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 between March and September 2024 and includes findings from the Internoise Congress held in August 2024, in Nantes, France.

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 2024

Community Response and Annoyance

2.1 This section focuses on the findings from the Internoise 2024 Congress, on community response to aircraft noise and annoyance responses.

2.2 The first paper was by **Kodji et al**, who examined the effect of aircraft noise on annoyance in a pooled analysis using data from the DEBATS and NORAH studies. The effect of non-acoustic factors was investigated.

2.3 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 included 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.

2.4 The NORAH study was conducted around Frankfurt airport and included adult volunteers living within the 40 dBA equivalent continuous sound level contours of aircraft noise for day and night-time. This study was based on a sub-sample of 1,039 participants in the NORAH who had their blood pressure monitored.

2.5 In both studies, aircraft noise annoyance was assessed using the ICBEN recommended question and its verbal five-point rating scale where the upper two verbal ratings (very, extremely) define high annoyance. Both studies used outdoor aircraft noise levels. The aim of this study was to test the contribution of non-acoustic factors to the prediction of aircraft noise annoyance and to determine whether there was a moderating effect between non-acoustic factors on annoyance. The potential moderating role of age, gender, noise sensitivity, and trust in authorities in the prediction of aircraft noise annoyance was explored.

2.6 A total of 1,039 (55% female) and 1,244 (56% female) participants were included in the NORAH and the DEBATS studies, respectively. The authors explain that the distributions of aircraft noise levels (L_{den}) were relatively similar in both studies (mean of 52 dBA in the NORAH study and 54 dBA in the DEBATS study). In the NORAH study, 54% of participants reported being highly annoyed by aircraft noise compared with 18% of participants in the DEBATS study. 18% of NORAH participants reported being very sensitive to noise compared with 7%

of DEBATS participants. Additionally, NORAH participants had a lower level of trust in the authorities than DEBATS participants (54 % vs 4% for the two lowest scores).

2.7 The analysis revealed that in both studies separately, and in pooled analysis, predictors of high aircraft noise annoyance were aircraft noise levels (beta=1.46, p<0.001 in the pooled analysis), noise sensitivity (beta=0.37, p<0.001 in the pooled analysis) and trust in authorities (beta=-0.75, p< 0.001 in the pooled analysis). In the DEBATS study and in the pooled analysis, age was also found to be a predictor of high aircraft noise annoyance. There was no significant interaction found between aircraft noise levels and gender, or trust in authorities.

2.8 The interaction between aircraft noise levels and noise sensitivity was significant in the NORAH study and also in the pooled analysis (p<0.05), but not in the DEBATS study. No interaction effects were significant for aircraft noise levels and age, gender, or trust in authorities. Figure 1 shows the exposure-response curve for highly annoyed (HA) as a function of aircraft noise, with respect to noise sensitivity levels, for the pooled analysis dataset.

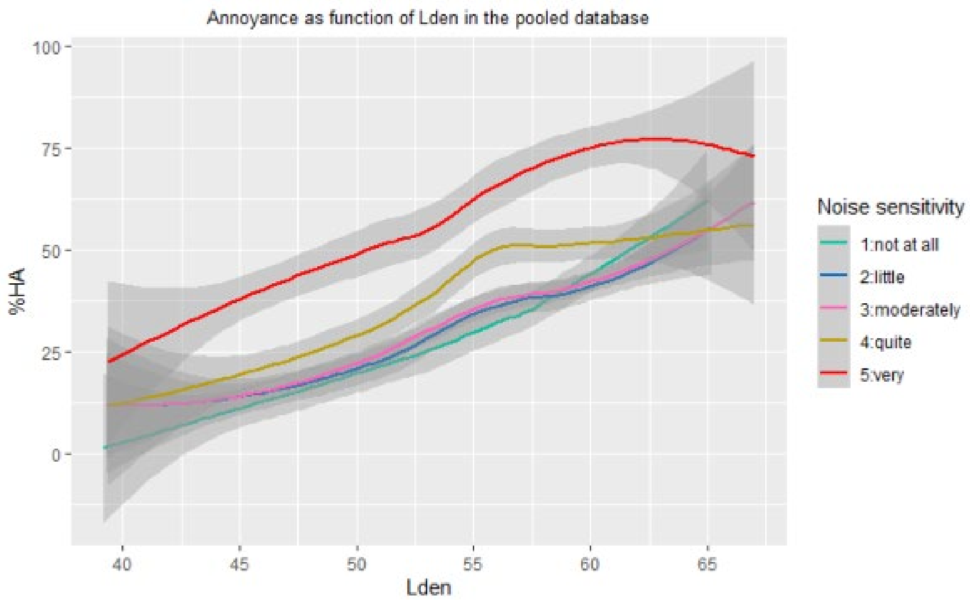

Figure 1: Annoyance as a function of L_{den} in the pooled dataset, stratified by noise sensitivity levels.

2.9 Figure 1 indicates that higher levels of noise sensitivity displayed higher levels of aircraft noise annoyance, with differences of more than 25% often observed between categories 1 and 5.

2.10 The authors concluded that these findings confirm the important role of non-acoustic factors such as age, noise sensitivity, and trust in authorities in the prediction of aircraft noise annoyance.

2.11 **Tardeiu et al** presented findings on qualifying and quantifying the different ways in which people are annoyed by aircraft noise. The rationale for this study was that quantitative methods are often required for noise mitigation measures, but field studies on annoyance due to aircraft noise illustrate the wide range of responses at a given noise level, suggesting that the noise source alone is not wholly responsible for the degree of annoyance. The aim of the study was to gather a wide range of disciplines (aeronautics, acoustics, linguistics, psychoacoustics, social and environmental psychology) together, to define a common framework for reconciling field and laboratory studies on aircraft noise annoyance.

2.12 A set of six quantitative variables and 41 qualitative variables were used for participants to describe semantic aspects of noise annoyance. Data on 15 sociodemographic variables were also collected. An online questionnaire was completed by 1249 participants, living near Toulouse (Blagnac) and Paris (Charles de Gaulle) airports. The respondents were recruited according to the noise exposure plan (NEP) of both airports, and from within four geographic areas.

2.13 Six annoyance profiles were revealed as a result of the questionnaire data, in terms of how participants describe their experience of aircraft noise annoyance. Twelve focus groups were conducted in video conference with 102 participants, with one focus group for each profile and each airport, and between 8 and 10 participants per group. Participants were chosen randomly within the initial 1249 participants panel. In addition, two laboratory experiments with the same protocol were run in Toulouse and Paris in order to evaluate the impact of annoyance profiles on a quantitative assessment of noise annoyance, with the aim to investigate whether the annoyance profile revealed in the questionnaire survey had a quantitative impact on noise annoyance ratings in a controlled laboratory experiment.

2.14 Participants were in an acoustically controlled room and asked to perform a simple reading task while exposed to four sequences of 15 minutes of aircraft noise in a random order. The profile was considered as a first independent variable, in addition to two acoustical variables: number of flyovers (3 or 10) and $L_{A,max}$ of each flyover (54 or 60 dBA). After each sequence, participants were asked to rate their annoyance on four different 6-point scales: task interference, mental effort, annoyance, and comfort.

2.15 The analysis revealed that all annoyance profiles were structured around 4 main non-acoustic factors: attitudes towards of air traffic, feeling about aircraft noise, quality of life, and way of reacting to problems. In addition, each profile is also described by the emotions perceived when overflown by an aircraft and the coping strategies (short versus long term). The main emotion of each profile was

2.16 used as a label to provide the general attitude of people within each profile, resulting in the following six emotions and attitudes going from negative to positive (Table 1):

Table 1: The main emotions and attitudes for the six annoyance profiles

Profile	Main emotion and attitude
1	Weary and demobilised
2	Angry and mobilised
3	Sad and worried
4	Not concerned
5	Satisfied
6	Pleased

2.17 The results of the focus groups are described by the authors, with all profiles agreeing on the aspects of aircraft noise that are particularly annoying when the following scenarios are present:

- It is impossible to enjoy outdoors (e.g., open the windows, enjoy the garden).
- It prevents an activity (e.g., conversations, sleeping, concentration).
- The noise is too loud, too frequent and the aircraft fly too low.
- The flyovers happen at an inappropriate time (e.g., night, resting time).
- It has an impact on health (e.g., sleep, fatigue, mood, stress, hearing problems).
- There is no positive personal return from air traffic (e.g., work, compensation, opportunity to travel).

