Implication of Aircraft Noise on Workers in Port Harcourt International Airport Omuagwa Rivers State

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Abstract
This paper describes the recent development on aircraft noise and the health consequences associated as a result of being exposed to it. The results connote that there a strong interference between aircraft noise and adverse health effects that develops as a result of exposure to it. The course of this paper is to analyse the findings that are involved which includes: Environmental Noise, Measurement of Noise, The Concept of Aircraft Noise, Sound production, Mechanism of Sound Production which is divided into three categories namely; Engine and other mechanical noise, Aerodynamic noise, Noise from aircraft systems. Other concepts are; Effects of Aircraft Noise on human health which are; cardiovascular health effect, sleep disturbance, annoyance, psychological health. Diseases associated with long time exposure to Aircraft Noise include; effects of noise on low birth weight and prematurity, endocrine responses to noise exposure, blood pressure responses to noise exposure, annoyance, noise-Induced hearing loss, noise and sleep disturbance in children, noise and psychological health in children, quality of life and well-being, psychiatric disorders and noise exposure, noise and cognitive impairment in children. Finally, recommendations were made alongside with ways of reducing the effects of noise and control measures.

Keyword: *implication, aircraft, noise*

INTRODUCTION

The report aims to provide an update to the Environmental and Research Consultancy Department Report 0907 entitled Environmental Noise and Health Effects. Published in 2009, that report examined the evidence to date relating to transportation noise, in particular aircraft noise and the resulting impacts on various health endpoints. These included cardiovascular disease, night-time effects on sleep disturbance, children's cognition, psychological effects, performance and annoyance.

Aircraft noise and health effects is a rapidly growing area of research worldwide, and there have been many important findings published in recent years. Of particular importance has been the European Network of Noise and Health (ENNAH), which has connected researchers in the field throughout Europe to critically assess the current evidence base and identify gaps in the knowledge as well as suggesting directions for future research. The World Health Organisation (WHO) published their Burden of Disease from Environmental Noise report, which has enabled the calculation of healthy life years lost due to environmental noise which is very important for decisions on policy making. The European Environment Agency

published their good practice guide on noise exposure and potential health effects which included important exposure-response relationships and thresholds for health endpoints and the Health and Safety Laboratory, through a Defra contract, produced their work on quantifying the links between environmental noise related hypertension and health effects.
In 2015 a review of aircraft noise and health effects by Charlotte Clark was published alongside the Airports Commission's final report on increasing airport capacity in the UK. The review was focused on the current state of knowledge concerning the effects of aircraft noise on a range of health outcomes, and the subsequent potential effects on exposed populations for three different expansion options. The review concluded that there is increasing evidence to support preventive measures such as insulation, policy, guidelines and limit values. Priorities for minimizing the effects of aircraft noise should be focused on reducing annoyance, improving school environments for children and aiming to lower cardiovascular risk factors.
In addition to these key publications there have been many more studies into aviation noise and health findings between 2009 and 2015 and will highlight areas that are considered important for future research The scope of this paper will focus around the cardiovascular impacts, sleep disturbance and children's learning with other areas such as performance and psychological effects being included. Although annoyance is often considered a health effect, for the purpose of this paper it will not be included as a single end point health effect, but of course it is appreciated that annoyance may be an important mediator in the relationship between aircraft noise, stress and various health endpoints such as cardiovascular disease. A dedicated CAP report on the current knowledge on aircraft noise and annoyance is planned.

