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 2022. The report will provide an overview of the most relevant findings that were published during this period, including the findings presented at the Internoise Congress, which was held in Glasgow.

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.

Chapter 2

Aircraft Noise and Annoyance

2.1 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 Internoise Congress, held in August 2022.

2.2 **Gjestland and Granøien** published a paper on a new method to quantify the level of aircraft noise annoyance in an exposed population, by combining noise level and number of people who are exposed. The rationale for this method is that most other methods focus on those people affected who are highly annoyed, whereas the proposed method also includes the larger proportion of the population who are annoyed, but to a lesser extent. It is argued that with the usual exposure-response relationship, no information is known regarding the population that is annoyed (but not highly annoyed), and no information is provided around the true extent of annoyance in terms of numbers of people affected.

2.3 The paper discusses an impact model that was originally developed as part of the EU-funded Market-based Impact Mitigation for the Environment (MIME) project (2010). The proposed methodology to assess annoyance uses the equation:

$$\text{Annoyance Score} = k\,(L_{den} - X)$$

Where the slope of the linear function, k, is similar for all transportation noise sources. A mean value for k for road, rail and aircraft noise is k = 0.0158. For aircraft noise alone the slope has been found to be slightly steeper, k = 0.016.

2.4 The value of the annoyance score is dependent on where the line crosses the zero point on the graph (X dBA) of the linear function. Values for X from different aircraft noise surveys can vary ± 10 dB or more. This can be attributed to the effect of non-acoustic factors. Miedema and Vos (1998) based their dose-response curve for aircraft noise on 20 different surveys. The average value for the zero crossing for these surveys is X = 33.4 dB, which would indicate that anyone exposed to noise above this level could be theoretically considered annoyed. However, the authors explain that it is not practical to include all of these in the total annoyance quantity, as the aircraft noise must be loud enough to be heard above general background noise. They suggest including areas within the 40 dB or 45 dB L_{dn} contour.

2.5 The authors explain that the annoyance score is a representation of the annoyance experience by a person exposed to noise. Similarly, the sum of the annoyance scores from all the residents around an airport can be used to quantify the total annoyance experienced by that community. They suggest that this quantity is therefore useful for noise management and control.

2.6 When the total annoyance impact on the community can be expressed by a single number, the authors propose that the following noise management measures are possible:

- The airport and the individual airlines may be granted permission to operate only within quantifiable impact limits
- Landing rights may be awarded and possibly priced based on individual impacts
- Limits for future expansions may be easily quantified
- Targets for noise mitigation measures may be quantified.

2.7 In this report, the units of annoyance are expressed as MIMEs. The quantity "1 MIME" is equal to one person extremely annoyed by aircraft noise, (annoyance score 1.0) or two persons moderately annoyed (annoyance score 0.5). The authors present an example of a calculation, which is cited below:

2.8 The total annoyance quantity for an airport community can be found by following this procedure:

1. Establish a "grid" of cells around the airport, for instance 100 m by 100 m. The grid must include all the impacted residents in the community

2. Measure or predict a noise level that is representative for each grid cell, for instance the noise level in the middle of the cell

3. Find the annoyance score for each cell using the equation above, k = 0.016, X = 33.4 dB (unless the exact zero-crossing has been established through a previous survey)

4. Find the annoyance quantity, AQc, per cell by multiplying the annoyance scores with the number of residents per cell

5. Find total annoyance quantity, AQt, for the community by summation across all cells.

2.9 The authors describe some practical applications the use of this model would allow, including the redirection of air traffic, assessing the effect on annoyance of replacing the aircraft fleet, calculating the effect of increased airport operations, and planning for specially protected areas. It is suggested that the method provides an easy-to-understand quantification of the effect of proposed changes in the operation pattern for a specific airport and can also be used as an illustrative tool in discussions and negotiations between an airport and the surrounding community.

2.10 **Wunderli and Brink** presented a paper on the long-term annoyance trends due to transportation noise type. The paper explores the possible explanations for why railway and aircraft noise annoyance appear to have increased over time, whereas annoyance due to road traffic has largely remained stable.

2.11 The paper examines the change in emissions at source for each of the transportation noise sources (based on data from Switzerland). In terms of road traffic noise, a Swiss dataset from 2004 onwards indicates that engine noise was successfully reduced over the years, but rolling noise increased instead. This was likely to be due to the tendency towards heavier vehicles and wider tyres over that time.

2.12 An alternative to assessing the change of noise emission over time is to compare different emission models, as they usually rely on extensive measurement data that were collected at that time. In Switzerland, such measurement campaigns were conducted in the years 1987, 1995 and 2018, as input for various road traffic noise models. Data showing pass-by levels for passenger cars and trucks, confirmed the findings of the long-term measurements (for higher speeds), namely, that noise emissions remained very stable over the years, with even a slight tendency towards higher levels in recent years.

2.13 The authors explain that there has been a decrease in railway noise in Switzerland during the period 2003-2020. On average, a decrease of about 10 dB is seen over this time. Passenger coaches were substantially improved, and cast-iron brakes were replaced by disk brakes, which helped reduce noise.

2.14 In terms of aircraft noise, taking into account typical operating durations of commercial aircraft and the delay in the renewal of aircraft fleets, a comparable reduction of the average noise emission per aircraft as for rail vehicles can be assumed for the period under consideration.

2.15 The changes in traffic volume are discussed. Data from the Swiss Federal Statistical Office indicates that the number of passenger kilometres increased by around 25% for road traffic and by 45% for rail traffic since 1995. For air traffic, the number of passengers increased by 145%. While the number of road traffic passengers can be regarded as constant over time, the transport performance of trains and aircraft has increased continuously, for example the ability to have increased capacity. Therefore, the growth of train and aircraft movements is in reality smaller that the passenger figures suggest.

2.16 Figure 1 shows aircraft noise contours of 60 dB L_{day} for Zurich airport between 1987 and 2018. In this period, the number of flights increased from 179,000 to 264,000. This growth in volume only corresponds to an increase of the long-term average sound pressure level L_{Aeq} of less than half a dB. However, the size of aircraft noise exposure contours decreased substantially, demonstrating the effect of quieter aircraft.

