Before an Independent Hearings Panel
appointed by the Waimakariri District Council

under: the Resource Management Act 1991

in the matter of: Submissions and further submissions in relation to the proposed Waimakariri District Plan, Variation 1 and Variation 2

and: Hearing Stream 7: Residential, Large Lot Residential, Ecosystems and Indigenous Biodiversity, Variation 1 and Variation 2

and: **Christchurch International Airport Limited**
Submitter 254

Statement of evidence of Professor Charlotte Clark (aviation noise and health)

Dated: 30 August 2024

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STATEMENT OF EVIDENCE OF PROFESSOR CHARLOTTE CLARK

1 My name is Professor Charlotte Clark.

2 I am a Professor of Environmental Epidemiology and psychologist, gaining my BSc (Hons) in Psychology from the University of Surrey in 1997 and my PhD in Environmental Psychology from the University of Surrey in 2001. I am a Chartered Psychologist and Fellow of the British Psychological Society, and a Member of the Institute of Acoustics (UK).

3 My areas of expertise are in the design and analyses of epidemiological research studies examining the effects of environmental noise on health, wellbeing, and learning, and synthesis of the evidence-base.

4 I am President of the International Commission on the Biological Effects of Noise (ICBEN) and have advised the World Health Organization, the UK Department for Environment, Food and Rural Affairs, and the UK Independent Commission for Civil Aviation Noise. I am currently the Principal Investigator of the £1.7M UK Department for Transport study of the effects of aviation night noise on sleep and annoyance (The ANNE Study) and previously co-managed the European Union funded RANCH study (Road traffic and Aircraft Noise effects on children's Cognition and Health).

5 I have undertaken influential evidence review and synthesis in the field of noise and health for the World Health Organization 2017 Environmental Noise Guidelines, and for the UK government. I also led the revision of (ISO/TS15666:2021, 2021), the international standard for assessing noise annoyance.

6 I prepared the report attached as **Appendix 1** on the evidence base for the effects of aviation noise on health. To the extent possible within my area of expertise, the report comments on the application of the evidence-base in the Christchurch context to assist with making future land use planning decisions for areas impacted by aircraft noise from Christchurch Airport.[1]

7 Although this is not an Environment Court hearing, I note that in preparing my evidence I have reviewed the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note 2023. I have complied with it in preparing my evidence on technical matters. I confirm that the technical matters on which I gave evidence are within my area of expertise, except where relying on the opinion or evidence of other witnesses. I have not omitted to

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[1] A full statement of my expertise and CV are included at page 4 and Annex 1 the report attached as Appendix 1.

consider material facts known to me that might alter or detract from my opinions expressed.

Dated: 30 August 2024

Professor Charlotte Clark

APPENDIX 1

Airport noise exposure and health effects

Information prepared by:
Charlotte Clark
Professor of Environmental Epidemiology
Population Health Research Institute
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Version 1.0 – 26 July 2024

Abbreviations

AMI	Acute Myocardial Infarction
CI	Confidence Interval
DALY	Disability-adjusted life year
dB	Decibel level
dBA	Decibel level (A-weighted)
ECG	Electrocardiography
EEG	Electroencephalography
EMG	Electromyography
ENG	Environmental Noise Guidelines
EOG	Electroculography
ERF	Exposure Response Function
GBD	Global Burden of Disease
GDG	Guideline Development Group
HA	"Highly annoyed", as defined by ISO/TS15666
ICAO	International Civil Aviation Organization
ICBEN	International Commission for the Biological Effects of Noise
ISO	International Organization for Standardization
L_{Aeq}	Average sound level (A-weighted)
L_{den}	Average sound exposure over the day, evening, and night-time period (A-weighted)
L_{dn}	Average sound exposure over the day and night-time period (A-weighted)
L_{max}	Maximum sound level (A-weighted) (s=slow)
L_{night}	Average sound level over the night-time period
NNG	Night Noise Guidelines
NZS	New Zealand Standard
PSG	Polysomnography
RANCH	Road traffic and Aircraft noise effects on children's Cognition and Health
SEL	Sound exposure level
SoNA	Survey of Noise Attitudes (UK)
SoNA 2014	Survey of Noise Attitudes 2014 (UK)
SPL	Sound pressure level
TS	Technical Specification
UK	United Kingdom
WHO	World Health Organization
WHO ENG 2018	World Health Organization Environmental Noise Guidelines for the European Region 2018
YLD	Years Lived with Disability
YLL	Years of Life Lost

TABLE OF CONTENTS

Statement of expertise

This report has been prepared by Professor Charlotte Clark, Population Health Research Institute, St George's, University of London, Cranmer Terrace, Tooting, London, SW17 0RE, United Kingdom.

Charlotte Clark is a Professor of Environmental Epidemiology and psychologist, gaining her BSc (Hons) in Psychology from the University of Surrey in 1997 and her PhD in Environmental Psychology from the University of Surrey in 2001. She is a Chartered Psychologist and Fellow of the British Psychological Society; and a Member of the Institute of Acoustics (UK). Her areas of expertise are in the design and analyses of epidemiological research studies examining the effects of environmental noise on health, wellbeing, and learning, and synthesis of the evidence-base. She is President of the International Commission for the Biological Effects of Noise (ICBEN) and has advised the World Health Organization, the UK Department for Environment, Food and Rural Affairs, and the UK Independent Commission for Civil Aviation Noise. She is currently Principal Investigator of the £1.7M UK Department for Transport study of the effects of aviation night noise on sleep and annoyance (The ANNE Study) and previously co-managed the European Union funded RANCH study (Road traffic and Aircraft Noise effects on children's Cognition and Health). She has undertaken influential evidence review and synthesis in the field of noise and health for the World Health Organization 2017 Environmental Noise Guidelines, and for the UK government. She led the revision of (ISO/TS15666:2021, 2021), the international standard for assessing noise annoyance.

Please see CV in Annex A.

Aviation noise and health

Introduction

I. Background Context

1. This report is intended to provide a summary of the evidence-base for the effects of aviation noise on health. It is understood that this report will be used to assist with making future land use planning decisions for areas impacted by aircraft noise from Christchurch Airport. In that respect, to the extent possible within my area of expertise, this report comments on the application of the evidence-base in the Christchurch context.

