

Aircraft Noise and Health Effects – a six monthly update

CAP 1883



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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 September 2019 to March 2020 and includes relevant findings presented at the International Congress on Acoustics (ICA), held in Aachen in September 2019. The report also discusses recent publications from the Department of Environment, Food and Rural Affairs (Defra) on environmental noise and health outcomes.
- 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 conference, nor takes any view on their applicability to UK policy making. The authors would like to thank Bernard Berry (Bel acoustics) for his valued contribution to the source material.

Chapter 2

International Congress on Acoustics (ICA) Findings

- 2.1 The ICA Congress was held in September 2019 in Aachen, Germany. The relevant findings relating to aircraft noise and health outcomes are presented in this chapter according to subject area.

Measuring Annoyance

- 2.2 The first paper is authored by **Quehl et al** from Germany, who examined the effects of nocturnal aircraft noise on short-term annoyance in children, and the influence of non-acoustic and acoustic factors. Children are considered a vulnerable group in terms of the potential impact of environmental noise due to their sensitive developmental stage and because of the lack of established coping mechanisms compared to adults. The effect of nocturnal aircraft noise on children has not been widely studied, and this field study examined 51 children aged 8-10 years old living around Cologne/Bonn airport.
- 2.3 The study occurred over four consecutive nights, with aircraft noise measurements taken inside the bedrooms. The number of aircraft movements was also considered. Short-term annoyance was measured the following morning, 30 minutes after waking, via a question recommended by the International Commission on the Biological Effects of Noise (ICBEN). The children were also interviewed on the first day and any moderating psychological factors relating to noise and annoyance were found. Questions to establish noise sensitivity, perceptions of air traffic and attitudes towards aircraft use were also asked within the initial questionnaire.
- 2.4 The results were analysed using logistic regression, and a model for short-term annoyance was established. Only those factors that showed an increased trend effect for annoyance were included in the model, until no further improvement in the model could be obtained. None of the noise metrics, including number of aircraft movements had any effect on short-term annoyance ($p \geq 0.6$) and the odds ratios of all noise metrics were close to 1, meaning that there was no effect of noise exposure on annoyance response.
- 2.5 When non-acoustic parameters were included, such as noise sensitivity, attitudes towards air traffic, e.g. 'aircrafts are dangerous', and coping behaviour in the presence of aircraft noise, the model improved to the best fit for predicting short-term annoyance due to nocturnal aircraft noise. The results from this study are quite surprising as the level of night-time aircraft noise and number of movements were not related to short-term annoyance in children, as would be

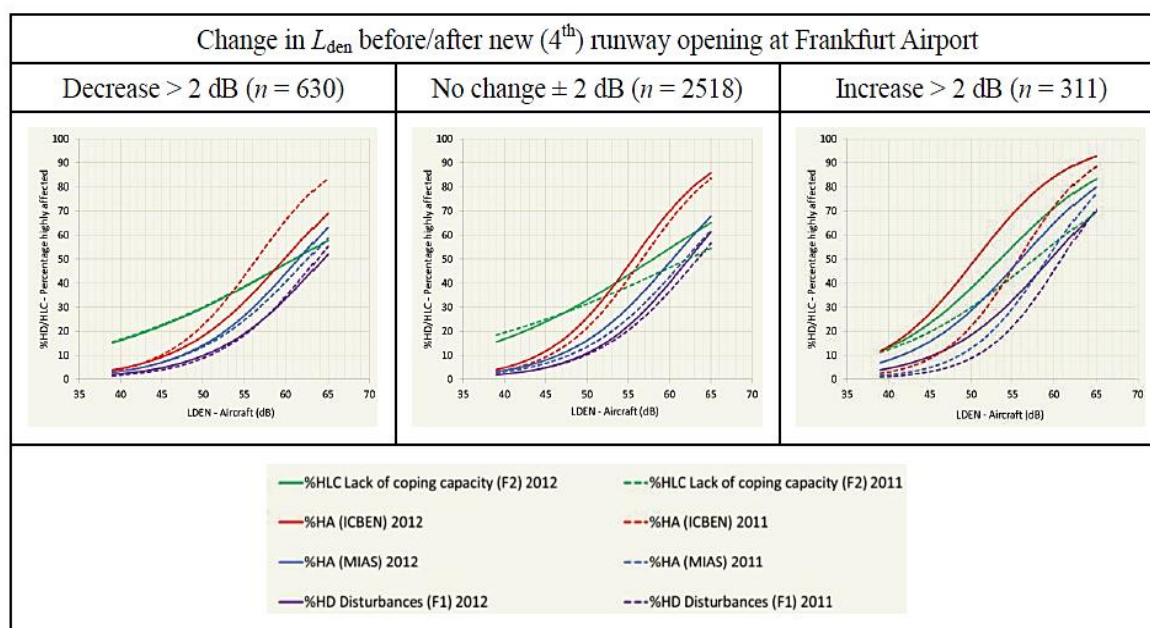
expected in adults. However, when combined with non-acoustic factors such as sensitivity and attitudes towards aircraft, the effect was significant.

- 2.6 **Marki et al** presented the outcomes from their work on using a mobile application to assess quality of the acoustic and visual environment, and the relationship with aircraft noise.
- 2.7 The basis for this work is underpinned by the importance of non-acoustic factors in relation to the perception of sound environments. The study was conducted under the Aviation Noise Impact Management through Novel Approaches (ANIMA) European project on the impact of aviation noise. It used an Experience Sampling method to assess people's perception of quality in their acoustic and visual environments around airports in real time rather than retrospectively as is usually the case with annoyance studies. The study is one of several pilot studies being conducted as part of ANIMA.
- 2.8 The advantages of using smartphones as a means of recruitment and data collection include: greatly reduced cost compared to traditional methods; convenience of recruitment using social media; high quality pictures and sound recordings can be taken; location can be accurately measured; and an instant two-way data flow is possible between the participant and the researchers.
- 2.9 For this study a dedicated mobile application was developed, and participants were notified 1-3 times each day for the duration of the study, with randomised data obtained for every hour during the day (07:00-23:00, weekdays; 08:00-22:00, weekends). When alerted, a snapshot of the acoustic environment was recorded, along with the location, a short questionnaire on perception of the surroundings, and a picture taken of the surroundings. The duration of the study was for two or three weeks. End of week and weekend questionnaires were also completed, and a larger questionnaire on noise sensitivity and well-being was completed at the end of the study. For this study, the app was tested on a small number of participants that were selected by the researchers, with the aim of obtaining feedback on the design and functionality of the app. This version of the app was the pre-release version, and the pilot study revealed that participants found the app easy to use but slightly too long. They suggested that the frequency of measurements could be increased to up to five times per day, which would decrease the overall length of the study. Photos will not be taken and stored in the release version, and instead the type of landscape will be assessed. The authors intended to begin another pilot study with the release version at the end of 2019. The release stage consists of:
- Refinement of the test method
 - Modification of the app and release in the Apple App Store and Google Play Store