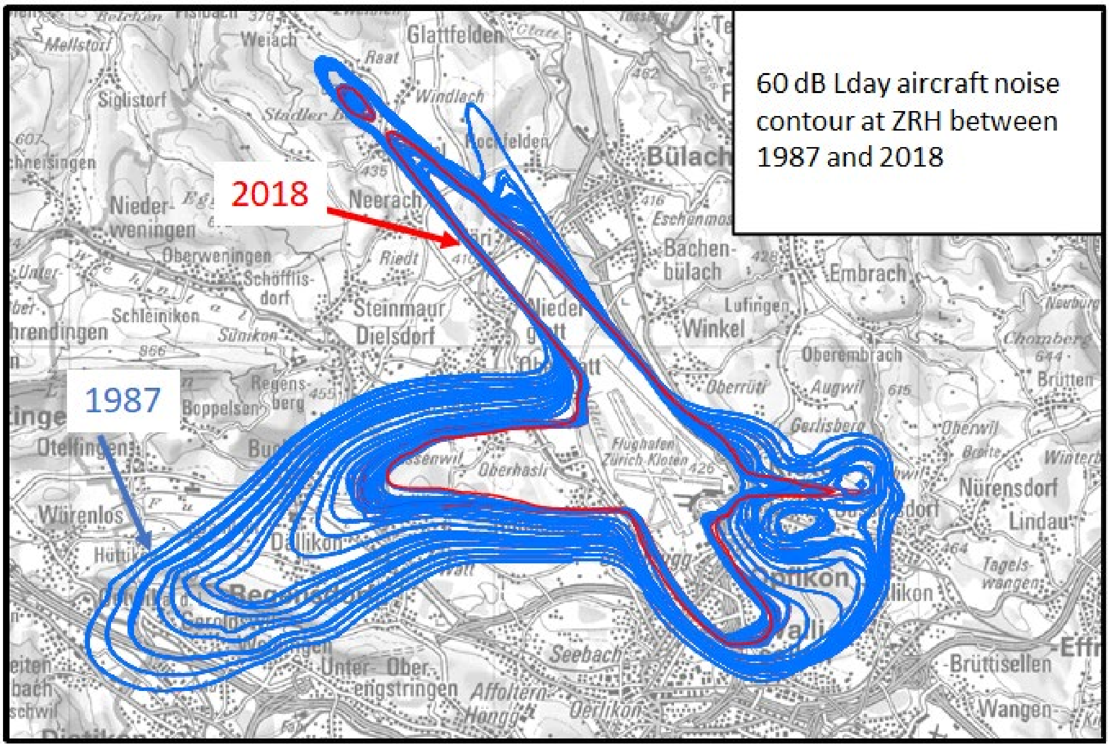

Figure 1: Aircraft noise contours for the 60 dB L_{day} between 1987 and 2018 at Zurich Airport (ZRH)

2.17 To illustrate the increase in annoyance levels for road, railway and aircraft noise, Figures 2-4 show the exposure-annoyance relationships from Swiss studies in comparison to the respective curves from earlier meta-analyses carried out by Miedema and Oudshoorn, also known as the "EU curves".

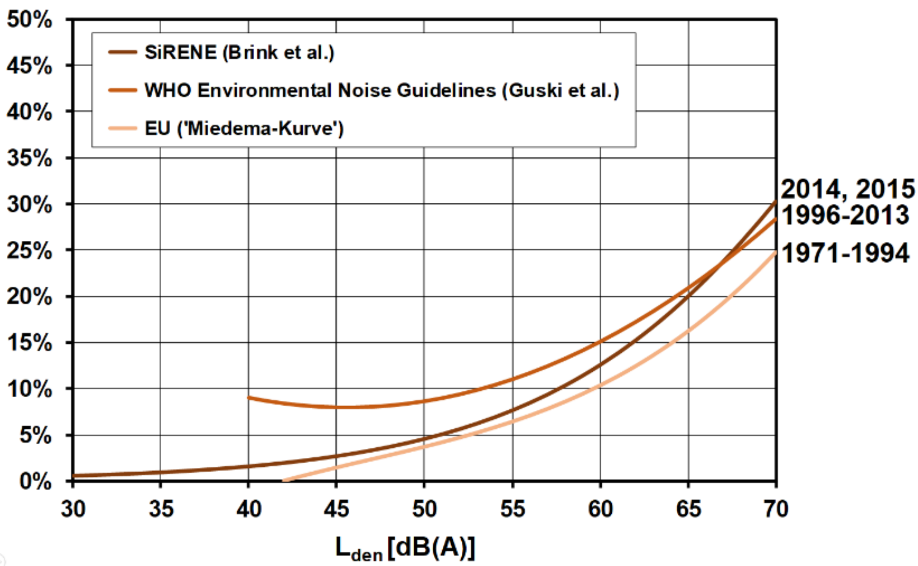

Figure 2: Exposure-response curves for %HA from road traffic noise through the years. The survey years in which the original data for the curves were collected are indicated on the right of the plot.

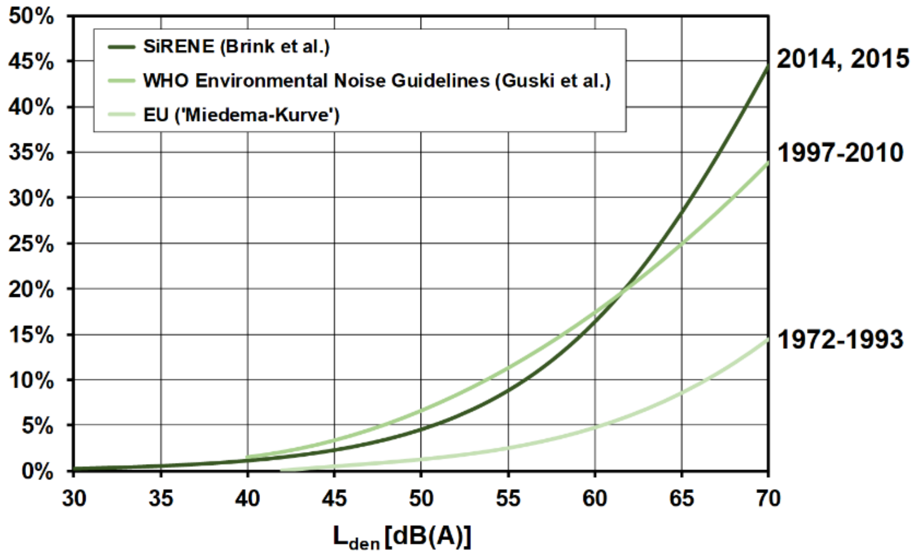

Figure 3: Exposure-response curves for %HA from railway noise through the years. The survey years in which the original data for the curves were collected are indicated on the right of the plot.

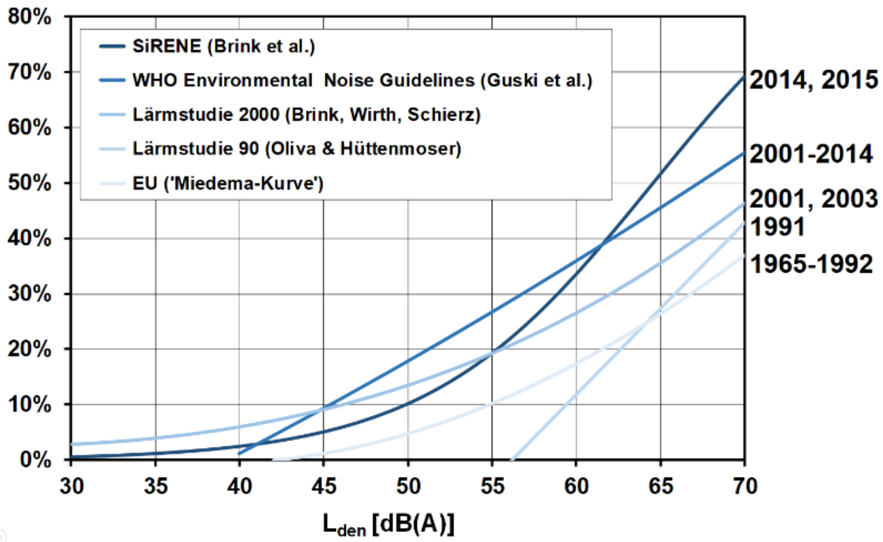

Figure 4: Exposure-response curves for %HA from aircraft noise through the years. The survey years in which the original data for the curves were collected are indicated on the right of the plot.

2.18 The authors discuss the possible reasons for the discrepancy in annoyance trends between the noise sources. These include changes in research methodology such as the different survey modes (face-to-face, telephone and postal surveys) and their potential effect on annoyance responses. There is some evidence to suggest that use of the 5-point ICBEN verbal scale yields lower annoyance responses than the 11-point scale, and use of the 11-point scale has increased over the years. The effects of response rate and changes in noise assessment methodology are also discussed as possible contributors to annoyance trends.