Environmental Noise

Noise pollution, also known as environmental noise or sound pollution, is the propagation of noise with ranging impacts on the activity of human or animal life, most of them harmful to a degree. The source of outdoor noise worldwide is mainly caused by machines, transport, and propagation systems. (Senate Public Works Committee, 1972), (Basner, Mathias; McGuire, Sarah 2018). Poor urban planning may give rise to noise disintegration or pollution, side-by-side industrial and residential buildings can result in noise pollution in the residential areas. Some of the main sources of noise in residential areas include loud music, transportation (traffic, rail, airplanes, etc.), lawn care maintenance, construction, electrical generators, explosions, and people.
Documented problems associated with noise in urban environments go back as far as ancient Rome. (Baudin, Clémence; Lefèvre, Marie; 2018).Today, the average noise level of 98 decibels (dB) exceeds the WHO value of 50 dB allowed for residential areas, (Bernie Baldwin 2017). Research suggests that noise pollution the United States is the highest in low-income and racial minority neighborhoods (Aircraft Airframe Noise 2008), and noise pollution associated with household electricity generators is an emerging environmental degradation in many developing nations.
High noise levels can contribute to cardiovascular effects in humans and an increased incidence of coronary artery disease. (Münzel, Schmidt, Steven 2018) (Hoffmann, Moebus, Stang 2006) In animals, noise can increase the risk of death by altering predator or prey detection and avoidance, interfere with reproduction and navigation, and contribute to permanent hearing loss, (Results and Discussion – Effects 2015). A substantial amount of the noise that humans produce occurs in the ocean. Up until recently, most research on noise impacts has been focused on marine mammals, and to a lesser degree, fish, (Results and Discussion Effects 2015), (Kershaw 2006). In the past few years, scientists have shifted to conducting studies on invertebrates and their responses to anthropogenic sounds in the marine environment. This research is essential, especially considering that invertebrates make up 75%

of marine species, and thus compose a large percentage of ocean food webs, (Kershaw 2006). Of the studies that have been conducted, a sizable variety in families of invertebrates have been represented in the research. A variation in the complexity of their sensory systems exists, which allows scientists to study a range of characteristics and develop a better understanding of anthropogenic noise impacts on living organisms.

Measurement of Noise

External noise exposure metrics are generally used in studies of noise effects on children's health. These measure the average sound pressure over a specific period using dBA as the unit (dBA is the unit of A-weighted sound pressure level in decibels where A-weighted means that the sound pressure levels in various frequency bands across the audible range have been weighted in accordance with differences in human hearing sensitivity at different frequencies), (Clark, Stansfeld, 2011) and (Kuczaj, Wright, Highfill 2007). L Aeq16 and L day indicating noise exposure over a 16-h daytime period are the most often used. The daytime period is most often defined 7 am–11 pm; L night indicating night-time noise exposure (11 pm–7 am); and L dn that is a combination of day-time and night-time noise exposure averaged over 24 h. This includes a 10-dB penalty added to the night-time indicator. The 10-dB penalty reflects people's greater sensitivity to noise exposure at night, and assumes that the effects of noise at night are equivalent to 10 dB more than the same level of exposure during the daytime. In recent studies, noise modelling is used employing geographical information systems, whilst older studies as well as some contemporary studies measure community noise exposure. Direct measurements over brief time periods can be less reliable because noise levels often vary by time of day, and short-term measures may not accurately capture long-term average exposure. More recently, there has been a trend towards measuring exposure to maximum noise levels (e.g. L Amax). It is still not certain whether the 'dose' of overall sound energy, the number of events or the peak sound pressure level of key events is most important for human health effects, (Clark, Stansfeld, 2011), These are relevant distinctions as, for instance, the number of aircraft overflights and cars on the road are increasing, whilst individual noise emission levels for each event are declining.

'Noise' is usually used to refer to the child's exposure to sound in research on non-auditory effects of noise exposure. This term is used, for both high and low exposure: lower levels in, particular may strictly be better described using the term sound. Noise typically implies that the sound exposure is unwanted and that it is a source of environmental stress. We follow this convention in our review.

The Concept Aircraft Noise

Aircraft noise pollution refers to noise produced by aircraft in flight that has been associated with several negative stress-mediated health effects, from sleep disorders to cardiovascular ones, (Nassur, Ali-Mohamed; Léger, 2019), (Basner, Mathias; McGuire, Sarah 2017) and (Baudin, Clémence; Lefèvre, Marie; 2018). Governments have enacted extensive controls that apply to aircraft designers, manufacturers, and operators, resulting in improved procedures and cuts in pollution.