Evidence Review

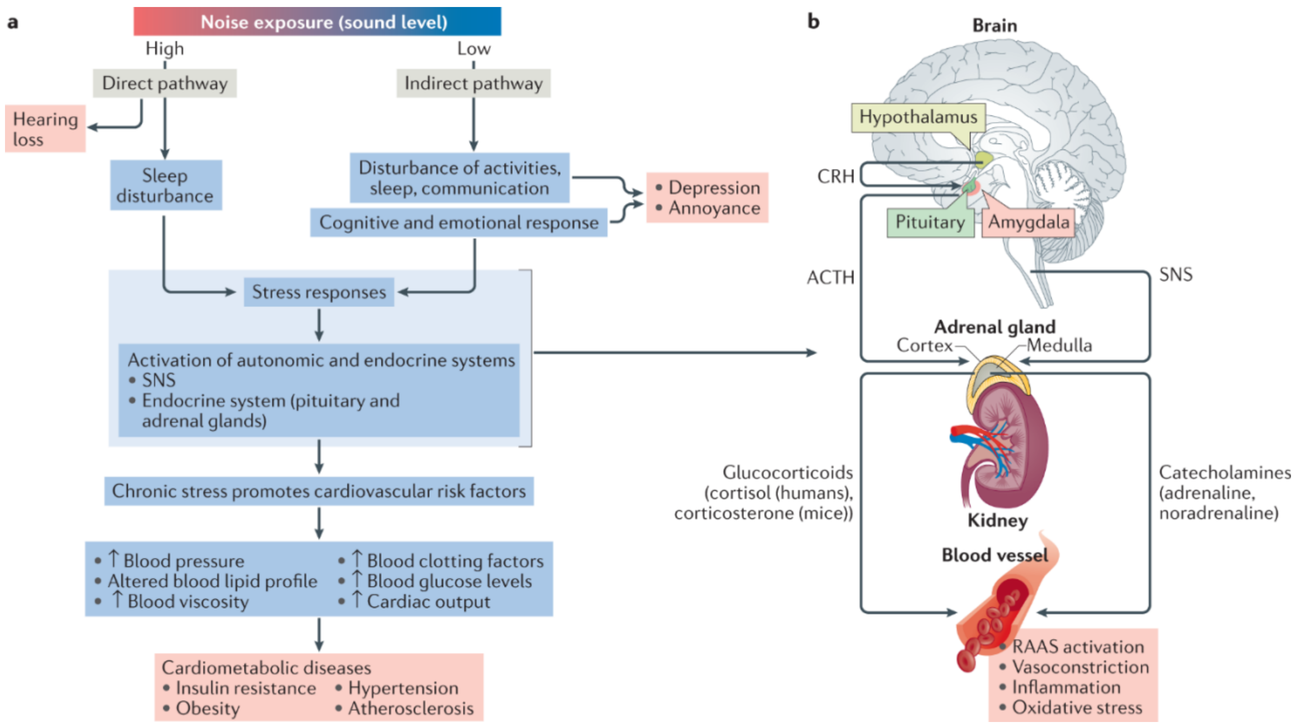
II. Overview of aviation noise effects on health and mechanisms

2. Environmental noise is accepted as a public health issue which has significant impacts on physical health, mental health, and wellbeing (European Environment Agency, 2020).

3. Environmental noise can influence health, as it can trigger biological responses in an individual. When sound enters the ears, it is also interpreted by the amygdala in the brain which handles endocrine and autonomic functions, and the flight or fight response. If the amygdala is overactivated by noise the endocrine system will increase levels of the stress hormones cortisol and adrenaline. The sympathetic nervous system will also be hyperactivated, resulting in a quickening heart rate, increases in blood pressure, the production of inflammatory cells, and a change in blood fats and blood glucose (Munzel et al., 2017; Munzel et al., 2018). If these biological responses are triggered over a long period (i.e., if exposure is chronic, over several years), they are risk factors for diseases such as diabetes, heart attacks and strokes. These biological responses can also influence mental health, and can also be triggered by annoyance and sleep disturbance associated with aircraft noise exposure.

4. Figure 1 below illustrates the mechanisms for how noise can influence health.

Figure 1: Mechanisms for noise effects on health (Münzel et al., 2021)



5. In terms of aviation noise specifically, the past two decades have seen an increase in evidence linking exposure to a range of health outcomes including annoyance (Guski et al., 2017), sleep disturbance (Basner, 2021; Basner & McGuire, 2018; Smith et al., 2022), cardiometabolic health (Münzel et al., 2021; van Kempen et al., 2018), children's learning (Clark, Head, et al., 2021; Clark & Paunović, 2018a), and mental health (Clark, Head, et al., 2021; Clark & Paunović, 2018b; Hegewald et al., 2020).

6. The following sections set out the evidence for effects of aviation noise on annoyance, sleep disturbance, cardiometabolic disease, mental health and children's learning, focusing on evidence from methodologically robust, higher quality studies and systematic reviews published in peer-reviewed journal papers or by reputable public health agencies, where possible. In general, evidence from systematic reviews is considered stronger than evidence from individual studies, as systematic reviews help us understand the strength of the evidence across studies and contexts. The evidence is then considered in light of the context of guidelines and thresholds for effects, and the Christchurch airport context.

III. Annoyance

7. Annoyance is one of the most prevalent community response and health effects in a population exposed to aircraft noise. The term annoyance describes negative reactions to noise such as disturbance, irritation, dissatisfaction, and nuisance (Guski, 1999). The European Environment Agency burden of disease assessment for noise effects in Europe in 2020 estimated noise annoyance to be the most significant health effect of environmental noise (road, rail, aircraft noise) (European Environment Agency, 2020), with 900 DALYs[1] (Disability-Adjusted Life Years) lost per year per million people. The assessment of noise annoyance in the home environment is undertaken using an International Organization for Standardization (ISO) Technical Specification, since 2003 (ISO/TS15666:2003, 2003; ISO/TS15666:2021, 2021). Whilst often