- Recruitment of 60 participants around two airports (London Heathrow and Ljubljana, Slovenia) for the post-release pilot study
 - Evaluation of the performance of the study
 - Evaluation of the data collected
- 2.10 **Schreckenber** **et al** authored a paper on the assessment of the impact of changes in noise exposure at an expanding airport by means of the Multiple Item Annoyance Scale (MIAS).
- 2.11 The purpose of the MIAS is to incorporate the different dimensions to the annoyance response. These include the experience of an often-repeated noise-related disturbance and the behavioural response to it; the emotional response to the sound and its disturbing impact; and the perception of control of the noise situation.
- 2.12 The advantages of using a MIAS include:
- It helps to understand the interrelations between different noise effects and therefore might be more effective in the assessment of the impact of noise-related interventions.
 - Using multiple items to assess annoyance means response bias is reduced and different causes of different components of annoyance are more explicit.
- 2.13 MIAS includes seven items, including the 5-point ICBEN annoyance scale and the sub-dimensions 'noise disturbances' and 'lack of coping capacity', which each consist of three items.
- 2.14 In this study, the aim was to investigate changes in the sub-dimensions for aircraft noise annoyance before and after a new runway was opened at Frankfurt Airport, and the introduction of a new night noise curfew for residential areas around the airport. Longitudinal survey data from the NORAH (Noise-related annoyance, cognition and health) study was used before (2011) and after (2012) the opening of the fourth runway at Frankfurt Airport. The night flight curfew also occurred in 2011.
- 2.15 Over 3,500 participants took part in the study, living within the daytime 40 dB $L_{Aeq,16h}$ (06:00-22:00) and night time $L_{Aeq,8h}$ (22:00-06:00) noise contours. They completed telephone interviews and were also given the option of completing an online survey. The MIAS comprises two Factors, the first being 'Disturbances due to aircraft noise' (F1) which include the standard ICBEN 5-point scale annoyance question, together with other forms of disturbance related to aircraft noise such as disturbance of activities (watching TV, listening to the radio, talking etc). The second Factor is 'Lack of coping capacity' (F2), which includes three items asking participants to judge statements referring to their perceived ability to protect themselves against noise, close windows, or whether they felt helpless

towards the noise. The components of F1, F2 and the 5-point annoyance score are combined using weights for the contributing items, to form a MIAS score.

- 2.16 Figure 1 shows the exposure-response relationships before and after changes in aircraft noise at Frankfurt airport. The percentage of people Highly Annoyed (%HA), Highly Disturbed (%HD), and perceiving a high lack of coping capacity (%HLC) are shown. Response scores above the 72% cut-off were classed as HA, HD and HLC.



Note. Blue/red curves: percentage (%) highly annoyed as assessed with MIAS (blue) and ICBEN item (red); violet: % highly disturbed; green: % perceiving high lack of control; dashed: assessments of 2011; solid: assessments of 2012. For better readability, limits of the 95% confidence intervals are not shown. All responses refer to aircraft noise.

Figure 1: Summary of exposure-response relationships for MIAS and its components against L_{den} in groups of changes in aircraft noise in 2012 after the opening of the new runway. Reproduced without permission from ICA proceedings.

- 2.17 The results indicate a change effect i.e. a shift in %HA in 2012 compared to 2011, particularly for those participants experiencing an increase of >2 dB L_{den} . The change effect observed is greater for annoyance assessed with the single ICBEN 5-point scale compared to assessment with the MIAS score. The MIAS score suggests little evidence for a change effect, particularly in the 'disturbances' element. In those areas of no change or an increase in aircraft noise exposure, a change effect was observed in the 'lack of coping capacity' factor, which increases as the noise exposure increases.
- 2.18 Previously, when the NORAH data has been analysed elsewhere, the results have indicated that in the condition that aircraft noise increases by >2 dB L_{den} , the sound level alone is not purely responsible for the increase in annoyance

values. In this instance, it was found that annoyance changes were predicted by coping ability, and attitudes and expectations regarding air traffic.

- 2.19 There is also evidence in this study that trust in authorities is a further consideration when investigating annoyance responses to aircraft noise. The authors suggest that when aircraft noise exposure increases, this threatens the perceived control and trust in others thought to be responsible for improving/not worsening the residential situation, which in turn also impacts the well-being of individuals.
- 2.20 **Flindell and Hooper** authored a paper on the meaning of noise annoyance, which discussed the issues surrounding the meaning of annoyance and subsequent assessment. The paper discusses the historical issues regarding the definition of annoyance and the subsequent development of the two IC BEN 5- and 11-point scales in 2001 for use separately or together within noise annoyance questionnaires. The development of these scales allowed for increased standardisation across studies, and because they were created in nine different languages, across countries also.
- 2.21 The authors discuss the possibility that in their recent experience, the supposed degree of benefit from using the scales may not have been achieved. They cite the differences in Guski's meta-analysis (Figure 2) illustrating the different dose-response relationships between aircraft noise and annoyance in various studies since 2001.

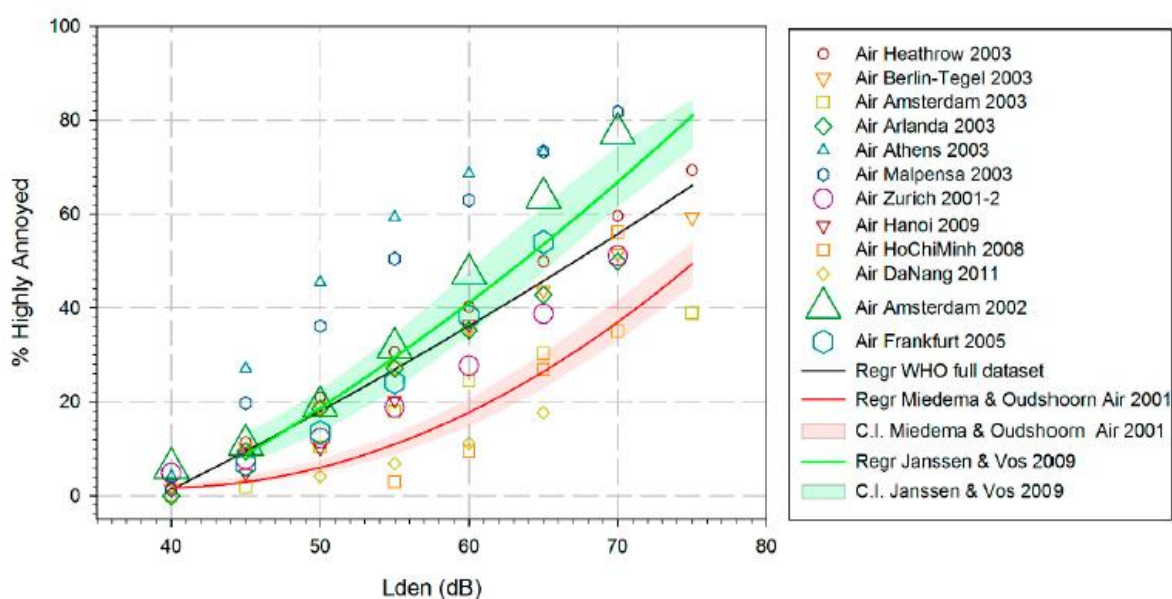


Figure 2: Scatterplot of the annoyance response data from 12 studies included in the WHO dataset, used to develop the updated WHO Noise Guidelines for Europe in 2018. Exposure-response relationships are also included from Miedema and

Oudshoorn and Janssen and Vos. The size of the data points corresponds to the number of participants.