Sound production is divided into three categories:

Mechanical noise—rotation of the engine parts, most noticeable when fan blades reach supersonic speeds.

Aerodynamic noise—from the airflow around the surfaces of the aircraft, especially when flying low at high speeds.

Noise from aircraft systems—cockpit and cabin pressurization and conditioning systems, and Auxiliary Power units.

Mechanism of Sound Production

Aircraft noise is noise pollution produced by an aircraft or its components, whether on the ground while parked such as auxiliary power units, while taxiing, on run-up from propeller and jet exhaust, during take-off, underneath and lateral to departure and arrival paths, over-flying while en route, or during landing. A moving aircraft including the jet engine or propeller causes compression and rarefaction of the air, producing motion of air molecules. This movement propagates through the air as pressure waves. If these pressure waves are strong enough and within the audible frequency spectrum, a sensation of hearing is produced. Different aircraft types have different noise levels and frequencies. The noise originates from three main sources:

1. Engine and other mechanical noise
2. Aerodynamic noise
3. Noise from aircraft systems

1. Engine and other mechanical noise

Much of the noise in propeller aircraft comes equally from the propellers and aerodynamics. Helicopter noise is aerodynamically induced noise from the main and tail rotors and mechanically induced noise from the main gearbox and various transmission chains. The mechanical sources produce narrow band high intensity peaks relating to the rotational speed and movement of the moving parts. In computer modelling terms noise from a moving aircraft can be treated as a line source.

Aircraft gas turbine engines (jet engines) are responsible for much of the aircraft noise during takeoff and climb, such as the buzz saw noise generated when the tips of the fan blades reach supersonic speeds. However, with advances in noise reduction technologies—the airframe is typically more noisy during landing.

The majority of engine noise is due to jet noise—although high bypass-ratio turbofans do have considerable fan noise. The high velocity jet leaving the back of the engine has an inherent shear layer instability (if not thick enough) and rolls up into ring vortices. This later breaks down into turbulence. The SPL associated with engine noise is proportional to the jet speed (to a high power). Therefore, even modest reductions in exhaust velocity will produce a large reduction in jet noise.

Engines are the main source of aircraft noise. The geared Pratt & Whitney PW1000G helped reduce the noise levels of the Bombardier CSeries, Mitsubishi MRJ and Embraer E-Jet E2 crossover narrow body aircraft: the gearbox allows the fan to spin at an optimal speed, which is one third the speed of the LP turbine, for slower fan tip speeds. It has a 75% smaller noise footprint than current equivalents. The Power Jet SaM146 in the Sukhoi Superjet 100 features 3D aerodynamic fan blades and a nacelle with a long mixed duct flow nozzle to reduce noise, (Bernie Baldwin 2017).

2. Aerodynamic noise

Aerodynamic noise arises from the airflow around the aircraft fuselage and control surfaces. This type of noise increases with aircraft speed and also at low altitudes due to the density of the air. Jet-powered aircraft create intense noise from aerodynamics. Low-flying, high-speed military aircraft produce especially loud aerodynamic noise.

The shape of the nose, windshield or canopy of an aircraft affects the sound produced. Much of the noise of a propeller aircraft is of aerodynamic origin due to the flow of air around the blades. The helicopter main and tail rotors also give rise to aerodynamic noise. This type of aerodynamic noise is mostly low frequency determined by the rotor speed.

Typically noise is generated when flow passes an object on the aircraft, for example, the wings or landing gear. There are broadly two main types of airframe noise:
Bluff Body Noise – the alternating vortex shedding from either side of a bluff body, creates low-pressure regions (at the core of the shed vortices) which manifest themselves as pressure waves (or sound). The separated flow around the bluff body is quite unstable, and the flow "rolls up" into ring vortices—which later break down into turbulence, (Aircraft Airframe Noise 2008).
Edge Noise – when turbulent flow passes the end of an object or gaps in a structure (high lift device clearance gaps) the associated fluctuations in pressure are heard as the sound propagates from the edge of the object (radially downwards) (Aircraft Airframe Noise 2008).