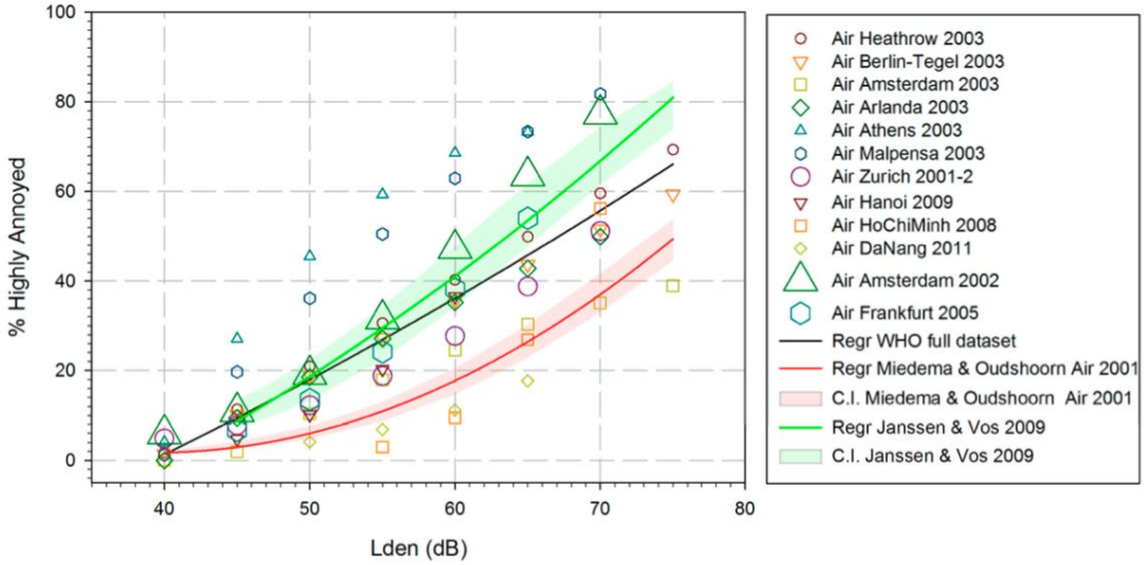
[1] One DALY represents the loss of the equivalent of one year of full health. DALYs for a disease or health condition are the sum of the years of life lost to due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population.

used to assess reactions to transportation noise, the TS can be used to assess annoyance in relation to a range of sound exposures in the home, such as neighbour noise, snoring, dogs barking (Notley et al., 2014), with the question focusing on longer-term exposure, usually over a 12 month-period, as opposed to during the event, itself.

8. Exposure-response functions (ERFs) showing the 'percentage highly annoyed' (%HA), assessed following Technical Standard which assesses noise annoyance in the home environment, plotted against noise exposure increasingly inform environmental and health impact assessments, guidance, as well as policy to protect public health. ERFs typically plot time-averaged metrics such as $L_{Aeq,16h}$, $L_{Aeq,8h}$, and L_{den} but are also starting to be published for event-based metrics such as the number of events above a certain decibel threshold.

9. In 2018 the WHO published an annoyance ERF (Guski et al., 2017), which informed the Environmental Noise Guidelines for the European Region (World Health Organization, 2018) (WHO ENG 2018). Guski et al. (2017) synthesised the evidence from 15 aircraft noise annoyance surveys published between 2000 and 2014 covering data from 17,094 respondents living near very small to international airports, ranging from 34 to 1200 flight movements per day estimating the %HA by L_{den} (see Figure 2, black line). Based on this evidence, the WHO set guidance for aircraft noise annoyance at 45dB L_{den}, as that was where the combined data across the studies suggested 10% of the population were highly annoyed. This level is acknowledged to be low. However, the evidence is increasingly establishing that effects of aircraft noise may be observed even at low levels of exposure.

Figure 2: Exposure-response function for aircraft noise exposure (L_{den}) and being highly annoyed from the WHO 2018 (Guski et al., 2017).



10. There has been much debate about the WHO 2018 data, analysis, and guidelines for aviation. Predicting or estimating annoyance at any given sound level has uncertainty, with wide-ranging estimates of annoyance being found for the same sound level across studies in the WHO ERF. For example, for the WHO 2018 data estimates for %HA at 60dB L_{den} range from ~15% to ~70%. Uncertainty is also associated with methodological differences in survey design (sampling, format of the survey (e.g., face to face, online, post), recruitment, population, range of exposure) but also in terms of how noise exposure is estimated; operational differences between airports (e.g. number of runways, night-flights, availability of respite) and non-acoustic factors (Clark, Gjestland, et al., 2021). Effects are likely to vary between contexts, with the WHO recommending the use of local data to estimate effects, where available (World Health Organization, 2018).

11. Further, the WHO analyses also found that for a given noise level, aircraft noise was ranked as more annoying at the same dB level, than road traffic noise and railway noise, indicating that noise annoyance depends not only on sound level, but on a range of other factors. This variation is also seen for other environmental noise sources, such as wind turbine noise, where annoyance responses are observed at much lower dB levels than for aircraft noise, road traffic noise or railway noise, with a recent review, estimating that at 35-40dB L_{Aeq} 11% were 'highly annoyed' and >40dB L_{Aeq} 21% were 'highly annoyed' (BEIS, 2023).

12. Acoustic factors, such as the source of the noise and sound level (in dB), account for only some of the annoyance response observed: other factors, referred to as non-acoustic factors, such as the fear associated with the noise source, interference with activities, ability to cope, noise sensitivity, expectations, anger, perceived fairness, attitudes to the source – both positive or negative, and beliefs about whether noise could be reduced by those responsible influence annoyance responses (WHO, 2000), as well as individual factors such as age, social disadvantage, and employment status (Civil Aviation Authority, 2021; Fenech et al., 2021; Notley et al., 2014)) or other environmental factors, such as ambient/background noise levels. These factors can considerably shift annoyance responses (Civil Aviation Authority, 2021).

13. More positive attitudes to the airport could potentially influence and lower an ERF. In the UK Survey of Noise Attitudes (SoNA 2014), high annoyance was associated not only with noise exposure, but also with noise sensitivity and expectations about aviation noise exposure next summer which were powerful modifiers of the ERF for aircraft noise annoyance adding 10 to 30% onto the estimates for being highly annoyed in the population (Civil Aviation Authority, 2021).