- 2.22 Flindell and Hooper offer possible reasons for the variations found in the annoyance studies, such as the populations selected at given times and locations exhibit fundamentally different responses; differences in acoustic factors that may be present when conducting surveys at different times and in different places; and the possibility that although standardised, the ICBEN questions may in fact be measuring different responses in different circumstances.
- 2.23 The paper goes on to offer a more detailed explanation of the various reasons for finding differing annoyance responses in relation to aircraft noise and discusses the effect of individual differences and the transactional model of stress and coping (by Lazarus, Figure 3). Studies based on this model identify certain pre-cursors, implications and consequences of noise annoyance models and integrate them into a single coherent model.

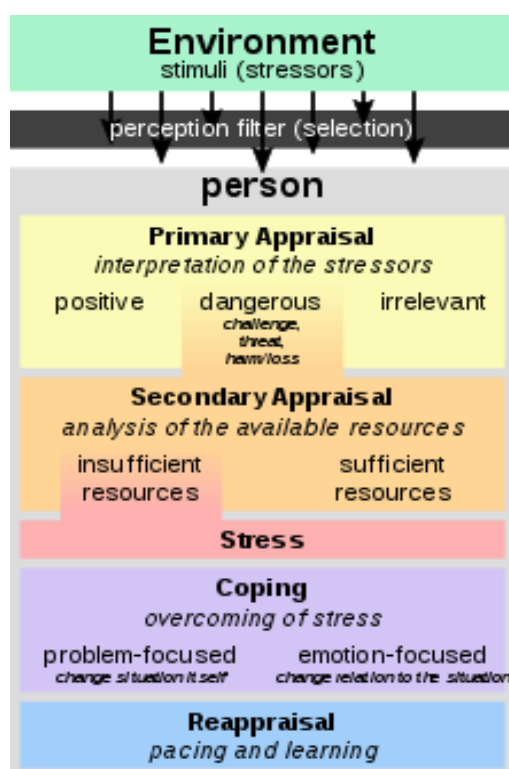


Figure 3: Transactional stress model (Lazarus and Folkman)

- 2.24 The authors explain this model in detail; briefly, that stress is the result of an interaction between environmental and personal factors. The subjective evaluation of the stressor and the person's available resources is an important factor. The model suggests that when the primary appraisal of the situation occurs (interpretation of the stressor) the person will either assess it as posi

tive, dangerous (challenging, threatening, harm/loss) or irrelevant. If perceived as positive or irrelevant then no stress occurs but when perceived as dangerous then stress ensues.

- 2.25 The secondary appraisal then deals with the resources available to the individual, and their control over the situation. If there is perceived control over the situation then problem-focussed problem solving occurs, such as changing the problem itself, using strategies like generating alternative solutions etc. If perceived as having insufficient resources, then stress occurs. How this is dealt with depends on the coping mechanisms employed, with emotion-focused strategies aimed at reducing negative emotions. After the coping attempts, a reappraisal and reassessment of the stressor occurs. For example, a stressor that may have been perceived as a threat may become a non-threatening challenge through coping strategies and learning.
- 2.26 Given the many possibilities for variation at any stage of this process, it is perhaps unsurprising that there is so much potential for individual variation with regards to the annoyance response.
- 2.27 The paper also discusses the importance of acoustic factors and that using an average level noise metric may not accurately represent an individual's experience of noise exposure on any given day, or at any particular location. The authors argue that actual noise exposure may vary in terms of time of day distributions and representativeness of a given day for any other day, or average day. They conclude that noise management may be better aimed at consensus outcomes rather than seeking to mitigate annoyance directly, given that annoyance as a concept remains challenging to quantify and relate to noise stimuli.
- 2.28 **Spilski, Bergstrom et al** presented a paper that discussed the idea of using different aircraft noise metrics to predict annoyance for different groups of people. Although L_{eq} and L_{den} are the most commonly used metrics for annoyance studies, the authors suggest that other metrics such as Number of aircraft noise events above a certain threshold (NA), L_{max} and Emergence¹ should not be ignored as they may explain further variance of 19% that the WHO found between aircraft noise levels and raw annoyance scores. The study re-examined the NORAH dataset with the aim of assessing the effectiveness of alternative noise metrics and differences in the level of relationships in different groups of people (children, parents and teachers) and in different settings (school: workplace or learning environment; residential environment).
- 2.29 The children were given questionnaires in groups of whole classes (the exact method has been reported in detail in previous reports), and also given a

¹ Emergence is the difference between L_{Amax} and L_{Aeq}

questionnaire to take home for their parents. The teacher questionnaire was given to them before the children's testing session and collected straight afterwards. The teachers' annoyance was assessed by a scale with five statements relating to aircraft noise at school, and other questions on the quality of their instruction and whether it is affected by aircraft noise (for example, having to stop teaching during an aircraft noise event). Parental annoyance was assessed using three statements, and the children's annoyance was assessed through a four-item scale.

- 2.30 The data was analysed using regression models for teachers and parents' annoyance responses, and for children's annoyance due to aircraft noise at home. For children's annoyance responses at school, multilevel model analysis was performed.
- 2.31 The results indicated a significant association for aircraft noise and annoyance, with a higher explained variance than reported by Guski in the WHO Noise Guidelines in 2018. In addition, this study found that other metrics such as NAT, Emergence and L_{Amax} are also significant single predictors of the annoyance due to aircraft noise. For each of the metrics, exposure was significantly associated with noise-induced annoyance for children and teachers during the lessons, and for children and parents at home. Further analysis indicated that within the model only the NAT metric was found to be a second significant predictor of annoyance more than daytime L_{Aeq} . The incremental effect was only present in the school context for teachers and children and was highest when the number of aircraft noise events in a band of 70-75 dB L_{Amax} increased. This effect was not present for children or parents at home. The authors suggest that this supports evidence that the inclusion of Number Above metrics should be included alongside the average noise intensity (quantified by L_{Aeq}) when assessing aircraft noise-induced annoyance.
- 2.32 In conclusion, the calculations with different noise metrics indicated that L_{Aeq} as a single noise metric is still the best predictor of annoyance, but for aircraft noise-induced annoyance in children and teachers in a school setting, there was a significant increase in explained variance when the NAT criterion was included as a second metric within the analysis models.