2.18 Results from the laboratory studies indicated that participants with the more negative annoyance profiles were more likely to give higher annoyance responses, compared to the participants with positive profiles. The results also revealed that noise annoyance ratings where not always explained by L_{Aeq} but also by the number of flyovers or by the L_{Amax}.

2.19 The listening tests found significant differences in the quantitative annoyance ratings between positive and negative profiles, which the authors explain validates the profiles obtained. They conclude that this method of using different scientific disciplines to link field and laboratory studies is a useful method of combining methodologies from social sciences and acoustics to further understand annoyance responses from aircraft noise. They suggest that future research in sound perception could use these profiles to investigate other aspects of noise annoyance and other interactions with non-acoustic factors.

2.20 **Barros et al** reported results regarding factors influencing annoyance from various transportation sources as part of the citizen science project “De Oorzaak". Citizen Science (CS) is an approach to scientific work that integrates the public into the scientific process, from the design of the research question to data collection, interpretation, or analysis. The project included residents of Flanders, Belgium, answering the Large Sound Survey (LSS), a 51-question questionnaire which sought information on annoyance from transportation sources, which were categorised as:

- Road traffic: passenger cars, trucks, buses, mopeds/ scooters/ motorcycles/ quads, military vehicles, emergency vehicles, and tractors on public roads.
- Rail traffic: passenger trains, freight trains, and trams/metro.
- Air traffic: passenger/cargo aircraft, sports and business jets, military aircraft, helicopters, drones.

2.21 Questions on noise sensitivity, sleepiness, and fatigue were asked alongside the ICBEN 5-point scale on annoyance. The results were compared to the Written Environmental Survey (SLO), commissioned by the Flemish government, as a reference point. Regarding annoyance levels by environmental noise in general, a large portion of participants (79%) reported being moderately to extremely annoyed with the percentage highly annoyed (%HA) equal to 33.3%. In the SLO- the %HA was 11.6%. The authors suggest this was due to sampling differences, with the participants in this study being more sensitive to noise.

2.22 In this study, relatively noise-sensitive participants reported more noise annoyance than relatively neutral or noise-insensitive participants. Residents of apartments or studios expressed higher noise annoyance levels than those residing in row houses with gardens, semi-detached or detached houses. There was no significant difference found between genders. There was an effect of age present, with adults reporting higher annoyance levels than retired or young adults. Those participants residing in urban areas reported higher annoyance than those people living in rural areas.

2.23 The transportation noise sources were analysed separately, for the scope of this report only the results relating to aircraft noise are shown. Figure 2 summarises the annoyance distributions for each aircraft noise source.

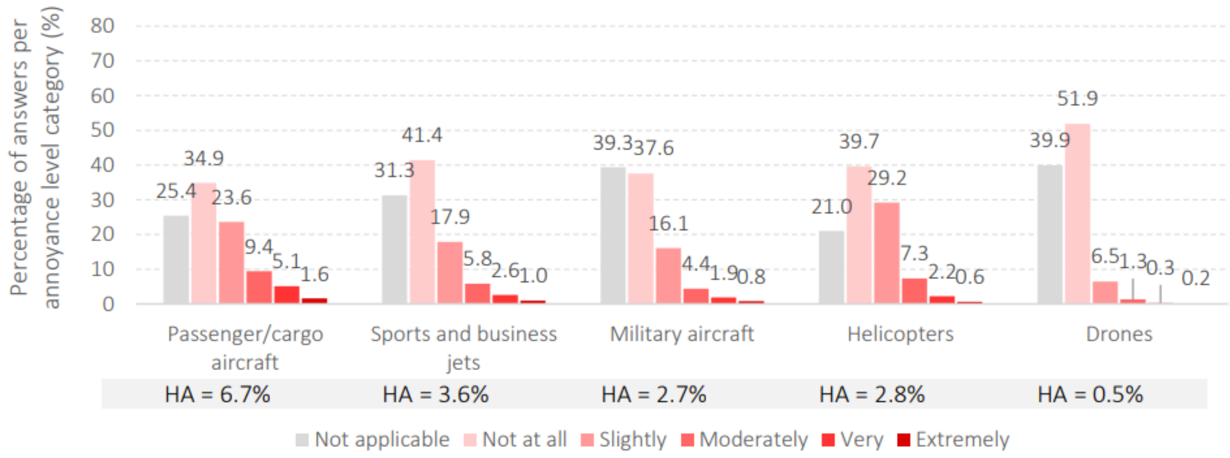

Figure 2: Annoyance by air traffic type.

2.24 Figure 2 indicates that a large proportion of respondents reported that annoyance due to aircraft noise was either not applicable or they were not at all annoyed by it. Passenger/cargo aircraft elicited a %HA about three times higher than passenger trains and two times higher than freight trains. Using established exposure-response relationships (ERRs), the %HA of passenger/cargo aircraft yields a L_{den} level of 45-50 dBA, and approximately 43.4 dBA as calculated by Guski et al.

2.25 The figures from road traffic noise annoyance indicate that passenger cars and trucks lead as the most annoying sources, with %HA of 24.5% and 23.5%, respectively. Motorcycles and alike entail a similar %HA (21.5). The authors report that the %HA of passenger cars would yield an L_{den} in the range of 65-70 dBA, which is notably high.

2.26 For rail traffic, most participants, likely living far from railway lines, expressed minimal annoyance, with a %HA less than 3.5% across all three categories (passenger and freight trains, and trams/metro).

2.27 The authors explain that surprisingly, noise sensitivity did not correlate or presents a very weak positive correlation with annoyance from most noise sources, although it did correlate with overall noise annoyance. Stress (Perceived Stress Scale) and fatigue (Fatigue Assessment Scale) correlated with environmental noise annoyance, while sleepiness (Epworth Sleepiness Scale) did not. It is reported that quality of life appeared to reflect noise annoyance levels the most accurately, given the strongest negative correlations with most sources of transportation noise annoyance. It is intended that the De Oorzaak study will provide the baseline for longitudinal studies that will include objective measures of environmental noise and health such as smart sound sensor networks.

2.28 Quality of life (QoL) was the focus of a study around Schiphol Airport by **Aalmoes et al**, as part of the wider Aviation Noise Impact Management through Novel Approaches (ANIMA) project.

2.29 To study the impact of the presence of a large airport on the QoL of residents in surrounding regions, a survey including nine indicators for QoL was conducted for two Dutch communities. A comparison was made between one community situated near Schiphol airport and one in Utrecht without a neighbouring airport. The nine indicators identified that are relevant for measuring the QoL around an airport were closely related to the indicators found by the European Union's EUROSTAT institute:

1. Health: self-perceived health and access to healthcare.

2. Economic and physical safety: economic stability and safety from physical harm.

3. Natural and living environment: perceived environmental influences, nearby green and recreational areas, and environmental pollution.

4. Work and other main activities: paid or unpaid work.

5. Education.

6. Material living conditions: person's income and ability to buy as a consumer.

7. Leisure and social interactions: quantity, quality and access to leisure, and social activities with and for people.

8. Governance and basic rights: attitudes towards government institutes and public services, equal opportunities, and active citizenship.

9. Overall quality of life: subjective rating of life satisfaction, affects and meaning and purpose of personal life.

2.30 Recruitment was undertaken in November 2020; participants were asked to answer the questions for pre-pandemic conditions and answered questions on an online survey website. A total of 1024 people participated, with 510 from Utrecht area and 514 from the Schiphol area.

2.31 Results showed a significant main effect of region on noise annoyance scores, ($F(1, 1049) = 33.88$, $p < .001$). Aircraft noise annoyance scores were higher around the Schiphol Airport region compared to the Utrecht-Control region. Region also had an effect on air travel ($F(1, 1049) = 4.57$, $p = .033$), as residents around Schiphol reported to generally make more use of air travel for holidays or work. The residents around Schiphol also had a more positive perception of aerospace than residents around Utrecht ($F(1, 1049) = 12.58$, $p < .001$).

2.32 Residents around Schiphol reported more neighbourhood trouble (M = 1.75, SE = .04) than the Utrecht residents (M = 1.62, SE = .04). Residents around Utrecht reported to have fewer social interactions (M = 1.62, SE = .04) than the Schiphol residents (M = 1.75, SE = .04), controlled for by socioeconomic indicators: education level and type of house, either bought or rented.