14. Evidence is starting to emerge about how changes in aircraft noise exposure associated with short-term changes in exposure caused by operational factors (e.g., runway alternation, operational modes) at the airport influence annoyance. This is referred to as 'respite' and the UK Air Navigation Guidance gives the following definition of respite: "The principle of noise respite is to provide planned and defined periods of perceptible noise relief to people living directly under a flight path." (Department for Transport, 2017). Analyses of SoNA 2014 for those living near London Heathrow airport, found that respite[2] due to changes in operational modes and runway alternation, was associated with a reduced likelihood of being highly annoyed. Respondents who experienced at least 9dB $L_{Aeq,8h}$ noise respite in the daytime were less likely to be highly annoyed, but this effect was not observed for those who received lower dB levels of respite. For residents experiencing no landing noise respite, 10% highly annoyed accorded with noise exposure of 52dB $L_{Aeq,16h}$. For residents experiencing at least 9dB $L_{Aeq,8h}$ noise respite, 10% highly annoyed accorded with a noise exposure of 59.5dB $L_{Aeq,8h}$, a shift of 7.5dB $L_{Aeq,16h}$ for the same annoyance response.

15. The SoNA 2014 analyses examined 'predictable respite' - that is scheduled short-term relief from aircraft operations for a few hours that occur for those living under flight paths, with these periods determined for two-week cycles for London Heathrow airport. Studies have yet to quantify how annoyance responses might be influenced by seasonality of operations for aviation noise. Many airports have periods when their operations increase or decrease due to demand, often associated with holiday/vacation seasons, or when meteorological conditions influence runway usage. Seasonality will also influence window opening behaviour, which influences noise exposure and health responses. In the UK a national survey is currently being conducted to quantify the influence of seasonality on annoyance responses for aviation noise.

16. Several international studies examining longer-term (permanent) change in aircraft noise exposure, including being newly overflown, airspace change, and runway alterations, have found that there is an excess annoyance response in relation to the change in noise exposure, both for increases and decreases in exposure (Brink et al., 2008; Brown & van Kamp, 2017; Fidell et al., 2002; Nguyen et al., 2018; Quehl et al., 2017). This means that when noise exposure increases

[2] Respite was defined as 'predictable periods of relief from aircraft noise'.

that the annoyance response is slightly higher than would be predicted from ERFs for the actual noise exposure. Studies from Switzerland and the Netherlands suggest that these excess-responses are not short-term but can endure for at least a couple of years, if not longer (Breugelmans et al., 2007; Brink et al., 2008). These studies included communities experiencing relatively small increases in aircraft noise exposure e.g., 1-2 dB L_{den} to larger increases e.g., 5-7dB L_{den}.

IV. Sleep disturbance

17. Sleep disturbance is a key health outcome in relation to aircraft noise exposure. Sleep is essential for good health, and it is recommended that adults should get seven to eight hours sleep each night (Watson et al., 2015; World Health Organization, 2009). The European Environment Agency burden of disease assessment for noise effects in Europe in 2020 estimated sleep disturbance to be the most second most significant health effect of environmental noise, after noise annoyance (European Environment Agency, 2020), with 800 DALYs lost per year per million people.

18. Measuring sleep is challenging, and studies have examined a broad range of outcomes. In terms of aircraft noise, two types of sleep outcomes have been examined (Basner & McGuire, 2018; Elmenhorst et al., 2019; Smith et al., 2022):

    - Subjective (self-reported) sleep disturbance which use questionnaires or diaries to assess an individual's perceptions of sleep quality and awakenings, and effects on mood or performance the next day, which are then related to external time-average noise metrics over several hours such as $L_{Aeq,8h}$ or L_{night}; and

    - Objective sleep disturbance which is assessed by recording biophysiological changes that occur during sleep and changes in sleep stages (e.g., awakenings, body movement, increases in heart rate and blood pressure) and related to event-based noise metrics such as indoor or outdoor L_{Amax} (e.g., did an aircraft noise event of a certain loudness cause an awakening), as well as time-average metrics (e.g., does the number of awakenings per night relate to the average noise exposure for that source over the night).

19. Polysomnography (PSG) records biophysiological changes that occur during sleep (Basner & McGuire, 2017). PSG is considered the Gold Standard methodology for assessing sleep and includes the measurement of brain waves using electroencephalography (EEG); eye movements using electroculography (EOG); muscle activity using electromyography (EMG). Polysomnography can also include measurement of heart rhythm using electrocardiography (ECG) and limb movements (indicative of sleep disturbance) using wrist-actimetry. This method can evaluate the sleep stages of an individual but is invasive, expensive, and time-consuming. More recent studies are using heart rate devices and actigraphy and can also infer sleep stages (Basner et al., 2019).

ERFs for aircraft noise effects on objective and subjective sleep disturbance were published to inform the WHO ENG 2018 (Basner & McGuire, 2018). For objective sleep disturbance the ERF plots the probability of an additional awakening by L_{Amax} level (Figure 3). The noise level at which the probability of an additional awakening began was around 37dB $L_{Amax,indoor}$. For subjective sleep disturbance the ERF plots the % of the population "highly sleep disturbed" by L_{night} (

20. Figure 4), showing that around 10% are highly sleep disturbed at 40dB L_{night}, rising to over 30% for exposures over 55dB L_{night}. The WHO review concluded that 'transportation noise affects objectively measured sleep physiology and subjectively assessed sleep disturbance in adults" and it is worth reflecting on the levels of sleep disturbance seen at even the lowest levels of aircraft noise exposure. The subjective data analyses were recently updated (Smith et al., 2022),

suggesting slightly stronger relationships between aircraft noise and sleep disturbance at higher levels of exposure.

21. Chronic exposure to aircraft noise during sleep can also lead to cardiovascular mortality, with robust longitudinal evidence for effects on ischaemic heart disease, acute myocardial infarction (AMI), and stroke, which is discussed in more detail in the next section (Saucy et al., 2021; Vienneau et al., 2022).