Cardiovascular Disease

- 2.33 **Baudin et al** authored a paper on aircraft noise exposure and salivary cortisol in people across seven European countries. Cortisol is a stress hormone that is secreted in a circadian rhythm, peaking in the early morning and at its lowest level at night. The basis of this study is that the effects of transportation noise from aircraft, road and rail on the production of salivary cortisol is not fully understood.

- 2.34 The HYENA (HYpertension and Exposure to Noise near Airports) study (2009) in over 430 participants reported that aircraft noise exposure increases morning production of salivary cortisol in women, but not in men. In contrast, the DEBATS (Discussion on the Health Effects of Aircraft Noise) study (2017) in over 1,200 participants found that aircraft noise exposure resulted in an increase in evening cortisol levels and a flattening of the usual hourly variation when aircraft noise exposure is increased. No significant difference between males and females was found in this study.
- 2.35 The aim of the study by Baudin et al was to combine the datasets from these studies to obtain a larger sample size and therefore more statistical power and re-analyse the effect of aircraft noise on the production of salivary cortisol. The dataset was $N = 1,300$ in total (359 from HYENA and 941 from DEBATS). The pooled analysis from both studies revealed that significant associations were found between aircraft noise and changes in salivary cortisol in women only. Associations were stronger for women who experienced aircraft noise exposure at night, with the strongest association found with the L_{night} metric.
- 2.36 The authors stress that the biological pathways between noise exposure and hormone regulation variation, such as seen with cortisol production, are not fully understood and more research is needed to investigate the cause and effect mechanisms.
- 2.37 **Vienneau et al** presented an update of the WHO meta-analysis on the association between transportation noise and cardio-metabolic diseases. The purpose of this was to update the database of studies used in the development of the WHO Guidelines, which included relevant studies up to 2015. The aim was to update recent meta-analyses for Ischaemic Heart Disease (IHD), and diabetes with studies up to early 2019. The same protocol was conducted as used by the WHO in developing their recent evidence base, with a systematic literature search and risk of bias calculated for each study.
- 2.38 Thirteen studies were included in the IHD meta-analyses; comprising thirteen risk estimates for road traffic, five for aircraft and three for railway noise exposure, with some studies comparing multiple sources. The results indicated that only the road traffic noise exposure was statistically significant in predicting the risk of IHD. For diabetes, six studies were included in the analyses, with five risk estimates from road traffic, three for aircraft noise and two for railway noise. A significant result was only found for road traffic noise exposure in this case also. The authors conclude that the inclusion of the most recent studies into transportation noise exposure and IHD or diabetes are important contributions to understanding the cardio-metabolic effects of noise, and for public protection. This update to the WHO database indicated that road traffic noise is an important risk factor for both IHD and diabetes. There are also indications of associations

with aircraft noise but in this sample the current studies were heterogeneous, indicating there was variation in the study outcomes.

Sleep Disturbance

- 2.39 **Bartels et al** presented further findings from the Quehl et al study on nocturnal aircraft noise and annoyance in children (described above). This study examined the effects of night-time aircraft noise on objective and subjective sleep quality in primary school children. The 51 children aged between 8-10 years old were residents in the vicinity of Cologne/Bonn airport, which has a 24-hour operating scheme. Children are known to sleep for longer periods than adults, and across the shoulder hours of the evening and morning and are classed as a vulnerable group to the effects of aircraft noise.
- 2.40 Sleep was measured for four consecutive nights by polysomnography using Electrocardiograms (EEG), Electromyograms (EMG), Electro-oculograms (EOG) and Electrocardiograms (ECG) along with pulse oximetry (measurements of oxygen level in the blood). Participants also rated their sleep quality and fatigue using a 5-point scale each morning of the study. This was a field study, with sound levels recorded by a sound level meter placed near the children's ears that captured ambient noise levels and aircraft noise events. Aircraft noise was quantified by the number of events above 30 dBA L_{max} per night.
- 2.41 The variables measured included:
- Sleep onset latency (how long it took to fall asleep)
 - Sleep efficiency
 - Proportion of slow wave sleep
 - Proportion of Rapid Eye Movement (REM) sleep per total sleep time
 - Wake duration during sleep period
 - Self-rated sleep quality
 - Self-rated fatigue in the morning
- 2.42 Linear mixed models were applied in the analysis to investigate the relationship between objective and subjective sleep quality.
- 2.43 The results indicated that a higher number of aircraft noise events at night was associated with a reduction of slow wave sleep by 2.6% and an increase in waking during the sleep period by 1.2%. Sleep onset time was 3.3 minutes longer in those nights with higher aircraft noise exposure. The subjective measures of sleep quality and fatigue were not associated with an increase in aircraft noise exposure. Self-rated fatigue was related to longer wake durations during the total sleep period.

- 2.44 The authors point out that there is evidence to suggest that disruption of slow wave sleep can appear to increase the risk of metabolic, cognitive and cardiovascular diseases, and that the effect of nocturnal aircraft noise in children needs to be further investigated. Cologne/Bonn airport, with its 24 hour operating schedule, is different to other airports that implement a night flight ban, and it has a moderate number of movements during shoulder hours; other airports have fewer movements.
- 2.45 The results suggested that self-reported measures did not correlate with objective measurements in children, a finding that is often seen in studies on adults also. The authors state that this indicates the need for objective measurements to be included in studies investigating the effect of nocturnal aircraft noise and the impact of sleep parameters.
- 2.46 **Basner et al** reported on the results from a pilot field study on the effects of aircraft noise on sleep around Atlanta airport. The aim was to assess whether it was possible to obtain acoustical and physiological data without the presence of an investigator and with the equipment sent to the participants by post for their own application of electrodes and data collection. If successful, this protocol would provide a more objective measurement of sleep disturbance in a field study setting, but without the high cost of requiring investigators to be present for each participant for each set-up of recording equipment.
- 2.47 From 407 respondents to a postal recruitment drive aimed at residents experiencing >35 dB $L_{Aeq,8h}$ (23:00-07:00, outdoor), 34 participated in a field study at their homes over five consecutive nights. The results indicated that after adjustments for sociodemographic factors, outdoor night-time aircraft noise was significantly associated with self-reports of decreased sleep quality, with those people living in the 50-55 dB L_{night} region reporting significantly worse sleep quality than those in the reference group of 35-40 dB L_{night} . Participants in the >50 dB L_{night} regions were more annoyed than those in the reference group. Night-time aircraft noise exposure was also associated with difficulty falling asleep, staying awake during the day and increased difficulty concentrating.
- 2.48 The authors concluded that the physiologic and noise data collected was of sufficient quality and quantity to examine the effects of night-time aircraft noise on sleep. There were some technical issues and loss of data but in general the design was successful. Data was collected for 87% of all study nights. The authors suggest that a larger study on a more national level could be feasibly conducted using this protocol, with participants experiencing different patterns of nocturnal aircraft noise.