2.19 The changes of attitudes and values within societies are presented and the changing risk perception of people are discussed. The possible changing of semantics of the words within the noise surveys are described, for example: Do the words to express the intensity of one's noise annoyance used in questionnaires in socio-acoustic surveys still mean the same as they did several decades ago? Does the notion of "extremely annoyed" express the same degree of annoyance nowadays as it did the past?

2.20 Changes in exposure characteristics such as an increased number of aircraft events combined with quieter aircraft are often cited as a possible reason for the increase in annoyance. The authors suggest that the increasing number of movements alone cannot fully explain the observed annoyance trend. They question whether the same single events are evaluated differently today than in the past, or whether those affected by aircraft noise have noticed (a) the reduction in maximum levels and (b) the increase in the number of events, and if so, how these experiences are incorporated into their summary judgment of annoyance.

2.21 The authors conclude by stating that in their opinion, the increased comfort expectations of people over the years, and a lifestyle shift towards health and sustainability in conjunction with a growing awareness of the health effects of noise could be the most plausible explanations for an increase in annoyance for all three transportation noise sources.

2.22 However, they do not believe that the additional annoyance shift for railway and aircraft noise can be explained this way. They suggest a "frame of reference problem" and speculate that the successful noise abatement at the source could itself be the cause of rising comfort expectations and therefore stable annoyance even if the exposure levels decreased. In other words, it is suggested that people adapt very quickly to a more comfortable life, whereas losses of comfort are perceived as much harder to bear. Receiving protection from noise is clearly more comfortable than being exposed to noise. It is suggested that with ever better sound insulation of homes combined with lower emissions from trains and aircraft, the frame of reference about what is tolerable may shift over time. The railway and aircraft noise annoyance ratings of the population remained widely constant over time, despite the exposure having changed.

2.23 **Schreckenberg** et al published a paper on the role of sound emergence for aircraft noise annoyance. The ISO definition of sound emergence is given as the approach of subtracting a residual sound level (total sound level without the level of a specific source) from the total sound level.

2.24 In this study, data from the NORAH study was used to investigate the relationship between sound emergence and aircraft noise annoyance. As total background sound levels were not available, information about source-specific and combined sound levels was used instead. Road traffic sound levels for daytime ($L_{Aeq,day,road}$) at the home address of survey participants was subtracted from the combined sound level of aircraft and road traffic noise ($L_{Aeq,day,air+road}$) with the combined sound level being a proxy for the total sound level, and the road traffic sound level being a proxy for the residual sound level.

2.25 Previous studies have suggested that sound emergence is associated with noise annoyance, with higher annoyance responses associated with higher levels of emergence. In the cases of railway and aircraft noise, results have indicated that emergence can also be related to predicting self-reported and physiologically measured sleep disturbance. The impact of sound emergence on hypertension has also been studied, indicating a significant impact of emergence on reported hypertension for road traffic noise.

2.26 In this study, the aim was to estimate the impact of emergence in addition to the source-specific sound level of aircraft noise on the probability of being highly annoyed due to aircraft noise. The assumption was that for the same source-specific continuous sound level ($L_{Aeq,day}$) the probability of being highly annoyed is higher with higher sound emergence.

2.27 The NORAH study survey data used in this study was collected in 2012, one year after the new runway at Frankfurt Airport was opened and the night flight ban was implemented. All data was collected within a study region around Frankfurt Airport defined by aircraft noise exposure in 2011 being greater or equal to 40 dB $L_{Aeq,day}$ (6 am – 10 pm) and night-time (10 pm – 6 am). The source-specific $L_{Aeq,day}$ for both aircraft and road traffic noise ranged from 41 to 61 dB with mean = 51 dB.

2.28 Data from a cross-sectional survey collected in 2012 focusing on road traffic noise was also used. The study selection criterion was the $L_{Aeq,24h}$ for road traffic noise being 2.5 dB higher than the $L_{Aeq,24h}$ of any of the other two existing transportation noise sources (aircraft and rail noise). In addition, data from another cross-sectional survey conducted in 2012 was used with the $L_{Aeq,24h}$ of aircraft and road traffic noise being almost the same within a range of 2.5 dB, whereas the $L_{Aeq,24h}$ of the third transportation noise source (railway noise) is below 40 dB.

2.29 The results indicated that there was a main effect of sound emergence as a predictor for being highly annoyed, and an interaction with the source-specific $L_{Aeq,day}$. The authors explain that this means that the probability of being highly annoyed is higher with higher sound emergence. This was found to be particularly the case for survey participants exposed to aircraft noise < 55 dB $L_{Aeq,day}$.

2.30 The absolute road traffic noise level itself did not significantly affect aircraft noise annoyance, which is in line with previous findings. This indicates that it is the relative, differential contribution of the source of interest (here: aircraft noise) against the background noise (here: road traffic noise), which plays a role in the source-specific noise annoyance.

2.31 The authors provide a discussion around previous research findings on sound emergence and limitations of the study. They suggest that future research is needed to study the relationship between the sound of the source under study and the background noise for noise annoyance in more detail, including non-acoustic factors that relate to residents' perception and expectations related to the living acoustical environment as well.

2.32 **Porter** et al presented a paper on respite from aircraft noise and the knowledge gained at Heathrow Airport Ltd (HAL) to date in this area. HAL has collaborated with other airports with a shared goal to enhance the Quality of Life around airports.

2.33 The paper outlines the activities undertaken since 2014 in order to investigate the impacts of respite. The Respite Working Group (RWP) was set up in 2014 to review the current literature and knowledge on respite, and a report was published in 2016 with a review of the knowledge on respite and suggestions for future research, including the need for specific research at Heathrow to provide a scientific basis for any future respite policy. Working definitions were agreed for the terms 'relief' and 'respite':

- Relief - can be defined as a break from or a reduction in aircraft noise.
- Respite - can be defined as a scheduled relief from aircraft noise for a period of time.

2.34 Between 2017-2019 a HAL-funded research programme was set up, using active listening techniques in the Arup sound laboratory with members of the public, and also with residents at sites around Heathrow. The second phase of this work involved field studies with 461 participants to try and understand any differences in sensitivity to aircraft sound events under real-life conditions. The main findings of Phase 2 were:

- After having been told about managed respite, and for areas with average aircraft noise levels above 57dB $L_{Aeq,16h}$ where respondents expressed benefit of respite it was 'valued' above 9 dB and noticed between 4 and 9 dB.
- People largely value respite if they know it is being provided
- Further work was required to understand the different levels of annoyance against which any benefit of managed respite can be judged.

2.35 Phase 3 of the work was classed as qualitative and quantitative. The quantitative part with further statistical analyses of Phase 2 existing data and additional noise modelling down to postcode level to inform new higher resolution statistical analyses of existing data, and the qualitative work involving new data collection.

2.36 The results of this phase included:

- **Respite as an effective intervention:** predicable respite is effective as an intervention – it is (genuinely) valued by residents, when they are informed of it and they do not wish for it to be removed. There were indications that the overall value of predictable respite to the communities around Heathrow Airport could be maximised by increasing individual awareness through public engagement.
- **Relief versus managed respite:** Predicable respite, and east-west unpredictable respite, provided different patterns of noise reduction with variation in different areas around the airport, and only a few residents can differentiate between the two.
- **Maximizing effectiveness of respite though effective communication campaigns and increased educational efforts:** increasing residents' awareness of managed respite could have a positive impact on community relations.
- **Night-time versus Day-time Respite:** Aircraft noise at night was considered by many to be more annoying and disruptive than daytime noise. Most people thought that respite at night would be more beneficial than daytime respite.
- **Managed Respite and Annoyance:** non-acoustic factors were more highly correlated with reported annoyance than acoustic factors. More work required in this area.