Figure 3: Probability of additional[3] sleep stage change to wake or sleep stage 1 in a 90 second window following an aircraft noise event depending on the maximum indoor sound pressure level (LAsmax) (Basner & McGuire, 2018)

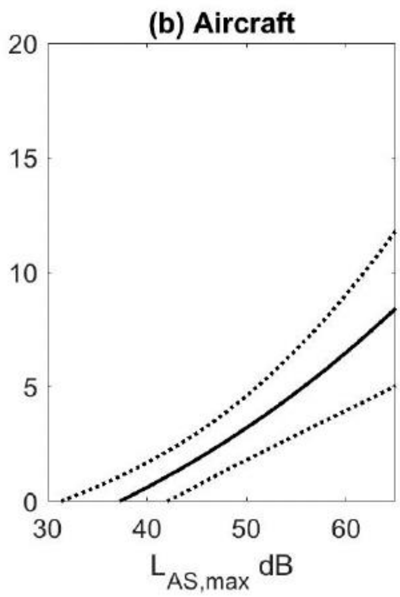
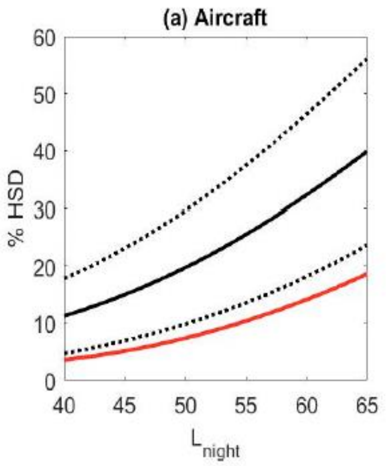


Figure 4: The percent highly sleep disturbed based on self-reported sleep disturbance for aircraft noise (outdoor) (red line is Miedema and Vos (2007) line)



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[3] For noise and health analyses, biological awakenings are referred to as 'additional' awakenings: this reflects that all humans experience a number of spontaneous biological awakenings per night and studies assess how noise events relate to 'additional' awakenings beyond that expected for the individual.

22. The health protection scheme proposed by Basner et al. (2006) to manage the risk of sleep disturbances associated with aircraft noise included the recommendation that on average there should be less than one additional EEG awakening induced by aircraft noise per night. This is an annualised metric, so there can be more than one additional EEG awakening per night if there are other nights when no additional EEG awakenings per night occur. Some airports, using this approach, plot 'awakening' contours for the local population, showing where there would be one or more additional awakening due to aircraft noise or how the awakening contours would change with operational changes to the airport. Awakening contours form an important additional tool for estimating and managing the effects of aviation night-noise. They take into account the noise level of individual aircraft noise events in the night-time period, taking consideration of health effects beyond time-average noise metrics which may not well represent exposure in terms of the noise level, distribution, and fleet mix of aircraft within the night-time period and variation by aircraft type (Civil Aviation Authority, 2022).

V. Cardiometabolic health

23. The importance of cardiometabolic health is well established, with cardiovascular disease and diabetes both having a considerable disease burden and being leading causes of death, worldwide (GBD 2021 Diabetes Collaborators, 2023; Mensah et al., 2023). Risk factors for these diseases include genetic and lifestyle factors, but it is increasingly acknowledged that environmental factors, including long-term environmental noise exposure contribute to risk. Noise is hypothesised to increase risk factors for poorer cardiovascular health, such as blood pressure (hypertension), stiffening of the arteries, and narrowing of arteries via effects on blood fats (atherosclerosis), which can lead to heart attacks and strokes (Munzel et al., 2017; Munzel et al., 2018). These factors are also risk factors for diabetes, and additionally stress can cause long-term elevation of cortisol, which increases a number of risk factors for diabetes including blood glucose and insulin resistance.

24. The European Environment Agency burden of disease assessment for noise effects in Europe in 2020 estimated ischaemic heart disease to be the most third most significant health effect of environmental noise, after noise annoyance and sleep disturbance (European Environment Agency, 2020), with 300 DALYs lost per year per million people.

25. Recent studies also suggest noise exposure might influence physical activity, which is plausible both via poorer cardiometabolic health which could reduce exercise but also via the potential for noisier environments to be less attractive for exercise. A study found that noise annoyance was associated with lower levels of physical activity (Foraster et al., 2016). As previously mentioned, sleep disturbance also contributes to the biological and stress responses which can influence cardiometabolic health.

26. There are several ERFs for aircraft noise and cardiometabolic outcomes available which find statistically significant increases in risk for a range of cardiovascular outcomes including AMI, coronary heart disease, and cardiovascular disease, as well as on cardiovascular risk factors such as hypertension, diabetes, and obesity (van Kempen et al., 2018; Vienneau et al., 2022; Vienneau et al., 2015). The systematic review carried out for the WHO ENG 2018 estimated that a 10dB L_{den} increase in aircraft noise was associated with a 9% (95%CI 4-15%) increase in risk for ischaemic heart disease, with an earlier review suggesting a similar effect of 6% (95%CI 4-8%) (Vienneau et al., 2015). These increased risks are acknowledged to be moderate compared to some other risks for cardiometabolic ill-health but could be important if a large population and also vulnerable groups are exposed.

VI. Mental health, quality of life and wellbeing

27. Noise as an environmental stressor can also impact mental health, wellbeing, and quality of life, both directly through influencing stress hormones which impact mood, but also indirectly through stress associated with annoyance and sleep disturbance.

28. A systematic review which combined estimates from five studies, found that a 10dB L_{den} increase in aircraft noise was associated with a 12% increase in risk for depression (95%CI 2-23%) (Hegewald et al., 2020).

29. Children's mental health can also be influenced by aviation noise, with several studies finding that aircraft noise is associated with small increases in hyperactivity symptoms (Clark, Head, et al., 2021; Clark & Paunović, 2018a).

30. In considering noise effects on mental health, it is also necessary to consider how other factors might also be important, namely noise annoyance, noise sensitivity, and existing mental health. A systematic review found that being highly annoyed, as opposed to noise exposure per se, was associated with a 23% increase in risk for depression, a 55% increase in risk of anxiety, and a 119% increase in risk for poor mental health (Gong et al., 2022) This illustrates the importance of noise annoyance not only as a health effect in its own right, but also as a risk factor for poor mental health. Noise sensitivity, defined as a stable trait that influences an individual's reactivity to noise, may also increase effects of noise on mental health, and vice versa (Cerletti et al., 2020; Stansfeld et al., 2021). A systematic review found that both noise annoyance and noise sensitivity were associated with use of anxiety/sleep medication, with no association observed for noise exposure (Baudin et al., 2021). Further, those experiencing poor mental health may also be more sensitive to noise and environmental stressors, so might be more vulnerable (Nordin et al., 2013).

31. Evidence is emerging to support a relationship between environmental noise and neurodegenerative outcomes and cognitive impairment such as dementia in later life (Cantuaria et al., 2021), which could be explained by damage to blood vessels in the brain (e.g., vascular dementia) or via inflammation associated with stress.