Implications of the 2018 WHO Noise Guidelines

- 2.49 Several papers were submitted to the ICA on the implications of the updated WHO Environmental Noise Guidelines for Europe, published in 2018.
- 2.50 **Notley et al** from Defra, UK, authored a review of the current guidance in England for the valuation of noise impacts. The current guidance for valuing the effects of environmental noise is published by Defra and the Interdepartmental Group on Costs and Benefits Noise Subject Group (IGCB(N)). IGCB is comprised of a group of government analysts and policy officials that provide advice regarding the quantification and valuation of environmental impacts. The basis of the paper is that the most recent WHO Environmental Noise Guidelines included separate systematic reviews of literature published between 2000 to 2014 or 2016 (outcome dependent). Since then there have been several high-quality studies published, and the paper describes the current steps being taken by IGCB(N) to evaluate whether they should update their recommendations following a recent literature review. The paper also discusses the assessment of various potential effects that are not included in the WHO Guidelines, for example tranquillity and quiet areas.
- 2.51 The IGCB(N) has published its methodology for valuing health impacts of noise in 2010 and 2014 and examines the following outcomes:
- Annoyance
 - Sleep disturbance
 - Hypertension (via stroke and dementia)
 - Acute myocardial infarction
- 2.52 The recommendations from IGCB(N) have been incorporated into the DfT transport analysis guidance (WebTAG). The endpoints in the guidance are health, amenity, productivity and environmental. For the purpose of the current review, amenity was removed from this list. Productivity and environmental endpoints will be defined, and their scope investigated further by the IGCB(N) in future. This review on health outcomes includes the following noise sources:
- Road
 - Rail
 - Aircraft
 - Windfarms
 - Industry
 - Noise from building services equipment

- Neighbour noise
- Neighbourhood noise

2.53 The IGCB(N) then identified the health outpoints for evaluation, and decided that the following should be included in the review:

- Annoyance
- Sleep disturbance
- Cardiovascular disease (Ischaemic Heart Disease, Hypertension)
- Metabolic disease (Stroke, Diabetes, obesity)
- Cognitive effects in children
- Mental health (excluding annoyance but including well-being and quality of life)
- Reproductive outcomes (birth weight)
- Cancers (Non-Hodgkin's lymphoma)
- Cognitive degeneration (dementia, Parkinson's)

2.54 At the time of ICA, the reviews for each of the noise sources and possible health outcomes had been completed, and a higher number of studies published since 2016 had been identified than was expected. For some of the noise source health outcomes, the evidence suggested that there is enough high-quality research to warrant new meta-analyses and to possibly define more robust, or different, exposure-response relationships.

2.55 Two further work packages that the IGCB(N) may consider in future are 'Change effect' and 'non-acoustic interventions'. The change effect package refers to a change in noise sensitivity irrespective of a change to the local environment. The determination of an exposure-response relationship can often be undertaken during a consideration of change and that this may influence the results. There would need to be investigation into whether there is evidence for a change effect over time and whether the effect reduces over time. Non-acoustic interventions include respite, which current noise metrics do not fully consider.

2.56 In terms of valuation of health effects, the current methodology uses Quality Adjusted Life Years (QALYs), which use weights to represent the impact of various health impacts compared to a life lived in perfect health. The paper concludes that the IGCB(N) are continuing to work on the scoping of some areas and have progressed in the reviews of the noise sources and associated health impacts. All the evidence will be considered and any appropriate updates to the current guidance will be made and published by the IGCB(N).

2.57 **Fenech and Rodgers** from Public Health England authored a paper on valuing the impacts of noise on health and compared current UK exposure-response relationships with the WHO Environmental Noise Guidelines (2018). The paper examines the studies that contributed to the exposure-response relationships in the two documents that inform UK valuation of noise-induced health effects published by Defra and IGCB(N) and compared them to those that informed the more recent WHO Environmental Noise Guidelines. The paper discusses in detail how the UK guidance came about, and the formation of the IGCB(N). The findings from IGCB(N) in 2010 led to the inclusion of the following recommendations:

- Inclusion of the risk of Acute Myocardial Infarction (AMI) into the monetary valuation
- Continuation of using monetary values for annoyance based on a hedonic pricing approach
- To use indicative quantification of hypertension and sleep disturbance impacts.

2.58 Following the publication of the WHO's Burden of Disease (BoD) report in 2011, which described a methodology to quantify the burden of disease caused by noise in terms of Disability Adjusted Life Years (DALYs), Defra published their own guidance in 2014 and recommended:

- Using a DALYs approach to quantify and monetise noise annoyance and sleep disturbance impacts
- Using a two-step approach to monetise hypertension effects
- Using the methodology from the 2010 IGCB(N) report to value AMI.

2.59 The paper goes on to explain the current UK guidance on sleep disturbance, which recommends that sleep disturbance impacts are monetised where it is proportionate to do so. The paper describes the equation for calculating the value of sleep disturbance; and explains Disability Weighting (DW) and the current exposure-response functions for sleep disturbance due to road traffic noise, railway noise and aircraft noise (L_{night}). The equations for these are equivalent to those in the BoD report.

2.60 The authors compare the current UK guidance for sleep disturbance to those presented in the WHO Guidelines, and explain that for aircraft noise the exposure response function is higher in terms of percentage Highly Sleep Disturbed (HSD) throughout the noise exposure range 40-65 dB L_{night} in the WHO Guidelines than those derived by Miedema and Vos, which feature in the current UK guidance. Basner and Maguire offered the following explanations as to why this may be the case:

- Different methodologies were used to derive the data
- Year of study – during and after 2000 in the WHO Guidelines; prior to 2004 in the Miedema and Vos' analyses
- Locations of studies – Miedema and Vos' analyses are largely from European countries; the WHO used data from many Asian studies in their meta-analysis
- Question wording – older studies ask about annoyance due to sleep disturbance; more recent studies ask specifically about symptoms of sleep disturbance, awakenings and difficulty falling asleep.