3. Noise from aircraft systems
Cockpit and cabin pressurization and conditioning systems are often a major contributor within cabins of both civilian and military aircraft. However, one of the most significant sources of cabin noise from commercial jet aircraft, other than the engines, is the Auxiliary Power Unit (APU), an on-board generator used in aircraft to start the main engines, usually with compressed air, and to provide electrical power while the aircraft is on the ground. Other internal aircraft systems can also contribute, such as specialized electronic equipment in some military aircraft.

Effects of Aircraft Noise on human health
1. **Cardiovascular health effect:** Over the past 10 years, evidence that aircraft noise exposure leads to increased risk for poorer cardiovascular health has increased considerably. A recent review, suggested that risk for cardiovascular outcomes such as high blood pressure (hypertension), heart attack, and stroke, increases by 7 to 17% for a 10dB increase in aircraft or road traffic noise exposure (Basner et al., 2014). A review of the evidence for children concluded that there were associations between aircraft noise and high blood pressure (Paunović et al., 2011), which may have implications for adult health (Stansfeld & Clark, 2015).
The HYENA study (Hypertension and Exposure to Noise near Airports) examined noise effects on the blood pressure (hypertension) of 4,861 people, aged 45-70 years, who had lived for over 5 years near 7 major European airports including London Heathrow; Amsterdam Schiphol; Stockholm Arlanda & Bromma; Berlin Tegel, Milan Malpensa; and Athens Eleftherios Venizelos (Jarup et al., 2008). High blood pressure was assessed via measurements and medication use. The HYENA study found that a 10dB increase in aircraft noise at night (Lnight) was associated with a 14% increase in odds for high blood pressure but day-time aircraft noise (LAeq 16 hour) did not increase the odds for high blood pressure (Jarup et al., 2008). The HYENA study did not find an association between day-time aircraft noise and high blood pressure which might be because many residents work away from home during the day-time, leading to potential mis-classification of their day-time aircraft noise exposure. The HYENA study also found that a 10dB increase in night-time aircraft noise was associated with a 34% increase in the use of medication for high blood pressure in the UK (Floud et al., 2011). The HYENA study is a high quality large-scale study of aircraft noise exposure effects on blood pressure, which includes a population sample around London Heathrow airport. One short-coming of the study is that it assesses noise and health at the same point in time, meaning that we cannot be sure whether noise exposure occurred before the poorer health outcomes, or whether the poorer health outcomes may have preceded the noise exposure.
A recent study around London Heathrow airport examined risks for hospital admission and mortality for stroke, coronary heart disease and cardiovascular disease for around 3.6 million

people living near London Heathrow airport (Hansell et al., 2013). Both daytime (LAeq 16 hour) and night-time (Lnight) aircraft noise exposure were related to increased risk for a cardiovascular hospital admission. Compared to those exposed to aircraft noise levels below 51dB in the day-time, those exposed to aircraft noise levels over 63dB in the day-time had a 24% higher chance of a hospital admission for stroke; a 21% higher chance of a hospital admission for coronary heart disease; and a 14% higher chance of a hospital admission for cardiovascular disease. These estimates took into account age, sex, ethnicity, deprivation and lung cancer mortality as a proxy for smoking. These results were also not accounted for by air pollution, which was adjusted for in the analyses. Similar effects were also found between aircraft noise exposure and mortality for stroke, coronary heart disease, and cardiovascular disease. The study concluded that high levels of aircraft noise were associated with increased risks of stroke, coronary heart disease, and cardiovascular disease for both hospital admissions and mortality in areas near Heathrow airport.

Further longitudinal evidence for an association between aircraft noise exposure and mortality from heart attacks comes from a large-scale Swiss study of 4.6 million residents over 30 years of age (Huss et al., 2010). This study found that mortality from heart attacks increased with increasing level and duration of aircraft noise exposure (over 15 years), but there were no associations between aircraft noise exposure and other cardiovascular outcomes including stroke or circulatory disease. The lack of association between aircraft noise and stroke differs from the findings of the similar study conducted around Heathrow airport, which did find an association of aircraft noise on stroke mortality (Hansell et al., 2013).

