as blood pressure. Age, gender and personality traits were discussed, and the importance of noise sensitivity in the relationships between noise and annoyance, cardiovascular diseases, and mental health outcomes. It was explained that noise sensitivity may also be linked to self-reported anxiety and depression. The author also discussed research examining the association between noise sensitivity and misophonia. Misophonia (or selective sound sensitivity syndrome, sound-rage) is described as a disorder of decreased tolerance to specific sounds or their associated stimuli, or cues. These cues, known as "triggers", are experienced as unpleasant or distressing and tend to evoke strong negative emotional, physiological, and behavioural responses that are not seen in most other people. Paunović stresses the importance of learning about human responses to noise for authorities to implement the most effective noise measures for public health.

Community response to noise and annoyance

7.6 **Nguyen and Yano** presented a summary on community response to noise and noise annoyance between 2021 and 2023. The review summarises 27 studies reported by Team 6 (Community response to noise and annoyance) on the community response to noise and noise annoyance between 2021 and 2023, including those presented at the 2023 meeting.

7.7 The highest number of studies (6) were on aircraft noise, which suggests that this is still the area of highest concern in terms of environmental noise. The recent research conducted by Team 6 focuses on noise generated by industry and sports activities, such as machinery, equipment, and human physical exertion alongside transportation noise.

7.8 The following recommendations for Team 6 for the next term were:

- Conduct further research on noise assessment methods – and explore ways to improve these methods.
- Develop standardised protocols for non-acoustic factors in noise assessments: A new working group of ICBEN is developing a new ISO Technical Specification to standardise the characterisation and use of non-acoustic factors for noise and soundscapes. Team 6 could contribute to this effort by developing standardized protocols for using non-acoustic factors in noise assessments.

- Conduct studies on noise impact on young children and explore effective methods to assess their perception of their living environment.
- Contribute to the development of exposure-response functions.
- Consider the impact of noise during remote work and classes - consider the impact of noise on individuals during these activities and explore ways to minimize excessive noise exposure.

7.9 Team 6 at ICBEN have proposed that data should be gathered from noise researchers across the world, in order to obtain an international archive of original survey response data from socio-acoustic noise surveys, named ISAR (short for ICBEN Socio-Acoustic Survey Archive). **Brink et al** explained that the proposal is the data would be anonymous, original raw data from social surveys, and freely accessible to researchers to allow for pooled analyses, cross-cultural comparisons of responses to noise, and other research to be conducted using the data. Data has already been collected and over 40,000 responses are in the new ISAR. The finalisation of the governing terms and conditions are now underway, with a view to further expanding the database and a possible first publication due by the end of the year.

7.10 **Nguyen and Yano** presented findings on residents' responses to aircraft noise scenarios in two airports in Vietnam. One airport Noi Bai Airport (NB) in Hanoi opened a new terminal building in 2014 and aircraft noise levels have been increasing since then. The other airport in the study was the Tân Sơn Nhất (TSN) which is the largest airport and in Vietnam, with consistently high noise levels. With the onset of COVID-19 the travel restrictions resulted in a significant drop in aircraft noise around this airport. The authors' aim was to examine the changes in the aircraft noise exposure around both airports, and to investigate the impacts on annoyance and the effects of non-acoustic factors.

7.11 A survey was conducted in 2009 around NB airport, and again following the opening of the new terminal building. Then two follow-up surveys were conducted in 2017 and 2018. At TSN, the first survey was performed in 2008 and then again in 2019. Following the closure of the airport in March 2020 due to the pandemic, health surveys were conducted three months and six months after the change occurred, and the results were compared with those obtained in 2019. Figures 5 (a) and (b) display the exposure-response relationships for all of the surveys for each airport.