- 2.61 In terms of annoyance, the authors also compare the UK guidance with the WHO Guidelines. Again, the WHO dataset shows higher percentage Highly Annoyed (HA) than in the curve from the Miedema and Oudshoorn study used for the UK guidance. Six of the studies used in the WHO meta-analysis are from the HYENA study, designed to examine hypertension in populations around airports. Guski et al offered some explanations as to why the difference may have occurred, which included reference to the HYENA studies only including participants between the ages of 45-70 years, which may have introduced some bias towards higher degrees of annoyance. In a later published study by Guski et al, the data from seven more recent studies (post 2014) were added to the dataset, including the UK Survey of Noise Attitudes (SoNA) study. Despite the additional more recent data, no significant changes were observed in the exposure-response function compared to the WHO Guidelines data for aircraft noise and annoyance.
- 2.62 The paper also discusses the discrepancies between the two sets of guidance in terms of transportation noise and cardiovascular disease and discusses some of the reasons why this may be the case. In conclusion, the authors suggest that due to the age of the studies used to inform the UK guidance, there is a need for new research on noise annoyance and sleep disturbance effects in the UK.
- 2.63 A well-documented critic of the WHO exposure-response functions for aircraft noise and annoyance is **Truls Gjestland**. Gjestland is an advocate of using the Community Tolerance Level when measuring annoyance, and authored a paper presented at ICA on a critical review of the basis for WHO's new recommendations for limiting annoyance due to environmental noise. The aim of the paper was to demonstrate that the WHO Guidelines are based on a non-representative sample of studies, whose findings cannot be generalised to a larger population. The WHO's 2018 recommendations are that aircraft noise levels should not exceed 45 dB L_{den} to prevent adverse health effects.
- 2.64 Gjestland discusses both road and aircraft noise in his paper, but for the purposes of this report only aircraft noise is focussed on. His criticisms of the WHO dataset and Guski et al's rationale for arriving at their recommendations have been discussed in detail in CAP 1841. Briefly, these include that about two

thirds of the variance found for the whole dataset is accounted for by non-acoustic factors, with only one third being attributable to the cumulative noise exposure. Reference is made to the inclusion of the HYENA studies in the dataset, and the participants being aged between 45-70 years which may introduce bias, along with sampling differences between the studies, and the differences between high rate of change and low rate of change airports in terms of annoyance responses.

- 2.65 Gjestland re-analysed the WHO dataset using the Community Tolerance Level (CTL)² method. Each study was analysed separately without weightings for sample size. This is shown in Figure 4, with the average exposure-response function using CTL analysis (red line) together with the exposure-response function derived by Guski (black line). The current EU reference curve is shown by the blue dotted line. The yellow line represents studies selected by Gjestland according to the WHO criteria post 2000 and for which half of the airports were classed as high rate of change. Gjestland points out that this curve, although lying above the EU reference curve, is considerably lower than the WHO curve. The new addition to this Figure is the data from Brink, who conducted a Swiss study on annoyance due to aircraft noise in over 2,660 people. The exposure-response function from this dataset has been plotted in red dots in Figure 4. Gjestland suggests that this curve is also evidence that the Guski WHO function is over-estimating annoyance at lower levels. Brink's data indicated that a rate of 10% HA is found at around 51 dB L_{den} . Gjestland concludes by stating that the WHO's findings are not representative and cannot be generalised as community response to aircraft noise around airports.

² Community Tolerance Level: the day-night sound level at which 50% of the people in a particular community are predicted to be highly annoyed by noise exposure.

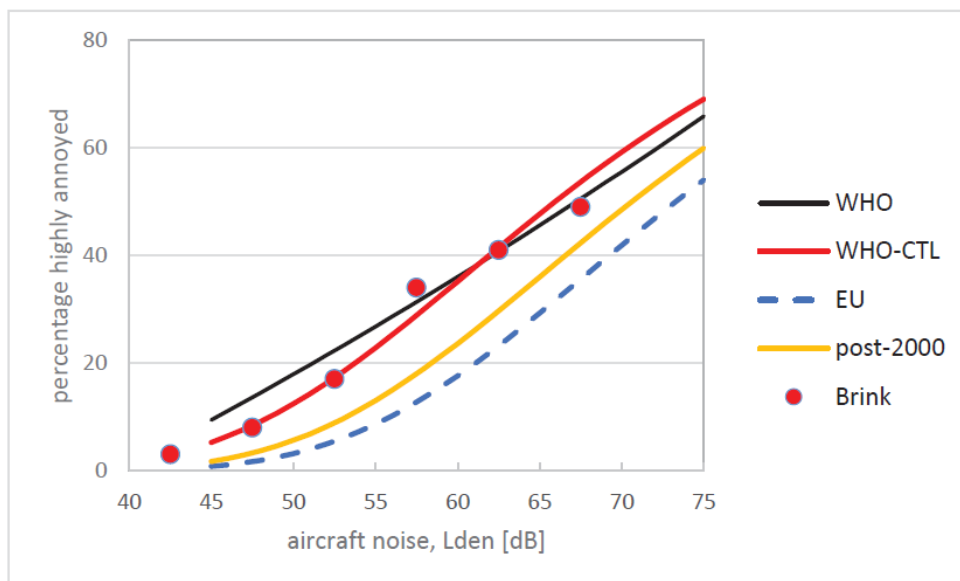


Figure 4: Exposure-response curves for aircraft noise annoyance (from ICA proceedings, reproduced without permission).

Children's Health

- 2.66 **Spilski, Rumberg et al** reported on the effects of aircraft noise and living environment on children's wellbeing and health. The current WHO guidance states that there is insufficient evidence to link chronic exposure to aircraft noise with poorer quality of life or health in children. The authors point out that previous research into this area has been conducted on single stressors for example aircraft noise or air pollution, and health in children. There has been a lack of consideration of combined environmental stressors such as degree of access to green spaces, amount of urbanisation, urban planning etc.
- 2.67 The NORAH study, conducted in Germany investigated health measures, noise exposure, and several moderating factors (residential environments factors) in over 1,200 second-graders (mean age 8 years 4 months) who lived around Frankfurt /Main airport. The authors used data from the NORAH study to perform secondary analysis using the diathesis-stress hypothesis. The diathesis-stress model is a psychological theory that attempts to explain a disorder, or its trajectory, as the result of an interaction between a predisposition vulnerability and a stress caused by life experiences. The term diathesis derives from a Greek term for a predisposition, or sensibility. A diathesis can take the form of genetic, psychological, biological or situational factors. A large range of differences exists among individuals' vulnerabilities to the development of a disorder. Post-analysis, the data was linked to spatial and urban planning data to model the impact of aircraft noise and children's real-life circumstances.