VII. Children's learning

32. There is robust evidence that aviation noise at school affects children's learning. The RANCH (Road traffic and Aircraft noise effects on children's Cognition & Health) study of over 2000 8-9 year old children attending schools around London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports found that aircraft noise at school was associated with poorer reading comprehension, as well as with annoyance responses (Clark et al., 2006; Stansfeld et al., 2005). A UK meta-analysis of three studies around London Heathrow airport, including the RANCH data estimated that a 10dB $L_{Aeq,16h}$ increase in aircraft noise at school was associated with a 40% increase in odds of scoring well below or below average on a reading test (Clark, Head, et al., 2021). Reading fell below average levels at around 57dB $L_{Aeq,16}$. Studies also find effects for aircraft noise for L_{Amax}, number of events and time above noise metrics (Sharp et al., 2014). Aircraft noise exposure at home shows similar effects on children's learning (Stansfeld et al., 2010).

33. Environmental noise can influence children's learning and health in many ways including via communication difficulties, impaired attention, increased arousal, learned helplessness, frustration, biological stress responses, noise annoyance, and as a consequence of sleep disturbance on performance (Clark & Paunović, 2018a). A study conducted in schools around Los Angeles airport found that there were a greater number of instances of teachers raising their voices and their voices being masked during aircraft noise events (Eagan et al., 2017).

34. A study that examined the relocation of Munich airport, found that children who were newly exposed to aircraft noise developed poorer cognition over time and that cognition improved for those who were no longer exposed to aircraft noise (Hygge et al., 2002). An American study found that performance on standardised test scores improved after insulation works within the school (Sharp et al., 2014).

VIII. Social inequality

35. It is hypothesised that those from lower socioeconomic status experience greater exposure to noise, which alongside increased vulnerability to poorer health, and the availability of fewer resources (coping behaviours) and poorer conditions (e.g., poor housing; less access to quiet areas) increases the risk for health related impacts of noise. (European Commission, 2016). A recent review by the European Environment Agency (2020) concluded that

"exposure to environmental noise does not affect everyone equally. Socially deprived groups as well as groups with increased susceptibility to noise may suffer more pronounced health-related impacts of noise."

36. Reviews suggest that other groups within society may also be vulnerable to the effects of aircraft noise on annoyance or health outcomes including the elderly, shift workers, children those with pre-existing ill-health, pregnant women, and those who are noise sensitive (European Environment Agency, 2020; Tarnopolsky et al., 1980; van Kamp & Davies, 2013). Reasons for increased vulnerability include increased risk for poorer health, spending more time at home, sleeping at times outside of the typical night-time period, and poorer coping capacities. Some recent studies suggest that ethnic minorities tend to be exposed to higher levels of environmental noise (Casey et al., 2017; Tonne et al., 2018) but again, such effects are likely to be strongly context dependent and need further study. Some ethnic groups also have much higher rates of cardiometabolic ill-health which may also contribute to vulnerability. Applying the evidence to protect public health in the New Zealand context

37. This section considers approaches and methods which have been applied to interpreting the evidence base for the effects of aviation noise on health to set and/or identify thresholds to protect and promote public health, and also interprets the findings of the evidence review above, in relation to the Christchurch airport context.

IX. WHO Environmental Noise Guidelines 2018

38. The WHO ENG 2018 provide recommendations for protecting human health from exposure to aircraft noise (World Health Organization, 2018). The WHO ENG 2018 partially superseded the WHO Community Noise Guidelines 1999 (World Health Organization, 1999) but do not supersede the Night Noise Guidelines, 2009 (World Health Organization, 2009) (WHO NNG). The WHO ENG 2018 were informed by a number of systematic reviews, summarising the strength of the evidence for noise effects on health, as well as a review of interventions (Brown & van Kamp, 2017).

39. The WHO recommended that:

"For average noise exposure, the GDG (Guideline Development Group) strongly recommends reducing noise levels produced by aircraft below 45dB L_{den}, as aircraft noise above this level is associated with health effects. For night noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft during night time below 40 dB L_{night}, as aircraft noise above this level is associated with adverse effects on sleep."

These levels represent those at which 10% of the population will be 'highly annoyed' for L_{den} and at which 11% of the population would report being 'highly sleep disturbed' for L_{night}.

40. There has been debate about the WHO guideline levels (Gjestland, 2018; Guski et al., 2019) and concerns that the Guidelines were not informed by a socio-economic assessment of the impact of setting these levels economically on the aviation industry and society. However, the guidelines are based on an established methodology used by the WHO. In Europe, a recent addition to the European Noise Directive requires that member countries estimate the WHO ERFs for % highly annoyed, % highly sleep disturbed and ischaemic heart disease to report the harmful effects of environmental noise for road, railway, and aviation noise (EU Directive, 2020).

Figure 5: summary of the WHO ENG 2018 for Aircraft Noise

Aircraft noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft below **45 dB** L_{den}, as aircraft noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft during night time below **40 dB** L_{night}, as night-time aircraft noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions the GDG recommends implementing suitable changes in infrastructure.	Strong

X. Thresholds & Mitigation

41. Increasingly evidence for the effects of aviation noise on health effects is considered in relation to 'thresholds' for effects, to ensure the planning system protects and promotes public health (e.g. Environmental Impact Assessments & Health Impact Assessments). Different approaches have been taken for setting and identifying thresholds, but all adopt a precautionary, public health focused approach focusing on where effects start, as opposed to setting 'limits' for the highest level of exposure. In fact, most thresholds are based on the evidence for effects of noise on annoyance and sleep disturbance, with daytime or 24 hour exposure thresholds linked to evidence for annoyance, and nighttime exposure thresholds based on evidence for sleep disturbance.

42. The WHO Environmental Noise Guidelines 2018 (WHO ENG 2018) (World Health Organization, 2018) whilst informed by systematic reviews of a range of health outcomes including annoyance, sleep disturbance, ischaemic heart disease, permanent hearing impairment, and reading skills in children, were based on where 10% of the population were 'highly annoyed' and 11% of the population were 'highly sleep disturbed''. The WHO identified the 'lowest' threshold across the health outcomes examined, therefore, adherence to the guidelines should protect across a range of health outcomes in the population, and not just protect from annoyance and sleep disturbance. The European Environment Agency also highlighted that annoyance and sleep disturbance are both also a pathway to cardiometabolic diseases (European Environment Agency, 2020), which further supports the idea that addressing annoyance and sleep disturbance can addresses other health outcomes.