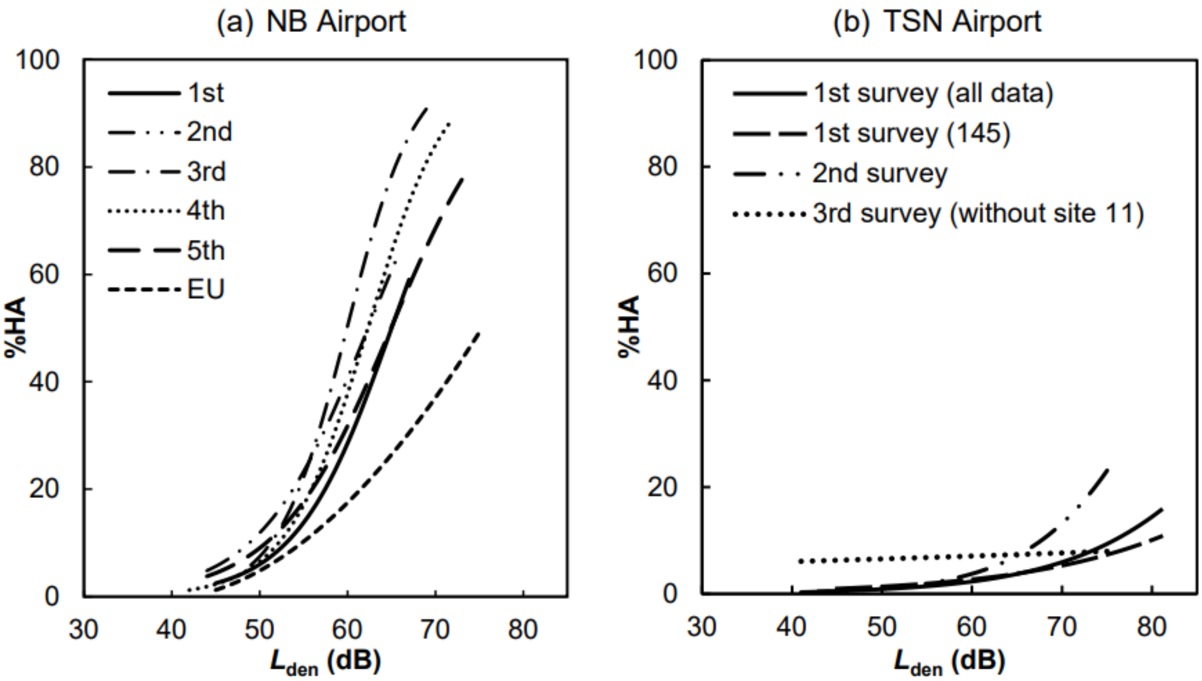

Figure 5: Comparison of the L_{den} and % HA relationships obtained from the data of each survey: (a) NB Airport; (b) TSN Airport.

7.12 Figure 5 (a) compares the relationship between L_{den} and %HA using data obtained from all the surveys conducted at NB airport. The number of aircraft operations gradually increased after the opening of a new terminal building in December 2014. Step-change surveys were conducted once before and twice after the change, and a significant change effect was observed with respect to annoyance. The change effect was observed immediately after the step change occurred. The L_{den} and %HA relationships of the follow-up surveys in 2017 and 2018, conducted about 3 and 4 years after the step change, were lower than those of the 2015 surveys carried out 3 and 8 months after the change. In other words, the effect of the step change appears to decline over time, and the 2018 follow-up exposure-response relationship is close to that of the pre-change situation.

7.13 Figure 5 (b) shows a comparison of the L_{den} and %HA relationships for the three surveys conducted at TSN airport. The authors explain that the relationship observed from the original 502 participants and that of 145 people who continued to participate in the next survey of the 2019 survey were not significantly different. At the same noise level, the percentage of people having a higher annoyance response is higher in the second survey, but this percentage is reduced dramatically in the 2020 September survey. The exposure-response relationship in the September 2020 survey is lower than in the June 2020 survey, but it remains higher than in the 2019 survey, regardless of the continuous decrease of noise exposure during the pandemic. In other words, an "under response" occurred with the reduction of aircraft noise exposure around TSN shortly after the change, but it eased six months later.