2.33 When the QoL factors were analysed for interactions, the authors found a (moderate) correlation between aircraft annoyance and the perception of aviation, where a higher level of annoyance correlated positively with a negative perception of aerospace. Additional analyses on aircraft noise annoyance revealed a weak (r = .26) but significant correlation between aircraft noise annoyance and neighbourhood trouble (nuisance). A similar result was found between aircraft noise annoyance, personal safety (r = .29) and financial worries (r = .28). These results were also supported by the correlations between the individual QoL questions for the two regions. Here, the main differences between the Schiphol-Airport region and Utrecht-Control region could be attributed to people that make more use of air travel and work for the airport in the Schiphol region than in the Utrecht region. Also, a stronger (though still weak) correlation was found between work and health in the Schiphol-Airport region than in the Utrecht-Control region, possibly due to the health concerns due to the neighbouring airport.

2.34 The authors concluded that this study suggests that local aviation in airport regions considerably affects residents' quality of life, both negatively and positively. Residents perceive both, the adverse as well as the beneficial impact of the airport's activity, and airport management may be able to learn more about individual communities and subsequent quality of life impacts, to enable effective engagement and improved relationships.

2.35 **Mietlicki et al** presented the development of a new noise point counter that integrates instantaneous annoyance at overnight. The rationale for this is that current regulations on transport noise are based on energetic acoustic indicators that may not adequately reflect the intensity and repetitive nature of noise peaks, particularly for aircraft overflights or rail traffic. It is argued that these indicators do not accurately reflect the annoyance induced on populations. Bruitparif, (a non-profit environmental organisation responsible for monitoring the environmental noise in the Paris agglomeration), proposed the introduction of a Noise Point Counter (NPC), based on existing Number Above indicators, but without a threshold effect. The idea is to count the number of noise events, and apply a to weighting each event according to the level of instantaneous annoyance it is likely to generate for residents (based on acoustic characteristics and period of occurrence).

2.36 The COGEN'AIR pilot study is planned to be conducted on three selected overflown areas in the Île-de France region between October 2024 and

September 2026, which will assess the feasibility of such an indicator. The aim of the COGEN'AIR feasibility study is to validate the proposed approach and adjust the calculation formula for the point-based noise event counter, with input from people living in the vicinity of airports. Data will be collected in three ways:

- The completion of a general questionnaire to characterise the long-term annoyance felt by participants in connection with their exposure to air traffic noise.
- Filling in a dashboard to collect daily information on short-term annoyance during a 15-day period, that have to be the same for all participants at a site, guaranteeing an assessment of annoyance over a common period and under same overflight conditions.
- The organisation of collective rating sessions, during which study participants at each pilot site will record their instantaneous annoyance levels during aircraft overflights, under identical noise exposure conditions (same aircraft overflights).

2.37 The authors explain that with the proposal of an indicator representative of the annoyance associated with air traffic noise, and developed in association with residents, the COGEN'AIR study will provide an operational tool to monitor the impact of the combined effects of changes in air traffic (number of overflights and fleet composition), changes in operating procedures (e.g. generalisation of continuous descents) and any additional actions such as operating restrictions that might be introduced at certain airports.

2.38 **Welch et al** presented findings on how the number and sound level of noise events and task engagement influences perceived loudness and annoyance. The paced visual serial arithmetic task (PVSAT) was used in this study, which is an engaging and cognitively demanding task that requires participants to perform mental arithmetic within a tight timeframe. It assesses concentration ability, capacity, and rate of information processing, as well as sustained and divided attention. Participants (N=29) were asked to rate the loudness and annoyance of the aircraft recordings presented to them while performing the PVSAT and while not. Changes in skin conductance, heart rate, and blood flow were measured at the same time in order to capture physiological comparisons of the task and exposures that might confirm the stressfulness of the stimuli and task for participants.

2.39 Participants were exposed to recordings of aircraft noise, presented either as a single 15-second overflight at 80 dB $L_{Aeq15seconds}$ or four 15-second overflights at 60 dB $L_{Aeq15seconds}$. The results indicated that generally, the higher noise overflight was perceived as louder and more annoying than the four lower noise overflights, whether participants were performing the task or not. When performing the PVSAT the perception of the four lower-sound-level overflights was louder and more annoying, than when not performing the task. The difference between the loudness and annoyance ratings of the two types of noise presentations decreased when participants were engaged in a task.

2.40 The authors explain that the physiological findings (greater skin conductance and lower blood volume pulse amplitude) support the idea that the PVSAT task was highly engaging and that the single higher noise-level stimulus caused greater stress in participants. Noise did not influence task performance and there was no significant difference observes when exposed to aircraft noise stimuli or not. It was suggested that future research into the relative roles of noise level and the number of events may provide a clearer picture of the ways in which noise level and the number of events interact to cause changes in reactions to sounds.

Aircraft Noise and Cardiovascular Disease

2.41 This section highlights the findings that were presented at the Internoise meeting, on the effects of aircraft noise on cardiovascular markers. **Seidler et al** provided an update on the evidence between aircraft noise and ischemic heart disease from 2015 to 2023.

2.42 Three publications on incident ischaemic heart diseases (IHD) and six publications on IHD mortality met the eligibility criteria for inclusion in the review. Four studies on IHD mortality were included in a meta-analysis. The importance of understanding IHD risks such as air pollution and transportation noise is highlighted by the authors, who explain that about 9 million deaths globally are caused by IHD per year, and the prevalence is still rising. It is estimated that the current prevalence of 1,655 per 100,000 population will rise to 1,845 in the next 10 years.

2.43 In the meta-analysis of the four studies on IHD mortality, the results revealed an increase in IHD mortality by about 9% per 10 dB L_{den} aircraft noise exposure (starting point 30 dB; risk ratio RR=1.085, 95% confidence interval CI 0.997-1.181, p=0.06). The authors also pooled the recent studies with the results of the WHO systematic review from 2018. The risk of aircraft-noise related IHD mortality was statistically significantly increased by 7% per 10 dB L_{den} (RR=1.069, 95% CI 1.004-1.139, p=0.04). For IHD incidence, the pooled risk estimate was 2% per 10 dB (RR=1.020, 95% CI 0.986-1.054, p=0.25).

2.44 The results from some of the studies included suggested that women may be more susceptible to aircraft noise related IHD incidence/mortality than men. Based on the updated literature and the results of the meta-analysis, the authors propose that limit values for aircraft noise should take into account risk increases for IHD even at relatively low aircraft noise levels.

Noise sensitivity

2.45 An individual's degree of sensitivity to noise has been acknowledged as an important non-acoustic factor in noise effects research. This section summarises two papers from Internoise 2024 that focused on this area. The first is by **Marquis-Favre et al**, who presented work on the results of a systematic review and suggested improvements for measurement.

2.46 The paper describes the lack of validation of measurements of sensitivity, with either single-item rating scales being used or full questionnaires, of which there has been a lack of validation in different languages or through psychometric assessment. There has also been no systematic review of the methodologies and tools used to assess noise sensitivity, even though it is studied widely.

2.47 In order to address this, the authors have embarked on a three-stage research project:

- Task 1: a systematic review of the measurement of noise sensitivity.
- Task 2: comparison of questionnaires.
- Task 3: Psychophysiological assessment of noise sensitivity. This may include measures such as pupil dilation and skin-conductance responses.

2.48 It is expected that the outcomes of this project will provide evidence on the quality of existing noise-sensitivity questionnaires, enable an objective comparison of the questionnaires across languages in terms of their psychometric characteristics, and their potential to predict noise annoyance reactions, and provide evidence on correlates of noise sensitivity captured by physiological measurements. It is hoped this project will result in more consistent measurements of noise sensitivity in noise and health research.

2.49 **Wu et al** authored a paper on the qualitative investigation into a noise sensitivity model, using semi-structured interviews to gain a greater understanding of the factors involved when determining noise sensitivity. The study was based on a previous model by Welch et al (2022), which focussed on a system model of noise sensitivity (Figure 3). Within this model, noise sensitivity involves all of the factors related to people's interpretation of the sound and is the result of a series of variables and processes that combine to produce it.