43. The WHO further suggested that

    "The WHO guideline values are public health-oriented recommendations, based on scientific evidence on health effects and on an assessment of achievable noise levels. They are strongly recommended and as such should serve as the basis for a policy-making process in which policy options are quantified and discussed. It should be recognized that in that process additional considerations of costs, feasibility, values and preferences should also feature in decision-making when choosing reference values such as noise limits for a possible standard or legislation." (Page 29 of the WHO ENG 2018.)

44. The WHO Night Noise Guidelines (World Health Organization, 2009) set a guideline of 40dB L_{night} to protect the public, including the most vulnerable groups such as children, the chronically

ill and the elderly, with an interim target of 55dB for countries who cannot achieve the target in the short-term and who are adopting a step-wise approach.

45. In England, The Noise Policy Statement for England (Department for Environment Food and Rural Affairs, 2010) adopts a toxicological approach for use in planning, requiring the setting of a 'Lowest Observed Adverse Effect Level' (LOAEL value) and a Significant Observed Adverse Effect Level (SOAEL value) for each individual scheme. These are defined as

- LOAEL value - "above this level the average person will begin to experience observable, or measurable, adverse effects on health and quality of life as a result of noise exposure."
- SOAEL value – "above this level significant adverse effects on health and quality of life from noise exposure can begin to be observed in an average person."

46. So, whilst different methods have and can be used to identify thresholds for effects, all the approaches aim to minimise and avoid population exposure to the noise source, as their start point. This argument is further strengthened, **given the difficulties and challenges of mitigating aviation noise** once it is present. It is also important to realise that there is no one 'mitigation' or 'fix' and that a multiple intervention approach is required for aviation noise. It should not be underestimated how difficult it is to mitigate aircraft noise exposure. Whilst the industry has reduced noise emissions as the fleet has modernised, further scope to reduce noise is likely to be limited. Further, slightly quieter planes have often gone alongside a significant increase in flight numbers, thereby often failing to reduce noise exposure in local communities. Communities grow tired of the 'quieter planes' rhetoric given the time for fleet modernisation to take place; the small reductions in noise that are generally achieved per flight; and the use of Performance Based Navigation which is perceived to concentrate flights within communities. **Mitigation should be a last resort and relied upon within the planning process sparingly.**

47. Acknowledging aircraft noise as the most significant cause of adverse community reaction to the operation and expansion of airports, ICAO state that limiting or reducing the number of people affected by significant aircraft noise as one of their main priorities and a key environmental goal (International Civil Aviation Organization, 2008). The ICAO Balanced Approach sets out how noise reduction should be managed by four principal elements (see below), with restrictions only to be considered when other options have been exhausted (International Civil Aviation Organization, 2008).

- Reduction of noise at source;
- Land-use planning and management;
- Noise abatement operational procedures; and
- Operating restrictions on aircraft,

48. Further, the WHO review of interventions for noise effects on health identified four types of interventions (Brown & van Kamp, 2017) which can be summarised as:

- reduction at source (e.g., regulation of emissions, curfews);
- path interventions (e.g., noise insulation);
- new/closed infrastructure (e.g., airspace design, urban planning); and
- other physical interventions (e.g., access to quiet, access to greenspace).

The WHO ENG 2018 recommendation in terms of interventions for aviation noise was 'implementing suitable changes in infrastructure', such as operational changes to runways and airspace, but which also included planning controls between receivers and sources of noise.

XI. Relevance for Christchurch context:

49. Christchurch Airport operates 24 hours per day, 7 days per week. As an international airport, Christchurch Airport is in a unique situation in that from the start, due to the relatively low density of development surrounding the airport, land uses around the airport have been able to be proactively managed.

50. The national standard, NZS 6805:1992 , "uses the airport boundary concepts as a mechanism for local authorities to establish compatible land use planning and to set limits for the management of aircraft noise at airports where noise control measures are needed to protect health and amenity values."

51. The current planning framework for Christchurch Airport was developed generally in accordance with NZS 6805:1992 . This includes an Outer Control Boundary set at 50dB Ldn. The planning framework currently contains a policy of "avoid new noise sensitive activities within the 50dB Ldn". This level is the threshold for where the use of land impacted by aircraft noise needs to be managed in relation to effects on amenity and community health.

52. I note that the evidence for the effects of aviation noise on health used to inform NZS 6805:1992 has increased considerably over the last few decades. Future land use planning decisions for areas impacted by aircraft noise from Christchurch Airport need to consider the evolving and increasing evidence that points to health effects at low levels of aircraft noise exposure.

53. In terms of **annoyance**, the current threshold of 'avoiding new noise sensitive activities within the 50dB Ldn contour is contributing to reducing levels of noise annoyance in the population. The threshold is a little higher than the WHO ENG 2018 guideline of 45dB Lden, which was set based on 10% of the population being highly annoyed. Whilst a slightly lower threshold would be supported by the health evidence, thresholds also have to consider the social and economic benefits of operating an airport, as well as costs, feasibility, values and preferences (World Health Organization, 2018). In terms of building in the 50dB Ldn contour, any new homes built near the airport could carry the risk of excess annoyance responses if the residents are newly exposed to aircraft noise, i.e., previously lived in areas without aircraft noise – that is annoyance responses being higher than would be predicted by the noise exposure, per se. Evidence finds that relatively small changes in noise exposure can magnify annoyance responses.

54. In terms of estimating the effects, given the relatively small population exposed to aircraft noise around Christchurch, and in New Zealand in general, no local estimates (ERF) for annoyance are available. Therefore, the WHO generalised curve from the WHO ENG 2018 should be relied on, which was established from studies across a range of contexts including very small to large airports. The WHO generalised curve shows that increasing the population exposed to aircraft noise above 45 dB L_{den} would harm public health via annoyance effects. It follows that this would result in increased health costs or increase pressure to reduce noise through restrictions on airport operations. Acoustic insulation cannot mitigate effects in people's gardens or in other outdoor community facilities. Further, the airport's community relations are likely be negatively impacted by bringing the population nearer, which could bring challenge to further and future development of the airport and its operation, as well as require increased focus and investment in community relations.

55. In terms of **sleep disturbance**, as Christchurch Airport operates 24 hours a day, the current Outer Control Boundary and Air Noise Boundary are likely to be greatly contributing to reducing the population experiencing more than one additional awakening per night. Should these zones be reduced in size or lost, the awakening contours for the airport are likely to increase considerably and impacts on public health will increase. Sleep disturbance in the population is a key driver for community concerns and would likely increase pressure to curtail night-time operations.