7.14 The authors found that non-acoustic factors such as noise sensitivity and survey type are important factors that moderate annoyance responses. Among the residential factors that influence responses to noise at NB airport, the assessment of sound insulation and duration of occupancy significantly affect annoyance. It is suggested that the effect of noise change scenarios should be investigated using both acoustic and non-acoustic variables.

WHO Guidelines revisited

7.15 **Gjestland and Evensen** presented a paper re-examining the WHO's Environmental Noise Guidelines (ENG) for Europe. The paper discusses the discrepancies between the recommended limits set in the 2018 WHO ENG and the subsequent studies that have been conducted and their resulting exposure-response relationships. The exposure response curves that formed the basis of the ENG from Guski[8] are shown in Figure 6.

7.16 Gjestland discusses the UK SoNA Study and the US FAA sponsored Neighbourhood Environmental Survey (NES) in relation to the ENG's exposure-response curves. The SoNA study uses $L_{Aeq,16h}$ as the aircraft noise metric. Gjestland proposes the conversion of this metric to DENL by use of conversion tables by Brink et al. Gjestland compared the SoNA annoyance curve with that derived by Miedema and Vos in 1998 and suggests that people appear to be less annoyed in 2014 than in 1998, for the same noise level (Figure 7).

[8] Guski, R., Schreckenberg, D. and Schuemer, R, WHO Environmental Noise Guidelines for the European Region. A systematic review on environmental noise and annoyance. Int J of Environmental Research and Public Health, 14 (12) 2017.

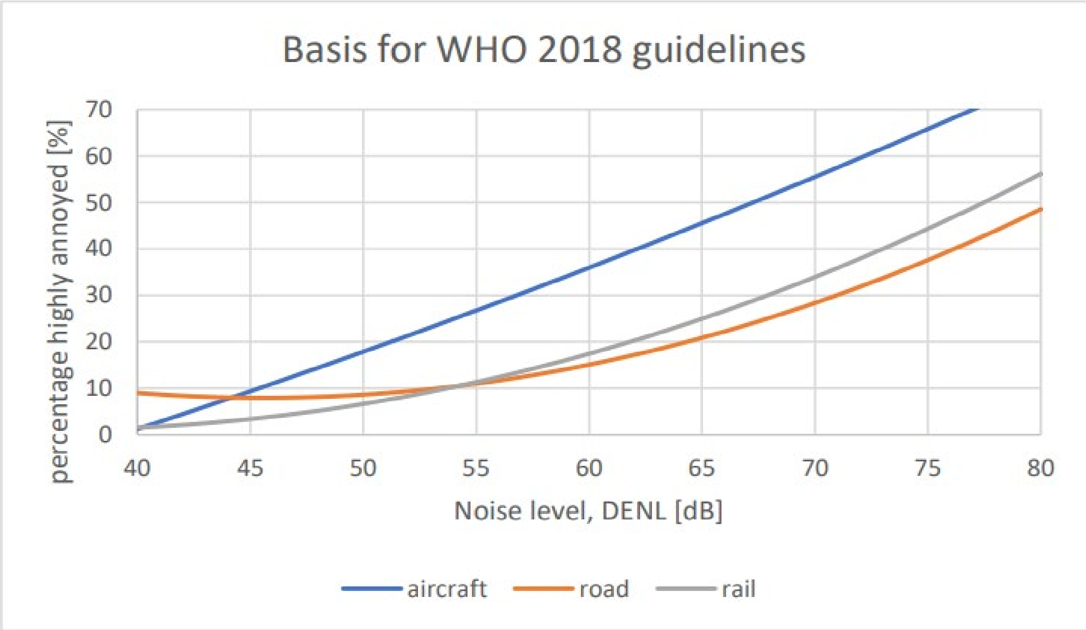

Figure 6: Exposure-response curves for transportation noise developed by Guski et al.