2.50 The authors explain that the theories of noise sensitivity are similar to those in the theory of perception, and LeDoux proposed that two neural pathways are involved in perception: the "high road", which refers to the cortical pathway in which people interpret meaningful information; and the "low road", which is a subcortical pathway, running in parallel with the high road, involving the limbic system, mediating emotional experiences, and linking to physiology.

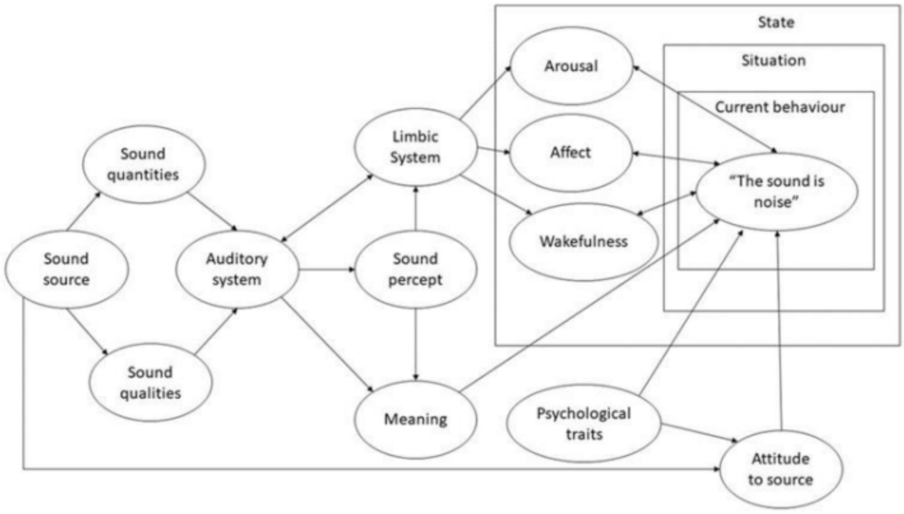

Figure 3: Process diagram of a System Model of Noise Sensitivity.

2.51 The authors aimed to gain qualitative data on what influences noise sensitivity, and what people understand noise sensitivity to be. Semi-structured interviews were conducted with each study participant via online video link, which lasted approximately 90 minutes and were transcribed. The results revealed four main areas that indicate what happens when people hear sound:

- The acoustic signal: the sound itself, qualities and quantity.
- Interaction between sound and the person: e.g. Sound masking.
- The 'high and low roads': factors relating to a person's perceptions and the process of how a sound signal is heard by a person and is then integrated to form their understanding or affect their state, and ultimately influence a person's perception of the sound.
- Outcomes: related to the final outcomes of all previous steps and whether a person considers sound to be noise, or experiences annoyance.

2.52 The authors found that the results supported the previous systematic model of noise sensitivity, but they also extended it to include their findings (Figure 4). It is explained that each circle represents a factor of noise sensitivity, and the final judgement of "annoyance" is the result of all the factors. The arrows between the factors show the direction of the processes, with the heavier arrows representing the two main routes associated with sound perception: the high road and the low road.

2.53 The high and low roads are still present in the model, with the low road representing a faster arousal route that influences mood (affect) and psychophysiological state, which may also influence the high road. This also depends on situational and personal factors in the evaluation process as to whether a person determines sound as noise.

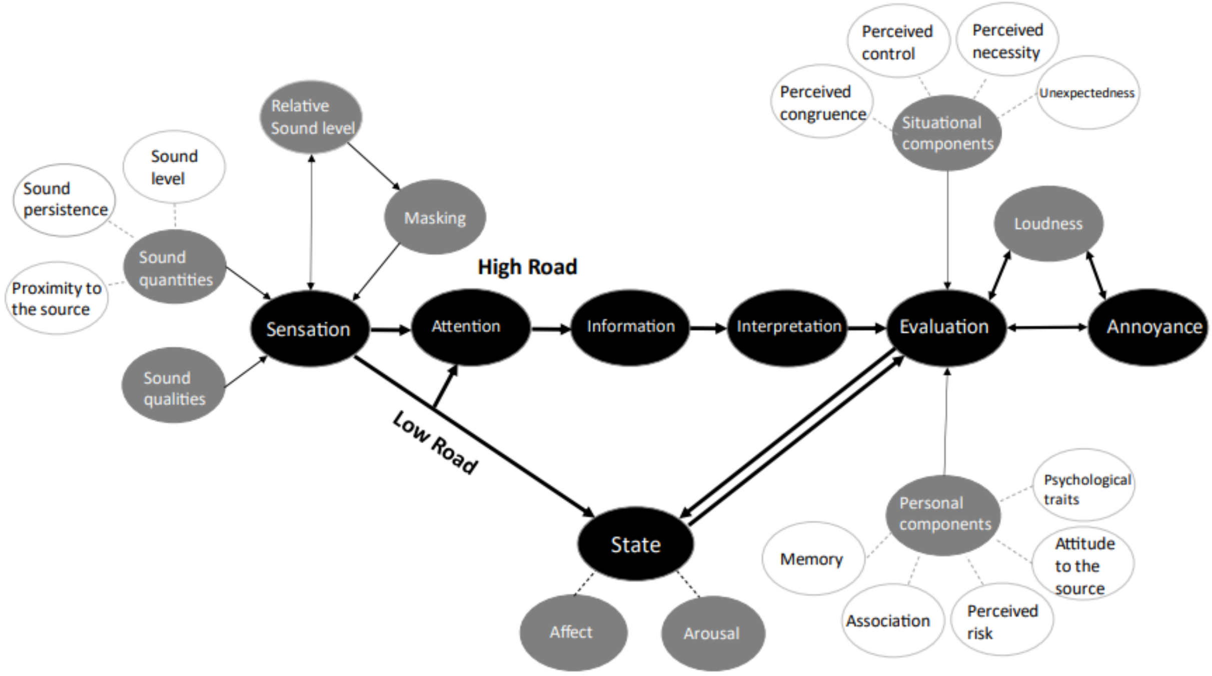

Figure 4: Revised system of noise sensitivity.

2.54 The authors hope to develop measurement methods to further test these factors, with the aim to achieve better understanding of the ways in which noise sensitivity can be identified and addressed.

Other papers

2.55 This section includes findings from a variety of subject areas that are relevant to aircraft noise and health effects, presented at the Internoise meeting. The first is by **Nguyen and Yano**, who presented findings on acoustic and non-acoustic factors when mitigating the effects of aircraft noise on wellbeing in Vietnam.

2.56 In 2008 and 2009, the first socio-acoustic surveys were conducted around Tan Son Nhat Airport (TSN) in Ho Chi Minh City (HCM) and Noi Bai Airport (NB) in Hanoi. NB's operations increased, especially after the opening of a new terminal building in December 2014. TSN International Airport is Vietnam's largest airport, situated in densely populated areas with very high exposure levels. However, due to travel restrictions during the COVID-19 pandemic in 2020, noise significantly decreased, creating a contrasting scenario around NB.

2.57 This long-term study had three aims to investigate:

- Whether there were effects of change when aircraft noise exposure increased or decreased.
- If existing exposure-response relationships for noise restrictions are applicable to Vietnam's changing aviation situation.

- To what extent non-acoustic factors influence the outcomes.

2.58 Data collection was via face-to-face interviews and included the ISO 11-point scale annoyance question. In all surveys, the proportion of women respondents was slightly higher than men, and respondents aged over 60 years accounted for less than 30% of the total number of respondents. Figure 5 shows the comparison of noise levels (L_{den}) and percentage Highly Annoyed (HA) for each survey at both airports.