It is not uncommon for studies in this field to demonstrate some inconsistencies in the specific cardiovascular outcomes for which significant effects of aircraft noise associations are found. There are several explanations for this. Firstly, demonstrating environmental noise effects on cardiovascular disease requires very large samples. Even in large samples effects may not be statistically significant, as the confidence intervals for the estimate of the effect can be wide, if the cardiovascular outcome does not have a high prevalence, e.g. incidence of stroke. Thus, studies vary in their sample size and in their ability to examine a range of cardiovascular outcomes. Secondly, with epidemiological studies, there is always the potential for residual confounding: the analyses may still not be taking into account all factors, which might be influencing the association between aircraft noise and cardiovascular disease. Thirdly, there is always the possibility of exposure mis-classification: the estimated aircraft noise exposure may be incorrect for some of the sample, which could influence the findings. For example, there is a limitation to using day-time aircraft noise exposure at home for adult samples, when they may work away from their home environment. Fourthly, there is variation in the level and range of aircraft noise exposures examined, which could explain differences between the studies. Despite these differences between the aircraft noise studies, the most recent meta-analysis of the field (Babisch, 2014) concluded that aircraft noise exposure was associated with increased risk for cardiovascular outcomes such as high blood pressure, heart attack and stroke.

It is biologically plausible that long-term exposure to environmental noise might influence cardiovascular health (Babisch, 2014). In brief, increased stress associated with noise exposure might cause physiological stress reactions in an individual, which in turn can lead to increases in established cardiovascular disease risk factors such as blood pressure, blood glucose concentrations, and blood lipids (blood fats). These risk factors lead to increased risk of high blood pressure (hypertension) and arteriosclerosis (e.g. narrowing of arteries due to fat deposits) and are related to serious events such as heart attacks and strokes (Babisch, 2014; Basner et al., 2014). The stress that triggers this pathway can operate directly via sleep disturbance or indirectly via interference with activities and annoyance.

To date, few studies have examined whether aircraft noise exposure influences metabolic risk factors for cardiovascular health, such as Type II diabetes, body mass index, and waist circumference. Such factors would lie on the proposed pathway between aircraft noise exposure and cardiovascular diseases. A recent study of long-term exposure to aircraft noise in Sweden found that exposure was associated with a larger waist circumference but less clearly with Type II diabetes and body mass index (Eriksson et al., 2014). This is an area of research where further evidence should be forthcoming in the next few years.

2. Sleep disturbance: The WHO estimated sleep disturbance to be the most adverse non-auditory effect of environmental noise exposure (Basner et al., 2014; WHO, 2011). Undisturbed sleep of a sufficient number of hours is needed for alertness and performance during the day, for quality of life, and for health (Basner et al., 2014). Humans exposed to sound whilst asleep still have physiological reactions to the noise which do not adapt over time including changes in breathing, body movements, heart rate, as well as awakenings (Basner et al., 2014). The elderly, shift-workers, children and those with poor health are thought to be at risk for sleep disturbance by noise (Muzet, 2007).

The effect of night-time aircraft noise exposure has been explored for a range of sleep outcomes ranging from subjective self-reported sleep disturbance and perceived sleep quality, to more objective measures of interference with ability to fall asleep, shortened sleep duration, awakenings, and increased bodily movements as assessed by polysomnography2 (Michaud et al., 2007). Most evidence comes from studies of self-reported sleep disturbance. However, self-reported sleep disturbance outcomes are vulnerable to bias, as such measures are likely to be influenced by noise annoyance and other demographic factors (Clark & Stansfeld, 2011).