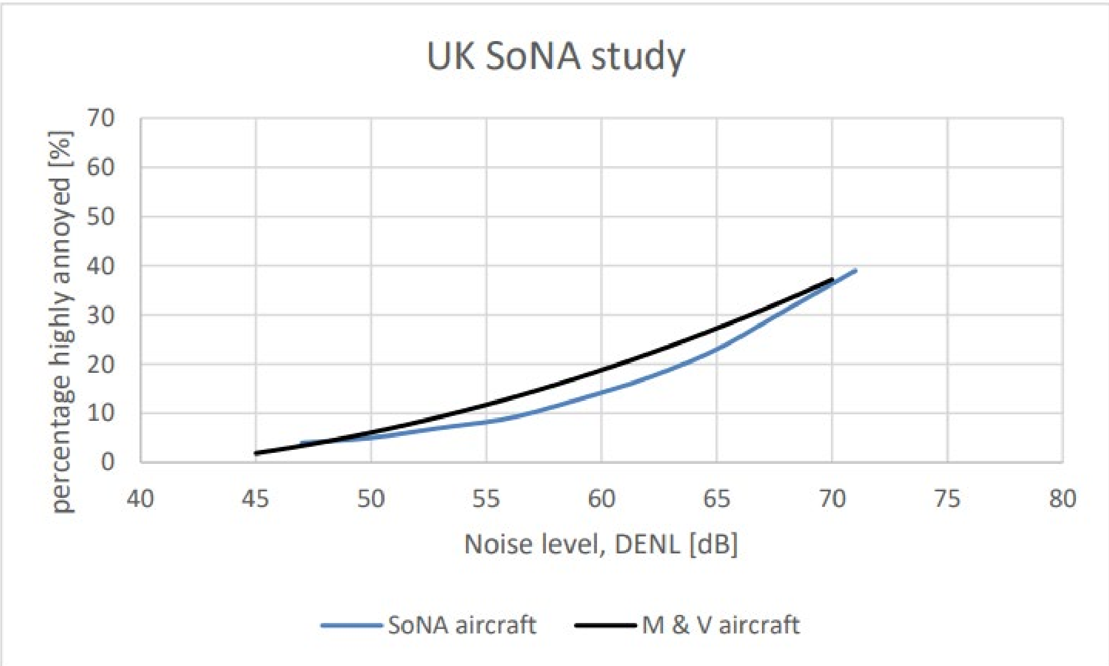

Figure 7: DENL Exposure-response curve derived from the UK SoNA study.

7.17 Gjestland discusses the US NES study in the context of survey presentation, and the use of postal questionnaires in this study rather than face-to-face methods. He explained that a limited number of residents (about 2,300) in the selected study areas were interviewed via telephone. The analysis indicated that people are more likely to express high annoyance when answering a written questionnaire than when being interviewed by a person. Miller et al who conducted the NES, found that the difference was equivalent to about a 5 dB shift in the noise exposure. Gjestland suggested that in order to compare the NES results with the Miedema and Vos curve, the NES data should be adjusted firstly by 5 dB to compensate for postal versus person interview, and secondly by 5 dB to compensate for verbal versus. numerical response scale. The original NES curve and the adjusted one are shown in Figure 8. The authors state that the adjusted curve is similar to the Miedema and Vos curve for exposure levels below about 60 dB L_{dn}