- 2.68 The authors hypothesised that in terms of aircraft noise, increased exposure leads to increased stress responses in children and subsequently affects their well-being and health, mediated through aircraft annoyance. Their second hypothesis was that the indirect effect of aircraft noise (described above) on well-being and health is moderated by the degree of urbanisation i.e. in less urban areas, aircraft noise has a relatively stronger impact than in more urbanised areas. The third hypothesis concerned the amount of imperviousness in the local environment (access to open spaces), with the theory that the indirect effect of aircraft noise on health and well-being is moderated by the degree of imperviousness. In less impervious areas aircraft noise would have a stronger effect than in more impervious areas.
- 2.69 The children were tested in groups and had the questions read out loud to them, with a combination of pictures and numbers for ease of understanding. They also took a questionnaire home for their parents to fill in on the children's well-being, health related outcomes and potential confounding factors such as socio-economic status.
- 2.70 The results indicated that there were significant indirect effects found for physical well-being. A 10 dB $L_{Aeq,16h}$ (06:00-22:00) increase in aircraft noise was associated with an increase of 0.81 scale points. This effect was passed on to physical well-being (increases in head aches and stomach aches). The inclusion of annoyance as a mediator in the model led to a non-significant direct effect, indicating a complete mediation effect. A mediator can be a potential mechanism by which an independent variable can produce changes on a dependent variable, in this case annoyance is producing changes on physical well-being. The results for psychological well-being were not consistent.
- 2.71 There was no effect found between aircraft noise and children's health-related outcomes and/or developmental disorder variables. When the moderator 'degree of urbanisation' was included in the model, no significant moderator effects were found, although the significant mediation effect between aircraft noise, annoyance and physical well-being remained. No moderator effects of 'degree of imperviousness' were found on the mediation relationship. However, the 'degree of imperviousness' was a significant predictor of annoyance. The second and third hypotheses were rejected, and the first one was accepted in relation to aircraft noise, annoyance and the physical well-being of children, but not the psychological well-being dimension of this hypothesis. Due to some of the other trend results regarding the degree of urbanisation and imperviousness, the authors suggest that the inclusion of further space variables should be included in models for predicting aircraft noise effects to map the living environment.
- 2.72 Although not part of the ICA, it is worth highlighting the work published by **Argys et al** examining aircraft noise and birth outcomes. It is a US study that used the concentration of flight patterns as part of a new Federal Aviation Administration

(FAA) policy, to investigate the effect of aircraft noise exposure on birth outcomes. The authors used birth records and the mothers' home addresses to assess the proximity to an airport. The findings suggested that the risk of low birth weight increased by 17% in mothers living near the airport in the direction of the runway and who were exposed to aircraft noise of above 55 dB L_{den} between 2004 and 2016.

Chapter 3

Defra commissioned reviews

- 3.1 In February 2020, Defra, in the context of IGCB(N) published two reports which they commissioned from Arup & Partners and RIVM with the aim of performing literature reviews relating to potential health outcomes from noise exposure to several sources. The reviews would span the years since the WHO performed their systematic reviews that would feed into their updated Environmental Noise Guidelines for the European region, in 2018. The purpose of the updated reviews was to evaluate how the evidence base has changed since 2018 and whether additional evidence should be considered beyond that in the WHO reviews.
- 3.2 The review from **Arup & Partners** assessed the quality of the evidence for environmental noise effects on mental health, wellbeing, quality of life, birth and reproductive outcomes, and cognition in the years since the WHO reviews (mid 2015 to March 2019), and cancer and dementia (January 2014 to March 2019).
- 3.3 The GRADE (Grading of Recommendations Assessment, Development and Evaluation) system was used to evaluate the evidence from the studies since the WHO reviews on the following noise sources:
- road traffic noise
 - aircraft noise
 - railway noise
 - wind-turbine noise (and other noise sources, neighbourhood noise, low frequency building noise)
- 3.4 The WHO review previously found that the evidence for mental health, well-being and quality of life in relation to the noise sources was very low. Moderate quality evidence was found for road traffic and railway noise on emotional and conduct disorders and hyperactivity in children, and very low-quality evidence for an effect of aircraft noise on medication use and measures of depression and anxiety.
- 3.5 The previous review found varied quality of evidence for effects of noise on cognition, with moderate quality evidence found for aircraft noise on reading comprehension and long-term memory, but no effect on attention and executive function. The WHO found very low-quality evidence for associations between aircraft noise and pre-term birth, low birth weight and congenital anomalies.
- 3.6 All the WHO reviews suggested a need for further research into these outcomes and for longitudinal studies.

- 3.7 In addition to these outcomes, Defra requested that evidence for other health outcomes were examined, such as cancer and vascular dementia.
- 3.8 The GRADE methodology was used in the WHO systematic reviews and was also used in this review. The system ranks the quality of evidence as high, moderate, low, or very low. The GRADE methodology is not used to rate individual studies but is used to rate the overall quality of evidence available for a specific environmental noise source and health outcome. The GRADE assessment was undertaken individually for each environmental noise and health outcome, even if only one study was available.
- 3.9 The Arup report gives full details of the studies included in their review, and the ratings of the quality of the evidence for each of the health outcomes concerned. For mental health, well-being and quality of life, 24 studies were included for eligibility in the review after screening. Most of the studies examined road noise. A comparison between the WHO review and the Arup review of the evidence for mental health, well-being and quality of life is shown in Table 1.

Table 1. Comparison of the strength of the evidence for the WHO 2018 review and the Arup review for Aircraft noise and mental health, well-being and quality of health

Outcome	WHO Clark & Paunovic 2018	Arup Review 2020
	Aircraft Noise	
Self-reported quality of life or health	Very low quality – no effect	Very low quality – no effect
Medication intake for anxiety and depression	Very low quality – harmful effect	N.A.
Self-reported depression, anxiety and psychological symptoms	N.A.	N.A.
Interview measures of depression and anxiety	Very low quality – harmful effect	Low quality – harmful effect
Emotional and conduct disorders in children	Low quality – no effect	N.A.
Hyperactivity	Low quality – harmful effect	N.A.
Well-being	Not evaluated in the review	Very low quality – harmful effect