Reviews have concluded that there is evidence for an effect of night-time aircraft noise exposure on sleep disturbance from community based studies (Hume et al., 2012; Miedema & Vos, 2007). However, some reviews have concluded that the evidence is contradictory and inconclusive (Jones, 2009; Michaud et al., 2007), which might be explained by methodological differences between studies of noise effects on sleep disturbance. A meta-analysis of 24 studies, including nearly 23,000 individuals exposed to night-time noise levels ranging from 45-65dBA, found that aircraft noise was associated with greater self-reported sleep disturbance than road traffic noise (Miedema & Vos, 2007). However, another study, whilst confirming that aircraft noise was associated with greater self-reported sleep disturbance than road traffic noise, found that when polysomnography measures of sleep disturbance were analysed that road traffic noise was associated with greater disturbance than aircraft noise (Basner et al., 2011).

Polysomnography enables the assessment of noise effects on different stages of the sleep cycle. The average sleep cycle last between 90 to 110 minutes, and an individual experiences between four to six sleep cycles per night (Michaud et al., 2007). The table below (Stages of sleep) describes the duration and characteristics of each stage of the sleep cycle (Clark & Stansfeld, 2011) from wake, through non-rapid eye movement (NREM) stages 1 to 4, and rapid eye movement (REM) sleep. It is usual for people to move between NREM sleep stages several times before undergoing REM sleep. Slow-wave sleep (NREM stage 3 and 4) occurs more frequently in the first half of the night, and REM sleep propensity is greater in the second half of the night. Sleep disturbance is indicated by less stage 3, stage 4 and REM sleep, and by more wake and stage 1 sleep, as well as more frequent changes in sleep stage (Basner & Siebert, 2010).

There is evidence that aircraft noise influences the time spent in different sleep stages, with aircraft noise reducing slow-wave sleep (NREM Stage 4) and REM sleep and increasing NREM Stages 1, 2 & 3 (Basner et al., 2008; Swift, 2010). This evidence, taken with the

increase in REM sleep in the later stages of the night might have implications for early morning (04.00-06.30 hours) flight operations at airports.
A laboratory study compared the potential effects of changes in the night-time curfew at Frankfurt airport on sleep disruption (Basner & Siebert, 2010), using polysomnography on 128 subjects over 13 nights. Three different operational scenarios were compared: scenario 1 was based on 2005 air traffic at Frankfurt airport which included night flights; scenario 2 was as scenario 1 but cancelled flights between 23.00-05.00 hours; scenario 3 was as scenario 1 but with flights between 23.00-05.00 hours rescheduled to the day-time and evening periods. The study found that compared to the night without a curfew on night flights (scenario 1), small improvements were observed in sleep structure for the nights with curfew, even when the flights were rescheduled to periods before and after the curfew period. However, the change in the amount of time spent in the different sleep stages for the different scenarios was small, which might be explained by the small number of night-flights (on average 4 take-offs per hour) in the Frankfurt airport scenarios examined: larger effects may be observed for airports with a greater number of night-flights. The authors concluded that the benefits for sleep seen in the scenario involving rescheduling of flights rather than cancellation may be offset by the expected increase in air traffic during the late evening and early morning hours for those who go to bed before 22.30 or after 01.00 hours. Typically starts 70-90 minutes after falling asleep Characterized by rapid eye movements Increases in brain activity Greater variability in respiration rate, blood pressure and heart rate typically starts 70-90 minutes after falling asleep Characterized by rapid eye movements Increases in brain activity Greater variability in respiration rate, blood pressure and heart rate

Stages of sleep, adapted from (Clark & Stansfeld, 2011).

Wake	
Non-rapid eye movement (NREM)	
Stage 1	Light stage of sleep Lasts 5-10 minutes Bridge between wakefulness and sleep
Stage 2	Light stage of sleep Lasts around 20 minutes Brain waves of increased frequency Increased heart rate variability
Stage 3	Transition to deeper stages of sleep Increased amount of delta waves of lower frequency
Stage 5	Deepest stage of sleep Characterized by a greater number of delta waves
Rapid eye movement (REM)	Typically starts 70-90 minutes after falling asleep Characterized by rapid eye movements Increases in brain activity Greater variability in respiration rate, blood pressure and heart rate