2.37 The paper discusses the consultations held in 2018 and 2019 as part of the Heathrow expansion project, that was subsequently halted in 2020. The paper concludes with a series of questions and answers around the definition, perception, measurement, and communication practices around respite. The authors recommend that a respite research roadmap should be developed with the RWG to take this area forward, in collaboration with other stakeholders and to seek funding for further work in this area. The definition of respite in this report is concluded as:

'A break from or a reduction in aircraft noise'. Predictable Respite is 'Scheduled respite from aircraft noise for a period of time'. Respite noise change is the difference in noise level between different operational modes, most commonly measured as $L_{Aeq,T}$ for each mode of operation. These changes can be classified into 3 bands; dB changes of greater than 9 dB, 4-9 dB, and less than 4 dB.

Unpredictable Respite - previously termed Relief – is 'Unscheduled respite from aircraft noise'.

2.38 **Chen** et al presented work on a systematic review of meta-analyses for noise. This work was conducted by authors from the University of Leicester, UK. The aim of the research was to identify meta-analyses to provide exposure response coefficients that would update those available from the WHO Noise Guidelines for the European Region, published in 2018. The authors conducted a systematic review of systematic reviews relating to noise exposure and selected health outcomes published in 2017 - 2020.

2.39 The review included twenty-three papers, of which 16 studies provided quantitative effects estimates. Eight considered environmental noise associations with metabolic outcomes, seven with mental health outcomes, six with cardiovascular outcomes, and five studies considered wellbeing, sleep, and annoyance. A breakdown of the studies is shown in Figure 4, which also includes the AMSTAR ratings of evidence.

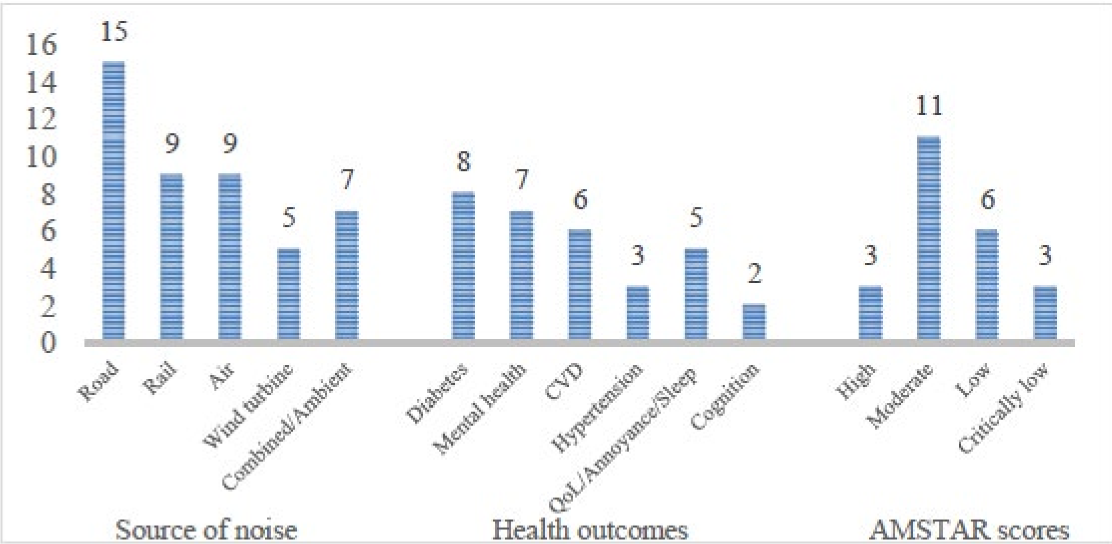

Figure 4: Key features of review studies

As a result of the review, the authors made several recommendations for the UK Health Security Agency burden of disease (toolkit for noise exposures in England):

1. For diabetes, hypertension and ischaemic heart disease (IHD)
   - recommended one new meta-analysis on diabetes (2018) and one on hypertension (2018), plus a further new meta-analysis on IHD (2019) to be considered for use in place of the evidence in the 2018 WHO environmental Noise Guidelines systematic review.
2. Updated exposure-response risk estimates for outcomes considered

- For future work, a new meta-analysis of noise and dementia as a new condition to be added into the BoD toolkit.
- For wellbeing, annoyance, and sleep, new reviews did not provide quantitative summary of estimates so these cannot be used in the BoD toolkit as alternative to WHO reviews.
- For cognition, neither of the reviews included provided quantitative effects estimates because of large amount of heterogeneity between studies. The authors do not recommend these reviews to use as alternative to WHO as no quantitative synthesis was provided.

2.40 In summary, the authors recommended one new meta-analysis on diabetes and one on hypertension, plus a further new meta-analysis on ischemic heart disease IHD to be considered for use in place of the evidence recommended in the 2018 WHO Environmental Noise Guidelines. The review also suggested there are now enough studies available to conduct a meta-analysis for noise and dementia.

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Chapter 3

Assessment methods of noise effects

3.1 Two papers were presented at Internoise that examined the Burden of Disease and health impact assessment methodologies for noise. The first was by **Röösli** et al which explored the differences in methodologies of the two assessment methodologies.

3.2 The authors explain the background to the study and that in a health risk assessment (HRA), Burden of Disease (BoD) studies are included to assess the noise impact on health at a given time and in a given population. Health Impact Assessment studies (HIA) are also conducted in the frame of decision-making to evaluate health effects of a policy, programme, or project.

- **BoD:** The public health burden associated with current or projected levels of noise is estimated. This may be done for specific sources of noise and/or for selected economic sectors.
- **HIA:** The human health impacts are estimated for a current policy or implemented action. It also may include human health benefits associated with changing noise policy or applying a more stringent noise standard.

3.3 The process of conducting a HRA is given in four steps:

1. Defining the scenario. This includes decisions about the noise sources to be included, the reference year, the geographic region, the choice of the counterfactuals and any other decisions relevant for conducting the HRA. The counterfactual for a BoD would typically entail a situation without any noise, i.e., the minimum noise level considered to have some health impact. In a HIA, the counterfactual could be the current policy situation or any other reference situation.

2. Estimation of the exposure distribution for the target population for the selected noise sources.

3. Selecting the outcomes and evaluating the exposure-response association for the selected out-comes.

4. Quantify the impact in form of number of attributable cases/deaths, number years of life lost, years lost due to disability or DALYs etc.

3.4 Röösli et al makes the case that the guidance methodology for conducting a HRA given in the WHO Environmental Noise Guidelines for the European Region (ENG) was based on data up to 2015. The authors argue that due to the large amount of research undertaken in the years since 2015, the guidance in ENG could be considered outdated.

3.5 The paper outlines the main areas in which the authors consider that the HRA process needs to be evaluated and or updated. These include exposure assessment, with a recommendation to develop noise exposure assessment methods which are comparable across countries and possible to implement in different settings.

3.6 A further recommendation is the focus on relevant noise sources, in particular the health effects of transportation noise where the data and evidence are most available. It is possible that other noise sources produce health effects, but the data is not yet at a stage for HRA.

3.7 Further investigation into the impacts of combinations of noise sources is suggested, to enable knowledge of the additive effects of multiple noise sources in terms of health outcomes.