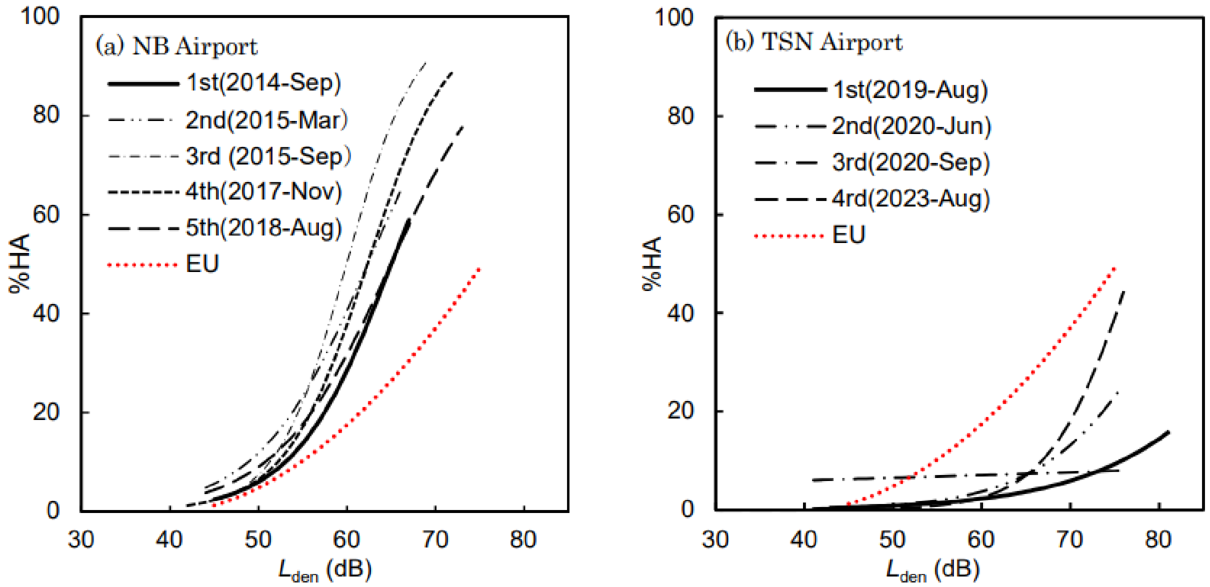

Figure 5: Comparison of L_{den} –% HA relationships for each survey (a) NB Airport. (b) TSN Airport

2.59 The relationship between L_{den} and %HA in the follow-up surveys conducted approximately 3 years and 4 years after the completion of the new terminal building at NB is lower than the 2015 survey conducted about 3 months and 8 months after the completion of the new terminal building. The exposure-response relationship in the 2018 follow-up survey is closer to the relationship in the pre-change 2014 survey. The authors describe this as the change effect due to the step change decreasing over time.

2.60 At TSN Airport, the survey conducted during the pandemic in 2020 showed a significant decrease in noise exposure compared to the noise levels measured in the 2019 survey. Even with the same noise levels, the percentage of people showing negative reactions was higher in the second survey, but this percentage dramatically decreased in the September 2020 survey. The exposure-response relationship in the September 2020 survey is lower than in the June 2020 survey and remains higher than in the 2019 survey, despite the sustained decrease in noise exposure during the pandemic. The exposure-response relationship in the 2023 survey is the highest. The authors explain that the results suggest that the exposure-response relationship based on studies conducted under stable conditions may not be applicable to the scenario around TSN. The relationships in all surveys at TSN are lower than that established in the EU position paper. Conversely, the relationships obtained from all surveys at NB are higher than the EU's relationships.

2.61 It is suggested that NB airport being situated in a less densely populated location may account for some of the increased amount of annoyance, as people may notice the aircraft noise more than in a more highly populated environment, such as TSN, and therefore report higher levels of annoyance.

2.62 The data on non-acoustic factors collected in the surveys included residential environment, individual characteristics, and attitudes. For NB airport, the results indicated that individual and residential environment factors such as noise sensitivity, length of residence, and evaluation of sound insulation significantly influenced annoyance in Hanoi. The interaction between noise sensitivity and noise exposure (noise sensitivity * L_{den}) also significantly affected annoyance. The coefficient of the interaction between L_{den} and noise sensitivity was negative, indicating that as noise exposure increases, the impact of noise sensitivity decreases.

2.63 For TSN airport, non-acoustic factors such as short residence duration, poor views, small floor area, and stressful situations were associated with higher prevalence of discomfort. Survey factors (dummy variables for 2019 and 2020) also influenced prevalence, with a high prevalence of highly annoyed reported in the 2020 survey. There was also an interaction between noise exposure and survey factors (L_{den} x survey), suggesting that the impact of survey factors decreases as noise decreases, and vice versa.

2.64 The authors suggest that the findings indicate that annoyance can be influenced by non-acoustic factors such as regional characteristics. The study implies that both acoustic and non-acoustic variables should be considered when investigating the impact of noise changes. In addition, they propose that this could assist in the development of noise policies to improve living conditions in developing countries.

2.65 **Bartels et al** presented findings from a study on aircraft noise in vulnerable populations. Although vulnerable groups such as children, older people and shift workers are often cited as requiring protection from the effects of aircraft noise, these sectors of the population have not been widely studied recently. The authors conducted two field studies around Cologne/Bonn airport in 51 children (8-10 years old) and 44 older people (55 – 76 years old), and a laboratory study of 33 young adults, comparing the effects of aircraft noise in a group scheduled to sleep during the day, compared to a group scheduled to sleep at night.

2.66 In the field studies the children and older participants were studied at home for three or four consecutive nights respectively, using polysomnography. Aircraft noise and ambient noise exposure was recorded using a sound meter inside the bedrooms next to the participants, and on waking ratings were given on annoyance and sleep quality.

2.67 In the laboratory study, participants slept in the laboratory for five sleep episodes. After an adaptation night, they returned to the laboratory for two visits during which they were exposed to aircraft noise or no noise during two consecutive sleep episodes in counterbalanced design. Participants were randomised to either sleep at night (23:00 - 07:00, referred to as “night sleepers”) or during the day (09:00 -17:00, referred to as “day sleepers”) during each of the two visits. During the sleep episodes with aircraft noise exposure, 81 aircraft fly-over sounds from eight different aircraft types were played (L_{eq} = 46.8 dBA).

2.68 For the field studies, sleep and annoyance scores between nights with higher versus lower aircraft noise exposure were compared. In children, higher noise exposure was associated with a longer wake time during the sleep period (lower exposure: M = 21.2 min, higher exposure: M = 28.5 min, p = .016) and a reduction of deep sleep (lower exposure: M = 251.1 min, higher exposure: M = 234.4 min, p=.010). There was no effect of aircraft noise exposure on annoyance or self-reported sleep quality. In older adults, the wake time during sleep was not affected by noise exposure. Deep sleep duration was slightly but significantly higher in higher noise exposure nights. Annoyance was higher after higher exposure nights, and self-reported sleep quality reduced.

2.69 The authors pooled the samples from the children and older adults with a sample of adults from a previous study, and applied a mixed model regression, for comparison between the age groups. At the same maximum sound pressure level of an aircraft noise event, the probability for a noise-associated awakening (= stage change to wake or stage 1) was significantly lower for children aged 8-10 years (p=0.006) and participants at an age of 55 years or older (p=0.022) than for the reference sample in the age range 18 < 55 years. Annoyance was also compared for the three samples, using the number of aircraft noise events as the exposure metric, and the results are shown in Figure 6.

2.70 The analysis of the night-time versus daytime sleep data revealed more distinct effects in participants who slept during the day. A significant increase in the non-restorative sleep stage 1 under noise exposure was found in day sleepers but not in night sleeper. There was also a trend for a noise-induced reduction of deep sleep duration found in participants who slept during daytime but not in those sleeping during the night. Aircraft noise exposure significantly evoked annoyance and reduced self-rated sleep quality in both day and night sleepers, but was more pronounced in those who were sleeping during the day.

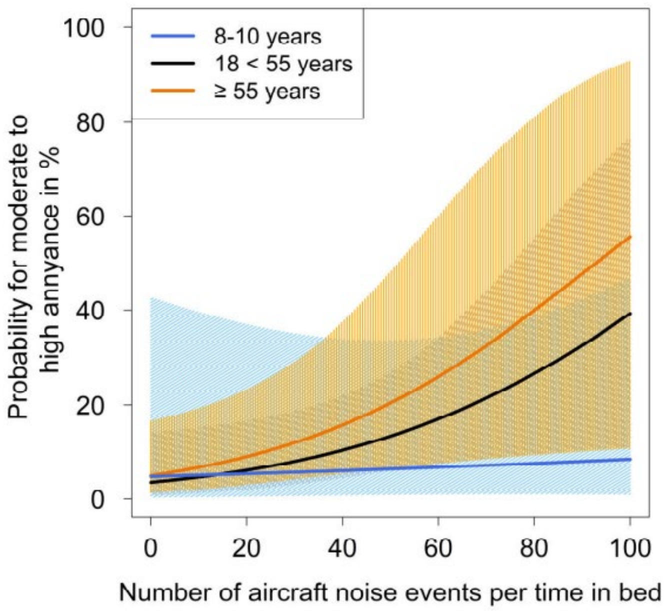

Figure 6: Probability for moderate to high annoyance based on the number of aircraft noise events per time in bed and depending on age.