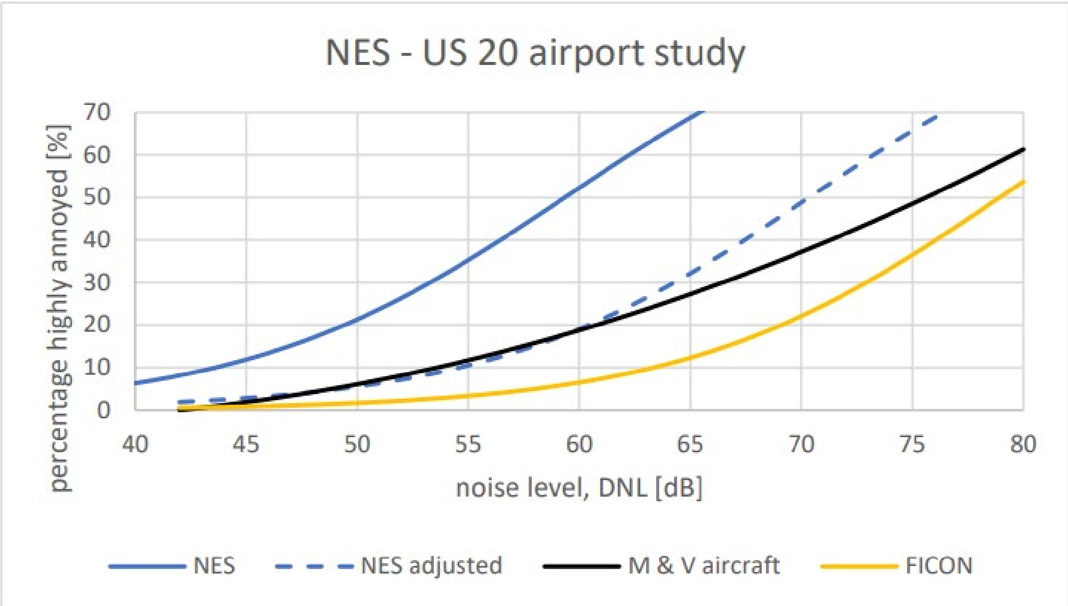

Figure 8. Exposure-response curves derived from the US NES study. Original Exposure-response function (blue) and an Exposure-response function adjusted for 10 dB according to the response scale and mode of presentation (blue dashed).

7.18 Gjestland concluded that although the WHO ENG recommends a limit of 45 dB L_{den} for aircraft noise, the subsequent studies have suggested limits of between 53 and 57 dB L_{den}. The NES study initially suggests that the exposure-response curve for annoyance is considerably higher than the previous FICON curve, but it is argued that if the results are adjusted to make them comparable with other surveys, the NES results are very similar to the Miedema and Vos curve for exposure levels below about 65 dB L_{dn}.

Burden of disease

7.19 **Röösli et al** presented data on estimating the burden of disease from transportation noise in Switzerland. The quality of evidence for various diseases in relation to transportation noise were rated either as sufficient (moderate or high) or not sufficient (very low or low). The authors used the WHO ENG as a basis and then examined subsequent systematic reviews and original research to determine the exposure-response relationships for health outcomes with sufficient quality evidence.

7.20 For cardiovascular disease the authors stated the evidence for a causal relationship between road, rail and aircraft noise and cardiovascular diseases and mortality is considered to be high. For aircraft noise, the association with depression was found to be highly significant, but the authors stress this result is largely determined by a case-control study (Seidler et al. 2017) and not by a prospective cohort study. The evidence for transportation noise and various birth related outcomes was considered to be insufficient, as was the evidence for cognition and behavioural problems.

7.21 For cardiovascular mortality, the authors derived age group specific risk estimates from a Swiss nationwide cohort study yielding risk increases of 0.0% (aircraft, ≥ 80 years) to 8.6% (road, 18-65 years) per 10 dB L_{den} noise increase. For diabetes and depression, pooling Swiss cohort data with international study results yielded risk estimates of 8.0% and 4.9% per 10 dB increase of any type of transportation noise, respectively.

7.22 **Jephcote et al** published their spatial assessment of the attributable burden of disease due to transportation noise in England. The health burdens of annoyance (HA), sleep disturbance (Highly Sleep Disturbed – HSD), IHD, stroke and diabetes that were associated with long-term transportation noise exposure in England in 2018 were estimated at national, regional, and local-authority level. The noise data was sources from strategic noise maps for each of the transportation modes and was allocated a lower threshold value of 50 dB L_{den} and L_{night}.