3.8 In terms of the outcomes selected, the authors suggest the addition of diabetes, obesity and mental health problems including depression. They state that because noise is a physiological stressor, noise HRA studies may also consider all natural-cause mortality as an outcome, as it is standard for HRA studies in the field of air pollution. For cost-benefit analyses, impact on all-cause mortality is usually the most relevant cost contributor and thus the decision which mortality outcomes to include has major implications for the result.

3.9 It is also advised that there should be transferability of exposure response functions in space and time, and that future HRA should use exposure-response functions from a similar context in terms of time period and geographic region. It is stressed that this is most important for self-reported outcomes.

3.10 The threshold for qualification is recommended to be reconsidered. The authors recommend re-evaluation of the threshold for BoD studies, considering newer studies with reliable noise modelling in the low and moderate exposure range.

3.11 **Faulkner and Murphy** also examined the methodology used in BoD and compared it to the EU's harmful effects assessment to quantify the health effects of noise. This paper evaluates how the different methodologies compare in terms of requirements for calculation, results, and their practical application for estimating health effects of environmental noise and uses the example of road traffic noise and the Ischaemic Heart Disease outcome in Ireland.

3.12 The paper describes the harmful effects methodology, and the authors conclude that this may be a better method to use for the following reasons:

- The harmful effect methodology is more efficient, less health data is necessary, and it requires less calculation.

- For assessment that requires the application of national incidence statistics, results can be obtained for spatially localised areas as opposed to overall national figures.
- Results from harmful effect assessment may be easier to interpret than is the case for DALYs.

3.13 It is stressed however, that the universal application of BoD assessment means that comparative analysis with non-noise-induced disease states is much easier. The authors explain that this is a primary and important advantage BoD assessment has over harmful effect assessment.

Chapter 4

Other health effects

Psychophysiological responses

4.1 Several papers were presented at Internoise that addressed other health outcomes of noise. The first was by **Qu and Xie**, who investigated the effects of aircraft noise on psychophysiological parameters (Heart Rate Variability) and skin conductance.

4.2 The minute-long aircraft noise clip that was played to participants was recorded in the community in Shenzhen, China. As part of the study protocol, the researchers were also interested in the possible effects of soundscape variation such as birdsong and waterfall noises, when overlayed on the aircraft noise recordings. These generated 2 new modulated samples, which were adjusted to 70 dB (L_{Aeq}) to control for the effect of sound pressure levels.

4.3 60 participants from Shenzhen University aged between 24 and 28 were included in the study. The study design is shown in Figure 5:

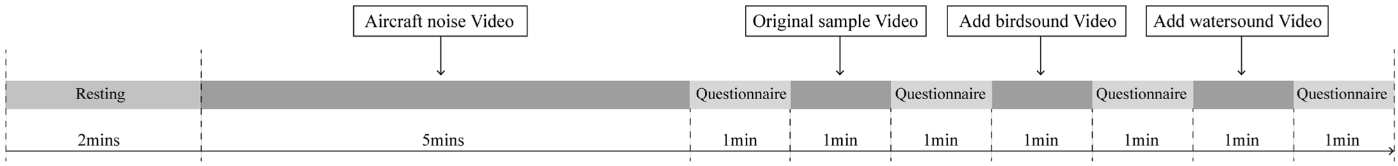

Figure 5: Study protocol

4.4 To begin with, data from the resting state for 2 min was used as the baseline index, which reflected the physiological relaxation state of the participants before noise stimulation. Then the sounds were presented in the following order: 5 min aircraft noise, 1min original aircraft sound clip, modulated samples adding birdsong and small waterfall sound respectively. The duration of each sound interval was set to 1 min, during which the participant filled in the corresponding questionnaire. The total time for the formal experiment around 15 minutes.

4.5 The results indicated that there was no association between the level of aircraft noise exposure and HRV and skin conductance. The noise samples that were superimposed with birdsong and waterfall sound significantly increased skin conductance levels (SCL), which is linked to pleasurable emotions. The soundscape masked with waterfall sound significantly increased heart rate variability (HRV), which is linked to a decrease in stress. The authors suggest that the importance of soundscape features such as waterfalls or fountains may serve to assist with modulating the negative impacts of aircraft noise.

Deprivation

4.6 **Gong** et al presented findings from a study into aircraft noise levels and deprivation. This is a UK study, using data based around Heathrow airport between 2014 and 2018. The rationale was that deprivation has been found to be a confounding factor in the relationship between aircraft noise and health effects. However, there is little firm evidence on the relationship between aircraft noise and deprivation. A previous study by Tonne in 2018 around Heathrow revealed that those people with the highest household income were more likely to reside within the 50 dB contour. The authors explain that research has focused on material deprivation, but there is a need to investigate other kinds of deprivation such as health inequality to fully understand the relationship between aircraft noise, deprivation, and health effects.

4.7 The study used modelled daily aircraft noise data for London Heathrow airport, L_{Aeq} at postcode level for eight different time periods (04:30-06:00, 06:00-07:00; 07:00-15:00; 15:00-19:00; 19:00-22:00; 22:00-23:00; 23:00-24:00; 24:00-04:30) throughout the day for the period of 2014-2018. Yearly mean aircraft noise levels were then calculated, which resulted in four metrics: L_{Aeq24}, L_{night}, $L_{evening}$, and L_{day}.

4.8 The measures of deprivation were Carstairs index of multiple deprivation, fuel poverty rate and avoidable death rate per 100,000. The data was adjusted for the percentage of non-white population per Local Authority District, given that ethnic concentration may be related to both deprivation and aircraft noise levels.

4.9 The findings indicated that areas with the least deprivation were the quietest, independent of deprivation variables used, and some evidence that areas experiencing the most material deprivation experienced the loudest aircraft noise. The authors explained that these findings suggested that aircraft noise near Heathrow has disproportionately impacted relatively less affluent areas. It should be noted however, that the relationship did not have a clear gradient except for avoidable death rate. Historically the results of studies looking into aircraft noise and deprivation have been ambiguous, and it is the intention of the authors to discuss these findings with community groups near to Heathrow.

Aircraft noise and diabetes

4.10 **Vienneau** et al investigated the effects of long-term transportation noise with mortality and diabetes mellitus (Type 2) in Switzerland. The rationale for this study was that the WHO identified diabetes as a health outcome from noise in 2018, and it is a growing research area. This study aimed to evaluate the association between road traffic, railway and aircraft noise exposure and mortality with diabetes mellitus in a nationwide cohort in Switzerland, and 15 years of follow-up.

4.11 Over 4.1 million adults in the Swiss National Cohort (SNC) were followed from 2001-2015. Road traffic, railway and aircraft noise from Swiss-wide models for the years 2001 and 2011 were linked to individuals in the SNC, based on their address and floor of residence. Noise levels (L_{den}) at the maximum exposed façade per dwelling were used. The mean exposure in three 5-year periods (2001-2005, 2006-2010, 2011-2015) were calculated. During follow-up (mean 13.4 years) over 72,000 deaths identified diabetes mellitus on death certificates. Approximately 20% identified diabetes mellitus as the primary cause of death while for 80% diabetes mellitus was an associated, consecutive or initial disease.

4.12 The results indicated that Hazard Ratios in the adjusted model for air pollution, which included $PM_{2.5}$ were 1.06 (1.05-1.07), 1.02 (1.02-1.03) and 1.01 (0.99-1.02) per 10 dB L_{den} road traffic, railway and aircraft noise, respectively. When the authors substituted $PM_{2.5}$ with NO_2 the results did not change. Associations between road traffic and railway noise and diabetes mortality were stronger in males than females, and in younger adults compared to older. The reverse could be seen for aircraft noise and the association with diabetes mortality. These results are shown in Figures 5 and 6.