2.71 The authors concluded that the results from the wake time, stage 1 and deep sleep duration data suggest that nocturnal aircraft noise exposure only slightly deteriorates sleep structure and depth beyond age-related changes, and not to the degree that was expected.

2.72 **Kuhlman et al** reported on an evidence-based recommendation of threshold values for protection against adverse health effects of aircraft noise in Germany. The German Aircraft Noise Protection Act (FluLaermG) is a legislation primarily regulating land use near airports and defines two noise protection zones (NPZ) for the daytime (6am – 10pm) and one for the night-time (10pm – 6am). The threshold values are reviewed every ten years, based on the knowledge of noise impact research and health effects. The authors, on behalf of the Aircraft Noise Commission, Frankfurt, prepared an expert evaluation on the threshold values for airport regions in the FluLaermG from the perspective of noise effect research.

2.73 A threshold value system (TVS) to mark the protection zones was developed following a literature review on the health effects from aircraft noise. A key objective of this project was to present the status quo of aircraft noise effects research since 2015, and to develop recommendations for a possible amendment of the FluLaermG.

2.74 The basis for the TVS was a systematic literature review with subsequent meta-analyses, supplemented by WHO reviews and original data from recent studies.

2.75 "Relative Risks" in the form of increased levels of disease risks with a 10 dB increase in noise exposure levels as well as “absolute risks” in the form of %HA or %HSD at different aircraft noise exposure levels were considered as aircraft noise effects. The health outcomes included were cardiovascular diseases, sleep disturbance (%HSD) , and noise annoyance (%HA).

2.76 The authors proposed a two-level protection concept.

- the preventive limit of acceptable health risks (R1) represents the highest protection level and is mainly based on the health outcome-specific relevant risk increases considered for the setting of guideline levels by the WHO (e.g., maximum of 10% HA).
- critical limit of acceptable health risks (R2), which requires less demanding acceptance values that are just acceptable from a health perspective but are easier to implement in aircraft noise protection measures (e.g., maximum of 25% HA).

2.77 Using the exposure-response relationships identified in the meta-analyses of the literature review, acoustic thresholds defining the acceptance limits R1 and R2 were derived for each health effect. These acoustic thresholds encompass continuous sound levels for both daytime and nighttime conditions and were subsequently combined into recommended trigger thresholds for aircraft noise protection measures.

2.78 The authors explain that the results from 19 studies fed into the exposure-response curve for %HA (Figure 7): 12 studies from the WHO review, three studies identified in the literature review of this project, and NORAH studies at four airports. The absolute risk for 10% HA is at 46 dB L_{den} and 43.8 dB $L_{Aeq,day}$ (R1). 25% HA was given as the acceptable risk R2, which translates into a noise exposure level of 53 dB L_{den} and 50.8 dB $L_{Aeq,day}$.

2.79 The exposure-response curve for %HSD due to aircraft noise was derived from four datasets (Figure 8). An acceptable risk of 3% HSD (R1), with DW = 0.07, as identified by the WHO is exceeded at 29 dB $L_{Aeq,night}$. However, it is explained that the acceptable risk for HSD (R2) should be practically achievable by noise mitigation measures. Therefore, the acceptable risk R2 of 15% HSD proposed by the Swiss FNAC was employed. The dB value for 15% HSD is approximately 43.5 dB $L_{Aeq,night}$.

2.80 It was concluded that the following trigger thresholds were recommended:

- Compelling trigger thresholds: 51dB $L_{Aeq,day}$ for the day and 44 dB $L_{Aeq,night}$ for the night.
- Preventive trigger thresholds: 44 dB $L_{Aeq,day}$ for the day and 40 dB $L_{Aeq,night}$ for the night.

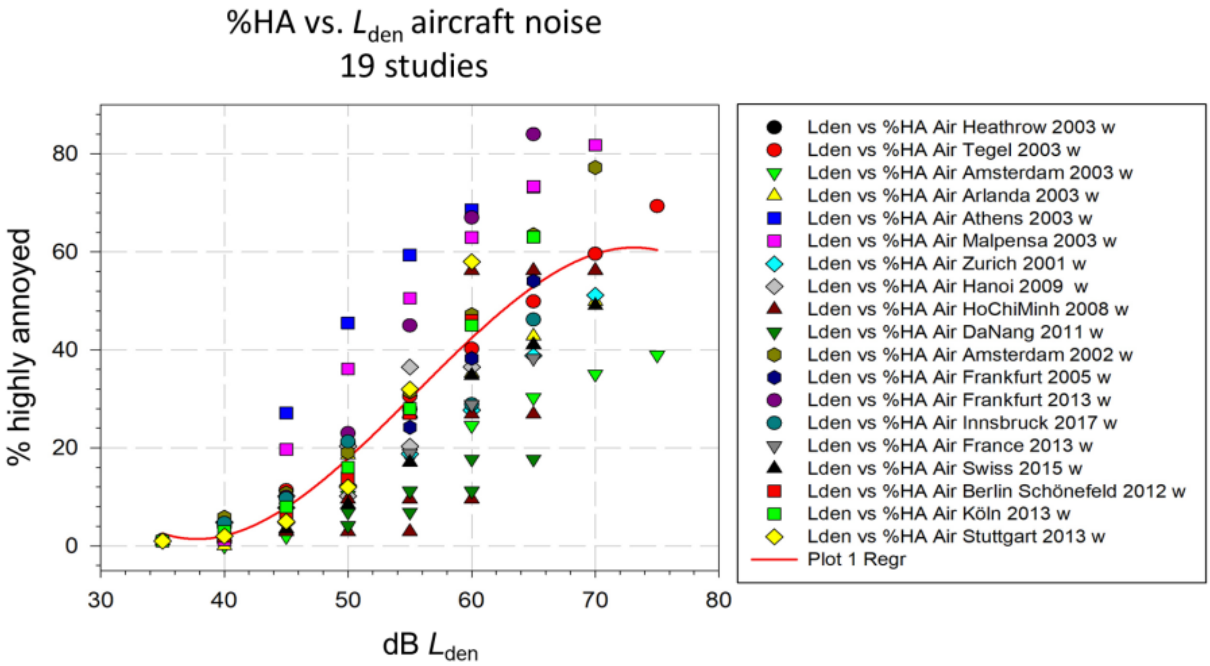

Figure 7: Exposure-response curve for the relationship between %HA and aircraft noise level L_{den} from 19 studies.

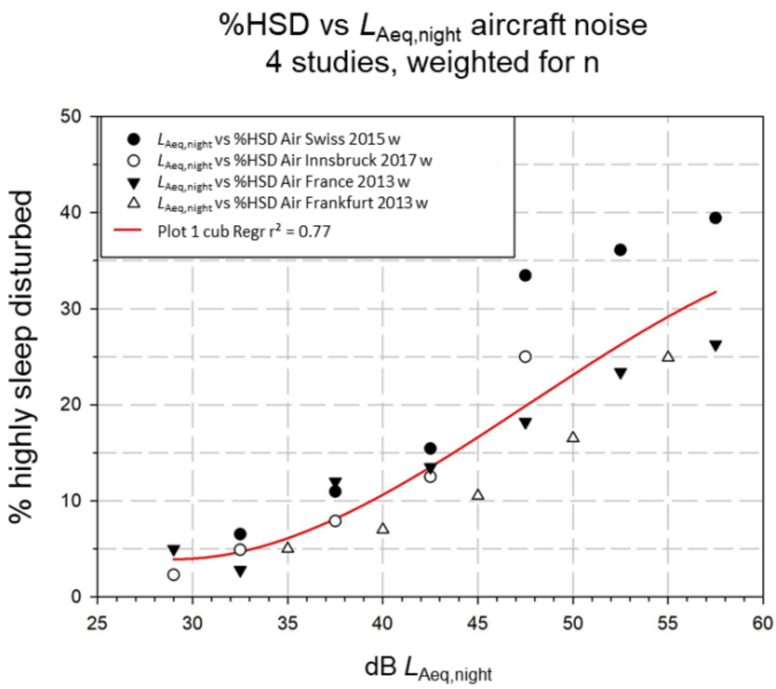

Figure 8: Exposure-response curve for the relationship between %HSD and $L_{Aeq,night}$ based on the 4 aggregated data sets.