56. In terms of **children's learning,** thresholds for effects, the RANCH study found that reading fell below average at 57dB $L_{Aeq,16}$. However, the relationship between aircraft noise and poorer

reading was linear, with no clear point at which effects 'began'. This suggests that any reduction of aircraft noise at school, regardless of the level of exposure, per se, would improve children's learning. Aircraft noise exposure at schools should be kept as low as possible. In terms of mitigation of aircraft noise at school this should be avoided. These are costly interventions to have to undertake, with location of school and learning environments best and most effectively managed via land use planning. Noise mitigation of school buildings is usually bespoke for each school, given variation in school building types and age, and requires ongoing maintenance, adding time, complexity, and expense to the process. Typically roof insulation, door insulation, and glazing would be provided, where they can be retrofitted (it is likely that not all school buildings can receive all of these treatments). Further, once classrooms are insulated, provision will usually have to be made for ventilation, which can add further complexity and ongoing running costs. Staff in the school may also still open windows as often people prefer to ventilate using windows than relying on ventilation systems which operate when the windows are closed. Staff often need training in how to use the building once noise mitigation and ventilation have been installed. Noise mitigation does not reduce noise exposure in outdoor areas where children spend a considerable amount of their school day playing and learning. Heathrow airport provided Adobe huts for schools in which children could play and be taught, but such provisions can only be used by a small number of children within a school at one point in time. In short, it is extremely challenging to mitigate aircraft noise exposure for children in schools. Land-use planning, avoiding aviation noise exposure in schools should be the promoted approach.

57. In terms of **social inequality,** in the absence of specific evidence for the New Zealand context a precautionary approach would acknowledge socioeconomic, health, and ethnic inequalities as vulnerability factors for the effects of aircraft noise exposure.

58. The ICAO Balanced Approach provides a framework for reducing aircraft noise exposure through multiple measures including land use planning. Christchurch Airport is in the unusual position to have operated under planning controls that have dramatically restricted the population exposed to aircraft noise. Urban planning has played a critical role here. It is one of the most effective mitigation methods for aviation noise, in general. Christchurch is in an enviable and unusual position in that it has protected areas defined by planning that protect community health. These should be maintained. Most international airports would want to be in this position but are unlikely to ever be in this position given existing development around their airports, and often, the lack of land use planning around their airports as they developed.

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Annex A: Curriculum Vitae

Charlotte Clark

Current Role

Professor of Environmental Epidemiology/ Institute Director

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Years of Experience

20+

Qualifications

Fellow British Psychological Society

Member Institute of Acoustics UK

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PhD Psychology University of Surrey (1997-2001)

BSc Psychology (Hons) University of Surrey (1993-1997)

Selected Publications

Clark, C. et al (2021). Assessing community noise annoyance: A review of two decades of the international technical specification ISO/TS 15666:2003. *Journal of the Acoustical Society of America*.

Clark, C. et al (2021). A meta-analysis the association of aircraft noise at school on children's reading comprehension and psychological health for use in Health Impact Assessment. *Journal of Environmental Psychology.*

Clark, C. et al (2020). Evidence for Environmental noise effects on health for the United Kingdom Policy Context: A Systematic review of the effects of environmental noise on mental health, wellbeing, quality of life, cancer, dementia, birth, reproductive outcomes, and cognition. *International Journal of Environmental Research and Public Health.*

Clark, C. & Paunović, K. (2018). WHO Environmental Noise Guidelines for the European Region: Systematic review of the evidence on the effects of environmental noise on mental health, wellbeing and quality of life. *International Journal of Environmental Research and Public Health.*

Charlotte is an expert in applying social science to the problem of noise effects on health and communities. She leads the design and analysis of surveys and psychoacoustic studies to assess the health and quality of life impacts of noise. She has produced influential evidence reviews on the effects of environmental noise on health, wellbeing and learning for the World Health Organization, the International Civil Aviation Organization and the Department for Environment (UK). She has advised on the health impacts of large infrastructure projects and was the sole advisor for the UK Airport Commission on the noise and health effects of the proposed runway expansion schemes (2013-2015). She is experienced at engaging with statutory consultees, communities and stakeholders. She has published over 80 papers in the field of environmental noise and health epidemiology and analysed National Noise Attitude Surveys. She is President of the International Commission on Biological Effects of Noise (ICBEN).

Charlotte has an international reputation for conducting robust policy relevant research on the effects of environmental noise on health, wellbeing, and quality of life.

Selected Activities

Sustainability Panel (Civil Aviation Authority) (2022-present) **–** appointed member of expert group advising on balancing carbon, noise, and air quality needs for sustainable aviation.

Aviation Night Noise Effects (Dept for Transport) (2022-2025) – leading £1.7M research study examining aviation night noise effects on subjective and objective sleep disturbance to inform policy. This includes a survey of annoyance and self-reported sleep disturbance for 4,000 residents to derive national exposure-response relationships.

Heathrow School Noise Insulation Study (Heathrow Airport/NIHR)) (2024-2027) – leading £750K research study examining the effect of Heathrow's noise insulation scheme of schools on children's learning and wellbeing.

ISO/TS15666 (WG 62) (2017- 2021) – project lead for the international team revising the 2003 standard 'Acoustics – Assessment of noise annoyance by means of social and socio-acoustic surveys.

Independent Commission on Civil Aviation Noise (UK) (2019- 2021) – member of expert panel advising the Commission on noise and health effects evidence, research needs, and stakeholder engagement.

High Speed 2 Railway Health - Research Advisory for epidemiological study (2019-present) – designed study scope and supporting HS2 to assess potential health impacts of Phase 2a on local communities.

Department for Environment, Food and Rural Affairs (UK) (2019) undertook systematic review of the noise effects on health to inform update to the UK's transportation noise and health monetisation tool.

Heathrow Airport Expansion, UK (2017- 2020) – Led assessment on noise effects of the third runway expansion (aircraft noise, ground noise, road traffic, railway noise) on health. Managed relationships with statutory consultee stakeholders and local communities.

World Health Organization Europe – Environmental Noise Guidelines for the European Region (2014-2018) – Led systematic reviews of the cognitive and mental health, wellbeing, and quality of life effects of environmental noise to inform the guideline revision.