7.23 Disability Adjusted Life Years (DALYs) were used to estimate the burden of disease regarding the health impacts of transportation noise. The analysis was limited to adults normally resident in England (20 + years, n = 42,738,500) in 2018. Figure 9 illustrates the spatial variation in the percentage (%) of the population exposed to road-traffic, railway, and aircraft noise from major sources above 50 dB (L_{den}).

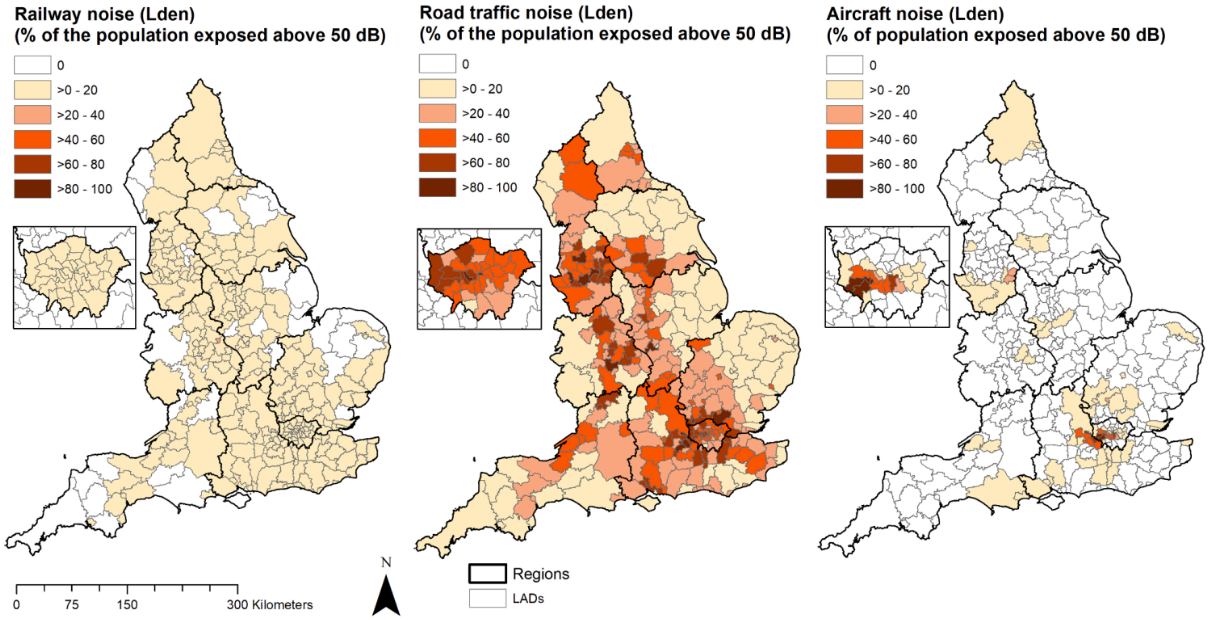

Figure 9: Spatial variation in the percentage (%) of the population exposed to road-traffic, railway, and aircraft noise from major sources above 50 dB (L_{den}) across Local Authority Districts (LADs) in England, based on strategic noise mapping carried out in 2012.

7.24 The authors observes that 40 % of the adult population in England were exposed to road-traffic noise that exceeded 50 dB L_{den}, however they stress that there was a large degree of spatial variation across LAD. 4.8 % of the population was exposed to aircraft noise above 50 dB L_{den}, though the spatial distribution was particularly skewed as 95 % of LADs had less than 20 % of populations exposed. The highest exposures to aircraft noise from major airports were found near London. 4.5 % of the population in England were exposed to railway noise from mainlines that exceeded 50 dB L_{den}. Similar patterns were observed for night noise.

7.25 In terms of the noise burden, road noise accounted for the largest number of DALYs (97,000 per year), followed by aircraft noise (17,000 per year) and then railway noise (13,000 per year). For annoyance, the highest number of DALYs per year was observed for road traffic (33,243), followed by aircraft noise (10,486). Railway noise was associated with the highest level of sleep disturbance 97,217 DALYs per year). Due to a lack of evidence and/or statistically significant relative risk estimates, the authors did not calculate attributable burden of disease for railway noise and IHD, stroke, and diabetes, as well as aircraft noise and stroke and diabetes. Road-traffic noise yielded estimates of 18,592 DALYs lost per year from strokes; 11,556 from IHD and 6,585 from diabetes.