2.81 **Spilski et al** reported on the importance of traffic noise in relation to children's wellbeing. The aim was to better understand the importance of traffic noise in comparison to other influencing factors on wellbeing in children, using the concept of exposome. The exposome is a concept used to describe environmental exposures that an individual encounters throughout life, and how these exposures impact biology and health. It encompasses both external and internal factors, including chemical, physical, biological, and social factors that may influence human health. The EU project Equal-Life is investigating the exposome and its influence on children's health and development.

2.82 In this study, datasets from three studies were included (ALPINE (Austria), NORAH (Germany) and RANCH (NL) to examine the effects of road, rail and aircraft noise on wellbeing in children. The concept of wellbeing comprised quality of life, happiness, and prosocial behaviour factors. Table 2 summarises the noise levels from each of the studies.

Table 2: Descriptive statistics for L_{den} levels at the home addresses (studies: ALPINE, NORAH, RANCH)

		ALPINE		NORAH		RANCH	
		M	*Range*	*M*	*Range*	*M*	*Range*
Lden Aircraft	dB (A)			51.74	40.80-63.60	51.24	37.70-66.10
Lden, Road	dB (A)	49.71	41.42-75.20	54.86	37.40-78.50	53.86	31.10-72.30
Lden, Railway	dB (A)	48.26	41.41-84.30	51.24	30.00-84.20		

2.83 71 indicators were included in the analysis, and the most important 20 predictors for happiness, and Prosocial behaviour were derived. The results indicated that for happiness, traffic noise was not among the Top 5 predictors in any data set, however aircraft noise was were in the top ten important predictors for the NORAH and RANCH datasets. Traffic noise from roads and railway was among the top 15 predictors in the ALPINE study. For pre-social behaviour, aircraft noise was the second most important variable in the NORAH study, and road traffic was in the top 20 predictors in NORAH and ALPINE. In both studies, social exposome variables were the most important variables for predicting prosocial behaviour. In the ALPINE study it was ‘harmony with parents’ and in NORAH it was ‘voter participation at the municipal level’.

2.84 The authors suggest that in addition to noise, a range of social and environmental variables such as building environment or quality of environment should be considered with regard to children’s wellbeing.

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 is a study by **Jemielita et al**, which examined the impact of noise and light exposure on cardiovascular outcomes. The potential pathways by which environmental noise could have an association with increased risk of cardiovascular disease (CVD) are well documented within aircraft noise and health studies. However, the impact of light pollution in addition to noise has not been as widely studied, despite the potential effects of additional light on the cardiovascular system. The authors conducted a literature review for both noise and light exposure and the potential impacts on cardiovascular outcomes and produced a narrative assessment of the risks.

3.2 The authors cite that as much as 83% of the world's population lives under light-polluted night sky. In the review they present scientific research to date regarding the associations between exposure to various sources of noise and light pollution and four ubiquitous CVD, including coronary artery disease (CAD) in both its stable and acute forms, heart failure (HF), stroke and atrial fibrillation (AF). These four CVD conditions alone accounted for over 17 million deaths and loss of more than 300 million disability-adjusted life years in 2021. In addition, the impact of environmental factors on the occurrence of widely recognized CVD risk factors, such as diabetes, arterial HTN and obesity is discussed.

3.3 The mechanisms by which noise and light can affect the cardiovascular system are discussed. These are summarised in Figure 9.

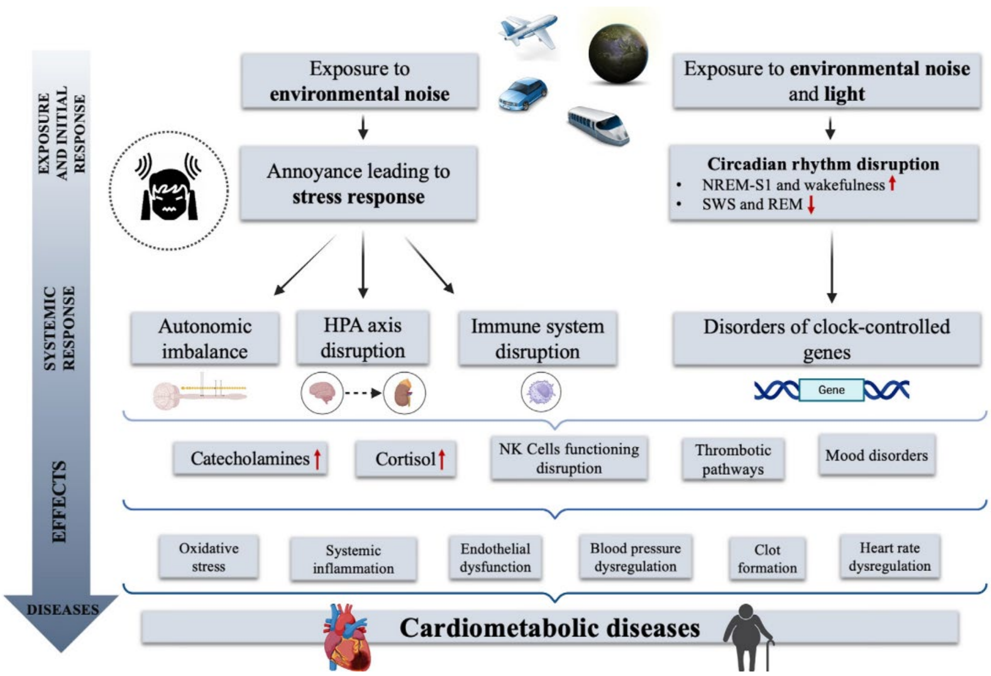

Figure 9: Potential mechanisms of the harmful impact of noise and light pollution. Abbreviations: NREM-S1, non-rapid eye movement sleep stage 1; SWS, slow wave sleep; HPA axis, hypothalamic-pituitary-adrenal axis; NK Cells, natural killer cells.

3.4 For noise, including aircraft noise, the prolonged exposure to lower-intensity noise, especially at night, may lead to autonomic nervous system dysregulation and hormonal imbalance, shown by excessive sympathetic nervous system arousal. This results in the disruption of the hypothalamus-pituitary-adrenal axis, leading to an excessive release of cortisol and catecholamines (hormones produced by the body when stressed). Additionally, noise exposure can activate the renin-angiotensin-aldosterone system[1], all these factors together increase the risk of CVD. Another potential mechanism is suggested, in the influence of noise on quantitative and qualitative changes in the immune system, including the functioning of natural killer cells. In addition, non-acoustic factors such as noise sensitivity may contribute to individual differences.

3.5 In terms of light pollution, the authors describe a common mechanism of light pollution and noise is their impact on circadian rhythm, potentially leading to sleep disorders and altering the duration of different sleep stages. This could result in increased wakefulness and light sleep, while simultaneously reducing the duration of slow wave restorative sleep and rapid eye movement sleep. CVD cells possess genes whose expression is dependent on circadian rhythm. Therefore, disruption of this rhythm can result in impaired endothelial function, clot formation, blood pressure regulation, and heart rate, ultimately contributing to the occurrence of CVD.

3.6 The review discusses the literature findings on each of the four cardiovascular outcomes in relation to environmental noise (road, rail and aircraft) and light exposure. It is highlighted that for aircraft noise, the WHO analysis revealed a statistically significant association only with the incidence of CAD, and the overall evidence level for the impact of aircraft noise on CAD was classified as “low”. Since the WHO analysis, two nationwide cohort studies from Switzerland suggest that a 10 dB L_{den} increase in noise level is associated with an increase in mortality caused by myocardial infarction for both road, railway, and aircraft noise. For light pollution, the authors describe a cohort study in 60,000 elderly people in Hong Kong. An increase in light pollution was linked to an elevation in both the risk of hospitalization and mortality due to CAD.