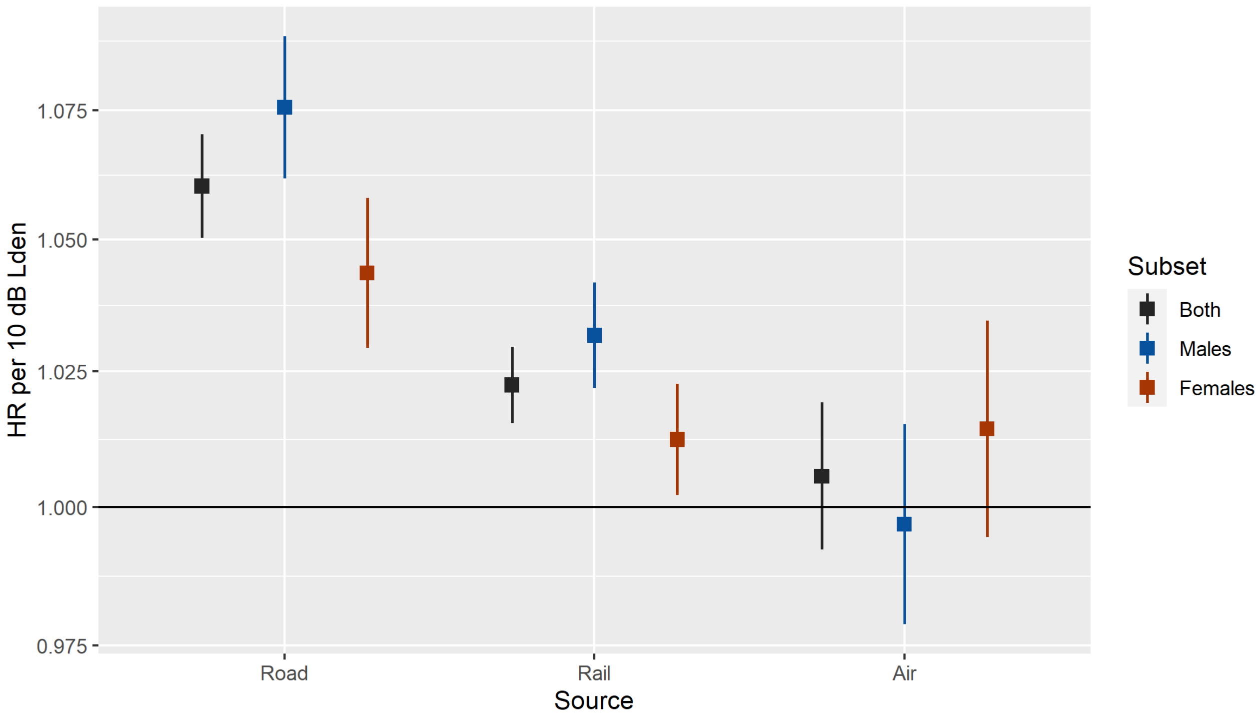

Figure 5: Sex-specific hazard ratios for mortality with diabetes mellitus, per 10 dB L_{den} for each noise source

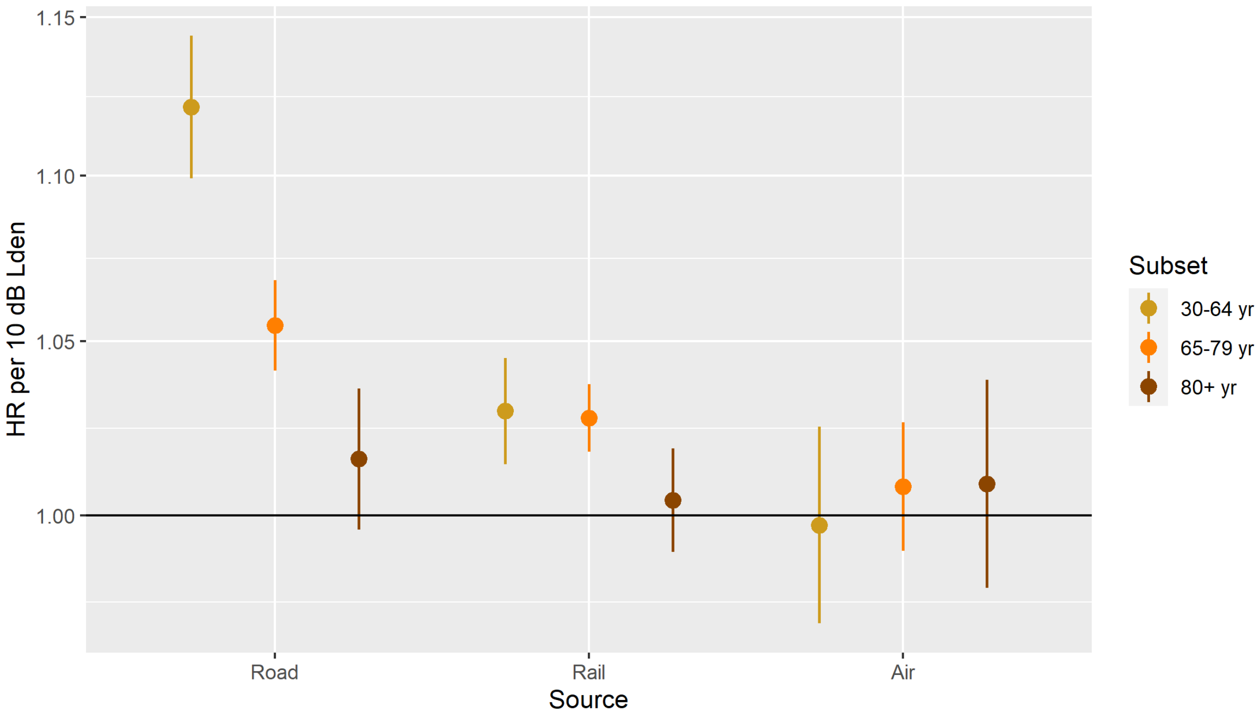

Figure 6: Age-specific hazard ratios for mortality with diabetes mellitus (both sexes combined), per 10 dB L_{den} for each noise source

4.13 The authors concluded that this study provides new evidence that mortality in people with diabetes mellitus is associated with exposure to road traffic and railway noise.

Children's health

4.14 **Spilski** et al published findings from a study on traffic noise and children's health, with regard to a machine learning algorithm. Machine learning is defined "as the use and development of computer systems that are able to learn and adapt without following explicit instructions, by using algorithms and statistical models to analyse and draw inferences from patterns in data." The advantage of using machine learning is that there are no limitations on the number of variables that can be considered in an analysis. Random forest models are one type of machine learning method for dealing with possible multicollinearity[1] of predictors or non-linear relationships.

4.15 This method has not been widely used in research into children's health and transportation noise, and in this study the results of random forest models for a specific, selected health-related outcome (intake of medically prescribed drugs) from the NORAH data set was presented. The authors' aims were to show how a

[1] Multicollinearity is the occurrence of high intercorrelations among two or more independent variables in a multiple regression model.

random forest approach can be used to discover the most important predictors of the selected variable. The goal was to leverage the potential of the wide range of potential influencing factors included in the NORAH study and overcome being limited to a few predictors. The exploration of further relevant predictors of aircraft noise effects can then provide further incentive for additional theoretical considerations. A further aim was to address the question of whether effects previously found in theory-based models can also be discovered by this machine learning analysis approach. The study compared the random forest results to the theory-based regression analyses in the NORAH dataset, and the strengths and weaknesses evaluated.