7.26 The authors explain that for aircraft noise the rates of DALYs were highest around London, particularly Hounslow and Richmond situated near to Heathrow airport, illustrated in Figure 10.

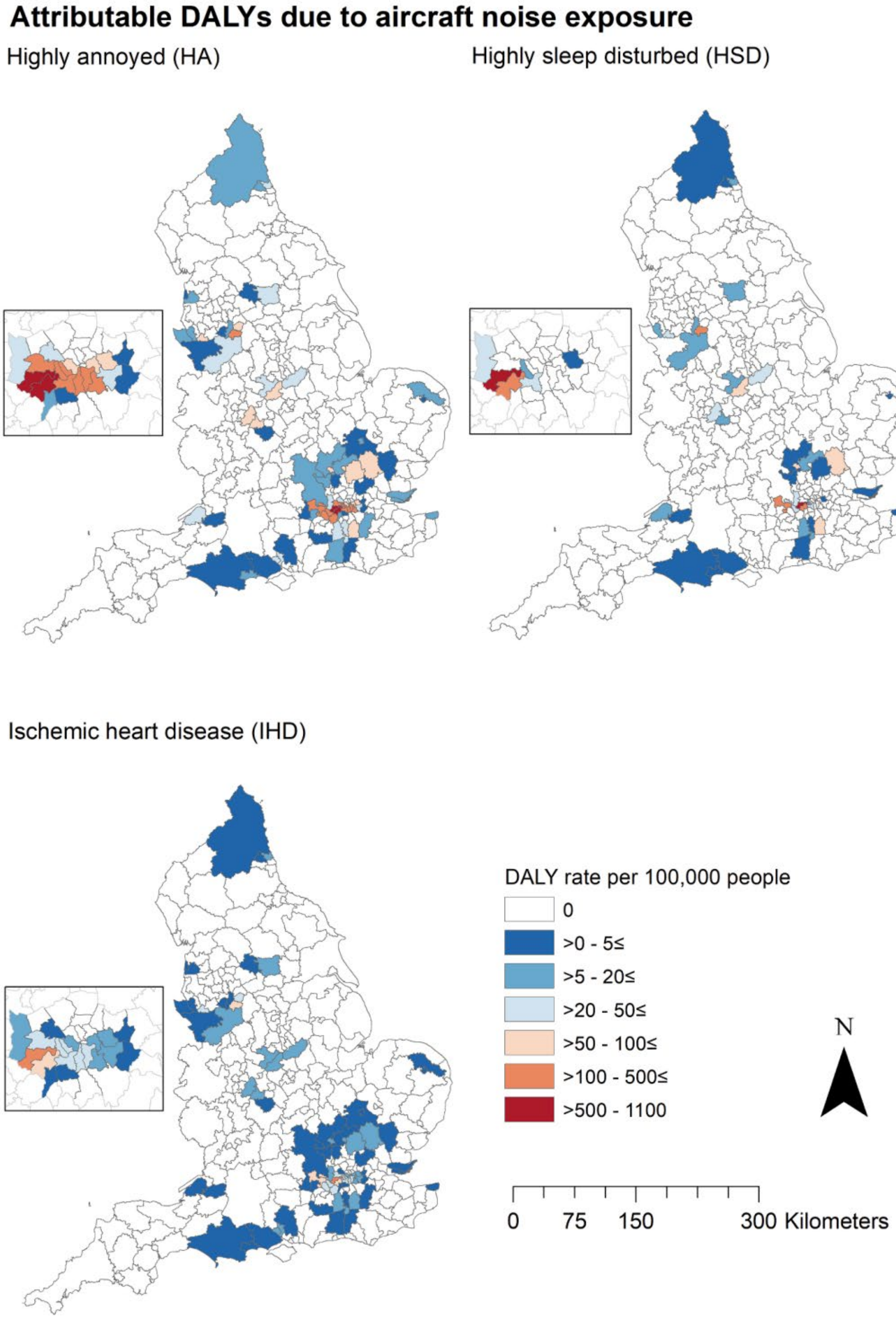

Figure 10: Attributable Disability Adjusted Life Years (DALYs) lost per 100,000 people/year due to aircraft noise exposure above 50 dB within Local Authority Districts (LAD) in England.