- 3.10 The authors explain that due to a lack of new studies the review was not able to reassess many of the outcomes for aircraft noise and mental health, well-being and quality of life. The Arup review evidence finds that the effect of aircraft noise on interview measures of depressive and anxiety disorders could be updated to low quality evidence, from very low quality in 2018.
- 3.11 Eight studies with cancer as a health outcome were included in the Arup review, most of which were conducted in Denmark. Most of the studies were on road traffic noise, but some also considered railway and aircraft noise. As cancer is a new outcome in the field of noise and health, the authors suggest that it may be worth exploring the application of meta-analysis to the evidence for cancer, to estimate the association of noise with cancer across the studies. They caution that a few more studies per noise source and cancer outcome may be needed before this would be possible.
- 3.12 All the studies examining dementia were on road traffic noise, with the evidence being very low, or low quality, for the given outcome measures. Seven studies were included for reproductive outcomes, but there were no studies on aircraft noise. Nine studies on cognition were included, and the conclusions differed to those in the WHO review. For reading comprehension, the review undertaken for the WHO concluded that there was 'moderate quality evidence for an effect of aircraft noise on children's reading and oral comprehension' and 'low quality evidence for no substantial effect of road traffic noise on children's reading and oral comprehension'. The current review finds very low-quality evidence for an effect of aircraft noise and road traffic noise on children's reading comprehension. However, this reflects the smaller number of studies in the current review, despite the inclusion of methodologically robust studies such as NORAH. The authors explain that this is due to the type of methodology used having an impact on the GRADE system, but the additional aircraft noise studies identified in the past four years and the conclusions drawn from their review would not conflict with conclusions of the review undertaken for the WHO. The conclusions of the review undertaken for the WHO should be considered to stand given the Arup review's conclusions.
- 3.13 In conclusion, many of the conclusions from the WHO reviews remain unchanged. Some of the evidence for road traffic noise and railway noise has increased since 2018, for example there is now low-quality evidence for road traffic noise effects on medication use and interview measures of depression and anxiety. There is also low-quality evidence for an effect of road traffic noise on some cancers where previously there was none.
- 3.14 The authors stress that there was a low number of studies for many of the health and cognitive outcomes and a classification of low-quality evidence does not mean that there is no effect, but that more studies are required.

- 3.15 The second review report published by Defra was authored by **van Kamp et al**, from the National Institute for Public Health and the Environment (RIVM) in the Netherlands. The review related to evidence on environmental noise exposure and annoyance, sleep disturbance, cardiovascular and metabolic health outcomes.
- 3.16 RIVM investigated whether there is sufficient new evidence since publication of the 2018 WHO reviews, to update the literature that informs UK policy. As explained with the Arup review, since the systematic reviews that informed the WHO Guidelines were conducted in 2014, there have been more high-quality studies published. The WHO did not cover all of the sources relevant within the scope of the IGCB(N), which include, in addition to transport and wind turbine noise: industrial noise, neighbourhood and neighbour noise, and low frequency noise from building services. Defra commissioned the RIVM to advise them of any updates to the evidence base which may impact their current recommendations.
- 3.17 For environmental noise (road, rail, aircraft noise, wind turbines) in relation to annoyance and sleep disturbance, the selection process resulted in 25 studies on road traffic, 20 on aircraft noise, 14 on railway noise and 11 on wind turbines. For sleep disturbance, the overall results were not consistent with each other. Twelve of the studies were on aircraft noise, ten on road traffic noise and six on railway noise.
- 3.18 The outcomes of the review revealed that for aircraft noise, new evidence from the DEBATS (France) and NORAH study (Germany) in relation to sleep disturbance suggest an update. This could also be considered for road and rail traffic noise, although for these sources no large differences are to be expected as far as annoyance reactions are concerned. A separate meta-analysis on the objective measures is suggested. The new studies also provide more evidence on the role of the number of events and the L_{max} levels and it would be worthwhile comparing the outcomes from the different new studies including the different noise indicators.
- 3.19 For annoyance, thirteen of the studies were related to aircraft noise, ten to road traffic noise and eight to railway noise. As with sleep disturbance, in terms of aircraft noise the DEBATS and NORAH studies offer updated results.
- 3.20 For environmental noise (road, rail air traffic and wind turbines) in relation to cardiovascular and metabolic effect, 26 new studies were selected to be included in the review, with eight updated studies. The findings of the aircraft noise studies and their related health outcomes are summarised below.

Aircraft Noise and Hypertension

- 3.21 The literature search revealed three cross-sectional studies on aircraft noise and hypertension, one case control study and two cohort studies. Two of the studies

had been included in the WHO review, but now had been updated with new data. One of the cohort studies in Stockholm had updated their findings and now reported a significant association between aircraft noise and the incidence of hypertension, brought about by improvements to study methodology. A further small cohort study also found an increased risk of hypertension in relation to aircraft noise exposure.

Aircraft Noise and Ischemic Heart Disease (IHD)

3.22 Five studies were identified in the literature review, one ecological, three cohort studies and one case-control study. The association between aircraft noise and the incidence of IHD was investigated in two of the three cohorts and in the case control study; the association between aircraft noise and mortality due to IHD was investigated in one of the three cohorts and the case control study.

Aircraft Noise and Stroke

3.23 Five studies were found investigating the association between aircraft noise and stroke. The association between aircraft noise and the incidence of stroke was investigated in two of the three cohorts and in the case control study; the association between aircraft noise and mortality due to stroke was investigated in one of the three cohorts and the case control study.

Aircraft Noise and Diabetes

3.24 Two cohort studies were identified as part of the literature review on aircraft noise and diabetes. The researchers of the Swiss cohort study on Air Pollution and Lung and Heart Disease in Adults (SAPALDIA) found an association between aircraft noise and the incidence of diabetes. In contrast, a follow-up of the HYENA study on Greek participants found no association between aircraft noise and incidence of diabetes, though this was a relatively small sample size.

Aircraft Noise and Obesity

- 3.25 Two new cohort studies were found in the new literature search that examined the association between aircraft noise and obesity. The Stockholm Diabetes Preventive Program (SDPP) presented new results that confirmed their initial analysis; aircraft noise exposure was associated with increase in waist circumference. Weight gain, incidence of being overweight, and incidence of central obesity were all significantly associated with aircraft noise.
- 3.26 The report goes into detail for each of the noise sources and outcomes, and the results are presented in tables for each outcome. In conclusion, the RIVM report makes the following suggestions:
- Advocating for the IGCB(N) to consider taking the new evidence into account where appropriate.

- New meta-analyses could be conducted over a range of noise sources and effects.
- For annoyance, meta-analysis for all noise sources is possible. For aircraft noise-induced annoyance, due to the debate surrounding the selection of studies included in the WHO meta-analysis, consideration of the review and its consequences is suggested.
- For sleep-related effects, a meta-analysis for all transport sources is possible.
- For cardiovascular effects, all outcomes for some transport sources could be updated.
- New evidence warrants a meta-analysis for diabetes associated with road traffic and aircraft noise.

Chapter 4

Summary

- 4.1 This report has provided a summary of some of the main findings in the past six months (September 2019 to March 2020) with regards to aircraft noise and health effects. It has included relevant findings from the International Congress on Acoustics (ICA) in 2019, and a summary of the two recently-published reviews commissioned by Defra. We wait to see if Defra will update their current guidance on environmental noise and health impacts in light of these.
- 4.2 Summary reports such as these are published on a six-monthly basis and continue to include all health outcomes in relation to aircraft noise exposure. The next update report will contain findings from the ICBEN Congress planned to be held in June 2020 in Stockholm.

Chapter 5

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