4.16 The mean age for children was 8 years and 4 months, and complete data were available for 1,118 children and their parents concerning children's health and living environment at home. Aircraft noise levels at children's school and home address (L_{Aeq}, L_{den}, L_{Amax}) and number above thresholds (NAT) for bands of five dBA were calculated for the year before data collection. Road and railway noise data were also calculated. Due to the NORAH study being focussed on aircraft noise, the study used 91 metrics related to aircraft noise, and 33 related to road and rail noise.

4.17 For statistical analysis, 570 predictor variables (including 91 traffic noise exposure metrics) were included in the random forest analysis. The results indicated that different aircraft noise exposure metrics were important predictors of the intake of medically prescribed drugs. Thirteen aircraft noise exposure metrics were among the top 20 predictors. In addition, different time periods and aircraft noise exposure metrics (L_{Aeq}, L_{Amax}, NAT) are important predictors, among them the noise metric $L_{Aeq,\ 06\text{-}22}$ dBA. Only the aircraft metrics were significant, not the road or rail ones.

4.18 The results also revealed that only aircraft noise exposure metrics for the home address were important predictors; aircraft noise exposure metrics for the school address were less important predictors of the outcome intake of medically prescribed drug.

4.19 The authors also explain the weaknesses of using the random forest methodology, for example, when these results were compared to previously reported theory-based regression analyses of the NORAH data, which found the variables ‘degree of urbanization’ and ‘degree of imperviousness’ to be moderators for aircraft noise effects. It is stressed that theory-based research methodologies remain important for revealing effects that cannot be identified in this type of analysis.

UK Communities

4.20 **Beckford**, from the UK’s Heathrow Association for the Control of Aircraft Noise (HACAN) published a paper on the communities’ perspective on the health effects of aircraft noise. The paper discusses the importance of overflown communities having knowledge of the potential health impacts that may be linked to more aircraft noise in future, even at lower noise levels.

4.21 The paper describes study findings that provide evidence that people are adversely affected from aircraft noise at lower levels, including findings from the Survey of Noise Attitudes (SoNA) study.

4.22 The issue of respite at Heathrow is discussed, with the belief from communities that the use of average noise metrics does not adequately reflect the number of people who are affected by aircraft noise in relation to runway alternation. The paper describes health effects results from studies on cardiovascular disease, mental health and cognition and sleep disturbance.

4.23 It is stated that the community groups "would like to see UK Government set out an independent research programme that seeks to ensure existing knowledge gaps are filled. This could include; protecting sensitive time periods, respite, noise insulation and the effectiveness of mitigation interventions."

4.24 The paper discusses the challenges around Heathrow in particular, with regard to numbers of movements, and night-time noise from aircraft. Beckford explains that the number of people experiencing >20 events grew from 389,900 in 2006 to 523,500 in 2018, an increase of 34%. The size of area experiencing >10 noise events rose by 15% and >20 noise events above 60 dB also increased by 23% in the same period.

4.25 The paper concludes by describing the actions that communities would like to see happen in future. These include: a debate about the economic, environmental, health and social impacts of aircraft noise; a decrease of the annoyance thresholds and wider appraisal methodologies; development of long-term targets, translation of academic research findings into policy; and a more active strategy to identify where the gaps are, and work commissioned to address them.

Chapter 5

Aircraft noise and Sleep Disturbance

5.1 **Smith** et al published a review paper on environmental noise and the effects on sleep. The aim was to provide an updated systematic review and meta-analysis to the WHO Guidelines in 2018, which included analysis up to the year 2015. A literature review on self-reported sleep disturbance of people at home was conducted to December 2021, with the outcomes of awakenings, difficulties falling asleep and sleep disturbance included.

5.2 The data was extracted to provide exposure–response relationships for the probability of being highly sleep disturbed by night-time noise (average outdoor A-weighted noise level $L_{night\ 2300–0700\ hours}$) for aircraft, road, and rail traffic noise, individually. All studies identified in the WHO evidence review for which data were already available for meta-analysis were included in the updated review.

5.3 Eleven new studies (n=109,070 responses) were included in addition to the 25 studies (n=64,090 responses) from the original WHO analysis. The SoNA and NORAH study data were also included in the updated review. Figure 7 shows the increase in sample size per question for the updated review sample (original WHO data plus newly identified studies to 2021) compared against the original WHO 2018 data alone for aircraft noise. (Road and railway noise not shown here).

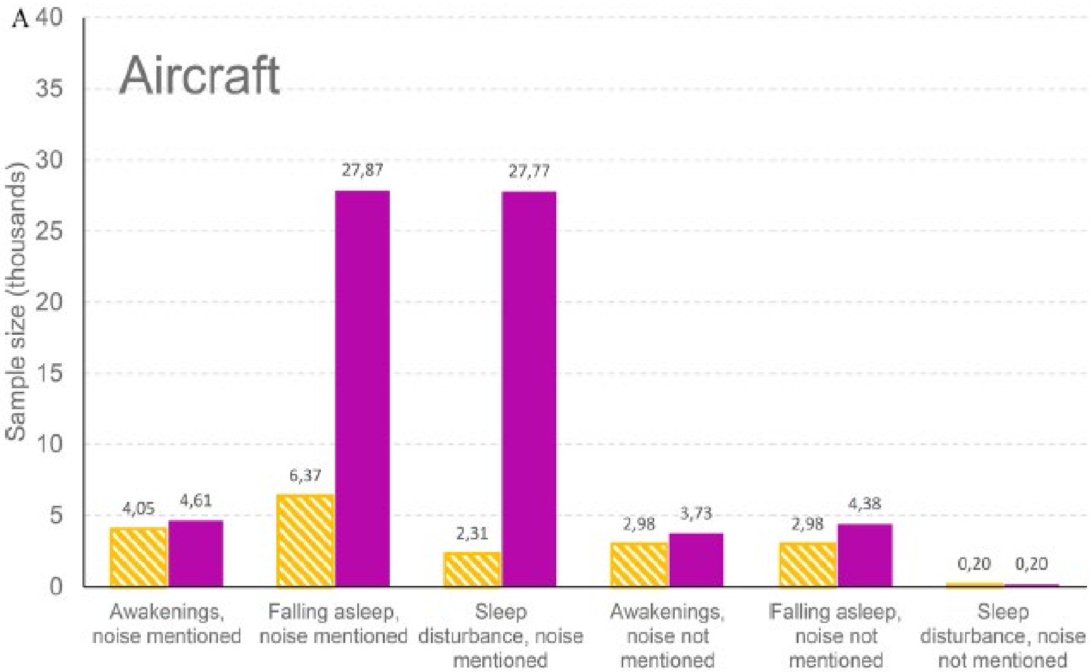

Figure 7: Effective sample sizes for aircraft for each sleep disturbance question in the updated analysis plus original WHO sample (purple), compared with just the original WHO 2018 review (orange).

5.4 Figure 8 indicates the updated exposure-response relationships for aircraft, road and railway noise in terms of L_{night} and percentage Highly Sleep Disturbed.