7.27 The authors explain that these findings are comparable to those in the European Environment Agency (EEA) report at a national level. The uneven distribution of noise is discussed, particularly in relation to aircraft noise, with London having 63 % of all attributable aircraft noise DALYs in England. They conclude that study, the first of its kind for noise in England, offers valuable information on the distribution of areas with burdens of disease due to transportation noise, which can ultimately prove useful for deciding research priorities, setting policy and decisions around interventions from noise exposure.

Mental health and noise

7.28 **Wicki et al** published findings on suicide and transportation noise in Switzerland. The aim of this study was to investigate the association between source-specific transportation noise, particulate matter (PM) air pollution, residential greenness, and suicide, by means of a nationwide cohort study. The authors explain that research has indicated that although suicide levels have decreased in Switzerland, they have not yet fallen to a level that the Sustainable Development Goal (SDG) have set as a reduction of one third. Therefore, there is a need to understand what risk factors may contribute to mental health disorders and suicide.

7.29 The study examined road, railway and aircraft noise levels and air pollution exposure ($PM_{2.5}$) and levels of greenness around participants' addresses in over five million people as part of the Swiss National Cohort study. Participants were followed over 15 years in five-year intervals from 2001-2015 and data on deaths from suicide were analysed in respect of the other factors.

7.30 The authors found that during the follow-up period there were 11,200 suicides, of which about three quarters were males. The mean exposure for road traffic noise was highest (54.4 dB L_{den}), followed by railway noise (38.6 dB L_{den}) and aircraft noise (34.5 dB L_{den}). The results indicated an association between road traffic noise and suicide with an HR of 1.040 (95% CI:1.015, 1.065) per 10-dB increase in noise exposure. Railway noise exposure was also associated with an increased risk of death suicide, but the relationship was not as strong as for road traffic noise (HR = 1:022; 95%CI: 1.004, 1.041). for both noise sources, the risk was higher in females compared to males. The authors did not find an association between aircraft noise and suicide. No association between air pollution and risk of suicide was observed.

7.31 The authors stress that their findings should not be interpreted as transportation directly influencing suicidal behaviour, but rather that suicide is a proxy for underlying mental health disorders which are linked to transportation noise exposure levels. It is suggested that for aircraft noise, night exposure is the main driver for the effects on mental health as reported in a 2020 meta-analysis by Hegewald et al, which reported an increased risk of depression per 10 dB aircraft noise. The main study in this meta-analysis for aircraft noise was set around the Frankfurt airport before the night flying ban was established in 2011.The authors conclude that further research is needed to add to the understanding of the complex relationship between noise exposure, other environmental stressors such as air pollution, socioeconomic factors, and mental health.

Chapter 8
Summary

8.1 This update report has summarised the main findings in the field of aircraft noise and health effects research over the six-month period March - September 2023. The chapters have included those findings presented at the ICBEN congress and in peer-reviewed academic journals in the areas of annoyance, sleep disturbance, cardiovascular disease, effects on children and other findings. In terms of cardiovascular research, there has been a particular focus in the past six months on the importance of endothelium function as a pre-cursor to more serious cardiac outcomes, and how this is impacted with noise exposure.

8.2 The report also includes descriptions of other published findings over the previous six months. Research on non-acoustic factors, community response to noise, the spatial distribution of burdens of disease due to transportation noise in England, and the effects of noise on mental health have also been described.

8.3 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 April 2024.

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