3.7 For heart failure there was a lack of data for aircraft noise, and no studies were available on light pollution. For stroke risk, most of the data concerns road traffic noise and railway noise, and there is a lack of studies on light pollution for this

[1] The renin-angiotensin-aldosterone system is a hormone system that regulates blood pressure, fluid and electrolyte balance, and systemic vascular resistance.

outcome. Based on the current research findings, the authors could not make definitive conclusions about the link between noise exposure and AF, and no studies assessing the impact of light pollution on the incidence of AF have been published, highlighting the importance of conducting research in this area.

3.8 The authors concluded that although there is a high number of studies on the effects of air pollution, the literature lacks comprehensive studies on the effects of light and noise pollution. They suggest that further research should focus on analysing prospective cohorts using personal measures of noise and light exposure, and stress the importance of including all environmental factors, as their combined impact could potentially be more harmful, for example as with the combined effects of noise and air pollution.

3.9 **Bozigar et al** authored a paper on aircraft noise exposure and body mass index (BMI) among female participants in two Nurses' Health Study cohorts living around 90 airports in the US. Results on hypertension, cardiovascular disease and mortality, and self-reported sleep quality from the national cohort of female nurses in the US called the Nurses' Health Study (NHS) and Nurses' Health Study II (NHSII) study populations have been included in previous reports.

3.10 The rationale for this element of the study is the potential risk factor obesity may present for cardiovascular disease linked to aircraft noise. Aircraft day-night average sound levels (DNL) were estimated at participant residential addresses from modelled 1 dB (dB) noise contours above 44 dB for 90 United States (U.S.) airports in 5-year intervals 1995-2010.

3.11 At baseline, the 74,848 female participants averaged 50.1 years old, with 83.0%, 14.8%, and 2.2% exposed to <45, 45–54, and ≥55 dB of aircraft noise, respectively. Surveys were completed every other year between 1994-2017 and included information on BMI and other individual characteristics. The change in BMI from age 18 at the start of the study, was also calculated. Aircraft noise exposures were dichotomised (45, 55 dB), categorized (<45, 45–54, ≥55 dB) or continuous for exposure ≥45 dB.

3.12 Non-acoustic factors such as socioeconomic status, neighbourhood greenness, population density and environmental noise were controlled for in the regression model. Effect modification was assessed by U.S. Census region, climate boundary, airline hub type, hearing loss, and smoking status.

3.13 The results indicated that in fully adjusted models, exposure to aircraft noise ≥55 dB DNL was associated with 11% higher odds of BMIs ≥30.0, and 15% higher odds of being in the highest tertile of BMI18 (ΔBMI 6.7 to 71.6). Aircraft noise exposure at DNL levels ≥45 dB was associated with higher BMI among participants, with the largest associations for exposures ≥55 dB, indicative of an exposure–response relationship independent of individual and neighbourhood factors. In addition, exposures to DNL ≥45 dB were also associated with higher

BMI of participants since they were 18 years of age. Less marked associations were observed for the 2nd tertile of BMI18 (ΔBMI 2.9 to 6.6) and BMI 25.0–29.9 as well as exposures ≥45 versus <45 dB. There was a statistically significant trend providing evidence of an increasing aircraft noise exposure-BMI response for DNL ≥45 dB. Stronger associations were observed among participants living in the West, arid climate areas, and among former smokers.

3.14 The authors concluded that the results provide evidence of an aircraft noise-obesity-disease pathway, and that the potential roles of stress and obesity in the risk of chronic disease warrants further investigation.

3.15 Transportation noise and obesity was the focus of a pooled analysis of eleven Nordic cohorts by **Persson et al**. The aim of this study was to comprehensively assess exposure-response relationships between road traffic, railway and aircraft noise, and obesity markers, including both BMI and waist circumference. Potential effect modification by air pollution, sociodemographic characteristics, and lifestyle factors was also considered.

3.16 The study included pooled data from 11 Nordic cohorts, with up to 162,639 individuals with either measured (69.2%) or self-reported obesity data, and . residential exposure to transportation noise was estimated as a time-weighted average L_{den} five years before recruitment. The results indicated that for road traffic noise, the OR for obesity was 1.06 (95% CI = 1.03, 1.08) and for central obesity 1.03 (95% CI = 1.01, 1.05) per 10 dB L_{den}. Thresholds were observed at around 50–55 and 55–60 dB L_{den}, respectively, above which there was an approximate 10% risk increase per 10 dB L_{den} increment for both outcomes. However, linear associations only occurred in participants with measured obesity markers and were strongly influenced by the largest cohort. Stronger associations were observed in men than in women, in current smokers compared with never and former smokers, and among individuals with a high level of physical activity compared with those less active. Young individuals (<45 years) had a lower risk of obesity in relation to road traffic noise than older ones. Similar risk estimates as for road traffic noise were found for railway noise, with no clear thresholds. The authors concluded that the results were uncertain for aircraft noise due to the low number of participants exposed to high levels, which led to a low exposure contrast and uncertain estimates of any association with health outcomes.

Chapter 4
Aircraft Noise and Other Findings

Diabetes Mellitus

4.1 This chapter outlines the research findings on aircraft noise and diabetes, published in the six months between March and September 2024. The paper, authored by **Vienneau et al**, presented findings on long-term transportation noise and diabetes mellitus (DM) mortality within the Swiss national cohort over a 15-year period.

4.2 The 2018 WHO Environmental Noise Guideline (ENG) systematic review on environmental noise and cardiovascular and metabolic effects identified DM as an important health outcome, although the evidence at the time comprised one study on road noise that reported an association for incident diabetes of 1.08 (95% confidence interval (CI): 1.02, 1.14) per 10 dB L_{den}, between 50- and 70-dB road traffic noise. The WHO recommended that further investigation was required into this health outcome and the potential effects of noise. Since then, two more studies have reported evidence to suggest an association between all types of transportation noise and DM, with aircraft noise having the strongest association in both cases.

4.3 The study included nearly all adults living in Switzerland, following them from 01 January 2001 to 31 December 2015. The Swiss National Cohort (SNC) was utilised, that links the national census with the births, mortality (providing date and cause of death). Residents under the age of 30 years at the start were not included, and final cohort was 4.1 million. Outcomes were defined considering DM, indicated on the death certificate, as the primary definitive cause of death, concomitant, consecutive or initial disease. The number of recorded deaths was 72,342 (1.7%) for non-Type 1-DM, 1046 (0.03% for Type 1-DM, 73,388 (1.8%) for total DM deaths.

4.4 The findings indicated that in the main regression model, which was adjusted for other noise sources, socio-economic indicators and NO_2, the results suggested an increased association with non-Type 1-DM mortality for road traffic noise (1.06 [1.05, 1.07] per 10 dB L_{den}) and to a lesser extent railway noise (1.02 [1.01, 1.03] per 10 dB L_{den}). The authors reported that the increase for aircraft noise was very small and only borderline significant (1.01 [0.99, 1.02] per 10 dB L_{den}). Meta-analysis was only possible for road traffic noise in relation to mortality (1.08 [0.99, 1.18] per 10 dB, n=4). Combining incidence and mortality studies indicated positive associations for each source, strongest for road traffic noise (1.07 [1.05, 1.08], 1.02 [1.01, 1.03], and 1.02 [1.00, 1.03] per 10 dB L_{den} for road traffic [n=14], railway [n=5] and aircraft noise [n=5], respectively).

4.5 The strengths and limitations of the study are discussed. The large sample size with little selection bias is an obvious strength, but the authors highlight that data on BMI, diet, physical activity, and sleep were not available. It was concluded that this study provides new evidence that transportation noise is associated with diabetes mortality. Given the increasing evidence and large disease burden, the authors suggest that DM should be viewed as an important outcome in noise and health research.

Chapter 5
Summary

5.1 This update report has summarised the main findings in the field of aircraft noise and health effects research over the six-month period between March and September 2024. The chapters have included those findings presented at the Internoise congress 2024, and in peer-reviewed academic journals in the areas of cardiovascular disease and metabolic factors, and diabetes mellitus.

5.2 The findings from Internoise largely centred around community response to aircraft noise, and annoyance. There is a growing evidence base on the links between transportation noise and cardiovascular effects, and the important non-acoustic factor noise sensitivity continues to be researched in relation to aircraft noise exposure. The impact of transportation noise on vulnerable groups, including children has also been reported on. It should be noted that although some studies have been published in academic journals in the past six months, if they have been previously reported on from conference proceedings and the results remain unchanged, they have not been repeated in this report.

5.3 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 March 2025.

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