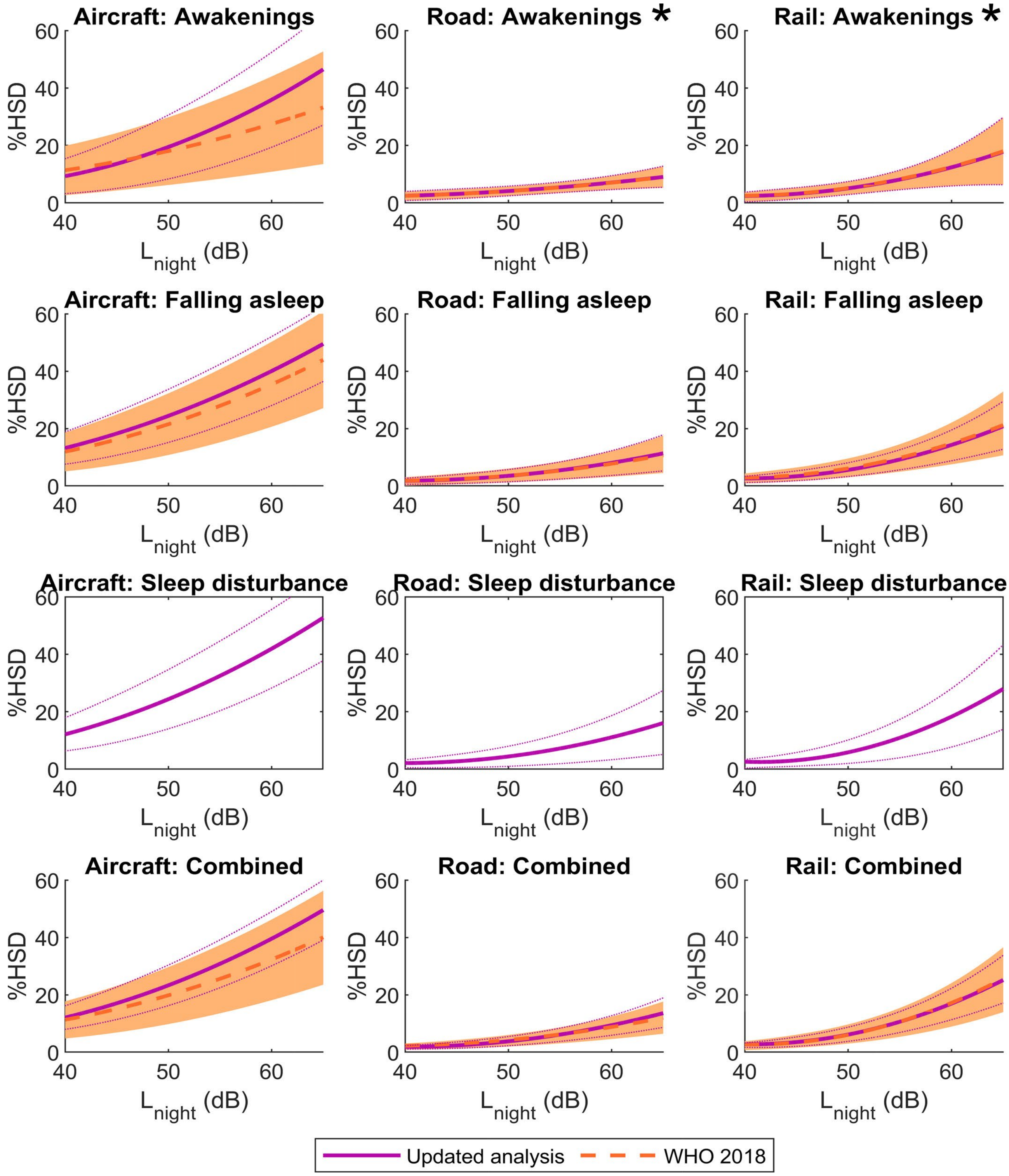

Figure 8: Probability of being Highly Sleep Disturbed (%HSD) by night-time noise, stratified by disturbance question and traffic mode. Exposure-response relationships derived using all available data, from the original WHO review and the 11 newly identified studies.

5.5 The authors explain that when the sleep disturbance outcomes were combined for each of the noise sources, the exposure-response relationship curves for road and railway noise were very similar to the ones in the original WHO review. Figure 9 shows the updated exposure-response curves for combined estimates, compared to curves derived using only the 11 new studies.

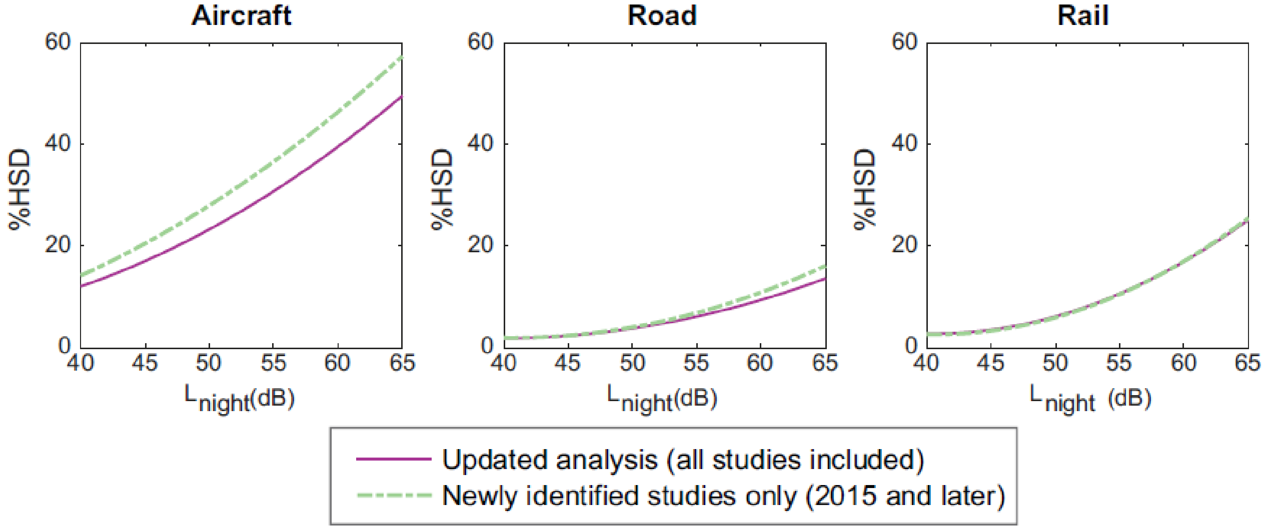

Figure 9: Exposure response relationships for the probability of being HSD (%HSD) by night-time noise for questions that mention noise.

5.6 The main findings of this study were that there was a significant probability of being highly sleep disturbed by night-time noise from all sources when the question mentioned noise. Based on the same grading system used by for the 2018 WHO systematic reviews, the evidence for these outcomes was found to be of moderate quality.

5.7 A further finding was that there was an increased probability of being highly sleep disturbed by aircraft noise at high noise levels.

5.8 The authors concluded that their findings did not warrant a change of the 2018 WHO recommendations for night-time noise, given that the results of this updated analysis were comparable even at low noise levels (40 dB L_{night}). It is however possible that the findings indicate that populations exposed to higher levels of aircraft noise may be more susceptible to sleep disturbance than previously reported.

Chapter 6
Summary

6.1 This update report has summarised the main findings in aircraft noise and health effects research over the six-month period March – September 2022. The chapters have included those findings presented at the Internoise congress in the areas of annoyance, methodologies to assess aircraft noise effects, metabolic effects such as diabetes mellitus, the effects of noise on children's health and UK communities' perspectives on aircraft noise. The report also includes a description of an update to the WHO systematic review and meta-analysis of aircraft noise and the effects on sleep disturbance, including analysis from findings between 2015-2021. Although this did not result in a change to the recommendations, there are potential implications for exposure to higher aircraft noise levels.

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