3. Annoyance

Annoyance is the most prevalent community response in a population exposed to environmental noise. The term annoyance is used to describe negative reactions to noise such as disturbance, irritation, dissatisfaction and nuisance (Guski, 1999). Annoyance can also be accompanied by stress-related symptoms, leading to changes in heart rate and blood pressure, as described above. Acoustic factors, such as the noise source and sound level, account for only a small to moderate amount of annoyance responses: other factors such as the fear associated with the noise source, interference with activities, ability to cope, noise sensitivity, expectations, anger, attitudes to the source – both positive or negative, and beliefs about whether noise could be reduced by those responsible influence annoyance responses (WHO, 2000).

Annoyance scales are commonly used within European policy to measure the quality of life impact of environmental noise exposure on communities around airports. An International Standard is in place governing the measurement of annoyance in community surveys (Fields et al., 2001; ISO/TS, 2003), with questions typically taking the format "Thinking about the last year when you are at home, how much does the noise from aircraft bother, disturb or annoy you?" with responses ideally given on a 10 point scale with 0 being 'not at all annoyed' and 10 being "extremely annoyed". This question is often reported as the % of the population "highly annoyed" or "annoyed", where "highly annoyed" is 72% or more on the scale and "annoyed" is 50% or more on the scale.

Exposure to aircraft noise at 60dB Lden is estimated to be associated with 38% of the population reporting being "annoyed" and 17% being "highly annoyed" (EC, 2002). Exposure to aircraft noise at 65dB Lden is estimated to be associated with 48% of the population reporting being "annoyed" and 26% being "highly annoyed" (EC, 2002). However, in recent years, several studies have suggested that aircraft noise annoyance around major airports in Europe has increased (Babisch et al., 2009; Janssen et al., 2011; Schreckenberg et al., 2010), so the percentage of the population reporting being "annoyed" or "highly annoyed" at each noise exposure level may have increased since these figures were put forward by the European Commission in 2002 (EC, 2002).

Annoyance responses can also increase in relation to a change in airport operations. A study around Zurich airport found that residents who experienced a significant increase in aircraft noise exposure due to an increase in early morning and late evening flight operations had a pronounced over-reaction of annoyance i.e. the annoyance reaction was greater than that which would be predicted by the level of noise exposure (Brink et al., 2008).

Children also report annoyance responses, although it is not known at what age children being to exhibit annoyance responses. The RANCH (Road traffic and Aircraft Noise exposure and children's Cognition and Health) study found that children aged 9-11 years of age living near London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports, reported annoyance for aircraft noise exposure at school and at home (van Kempen et al., 2009). For school exposure the percentage of "highly annoyed" children increased from about 5.1% at 50dB LAeq 16 hour, to 12.1% at 60dB LAeq16 hour.

4. Psychological health

Following on from annoyance, it has been suggested that long-term noise exposure might influence psychological health. However, overall the evidence for aircraft noise exposure being linked to poorer well-being, lower quality of life, and psychological illhealth is not as strong or consistent as for other health outcomes, such as cardiovascular disease. A recent study of 2300 residents near Frankfurt airport found that annoyance but not aircraft noise levels per se (LAeq16 hour, Lnight, Lden) was associated with self-reported lower quality of life (Schreckenberg et al., 2010).

Several studies of children around London Heathrow airport have shown no effect of aircraft noise at school on children's psychological health or cortisol levels (Haines et al., 2001a; Haines et al., 2001b; Stansfeld et al., 2009): we would expect cortisol levels to be raised in children with depression. However, there may be a small effect of aircraft noise on hyperactivity symptoms. The West London Schools Study of 451 children around Heathrow airport, aged 8-11 years found higher rates of hyperactivity symptoms for children attending schools exposed to aircraft noise exposure >63dB LAeq 16 hour compared with <57dB LAeq 16 hour (Haines et al., 2001a). A similar effect was observed in the RANCH study where 10dB LAeq 16 hour increase in aircraft noise exposure at school was associated with 0.13 increase in hyperactivity symptoms (Stansfeld et al., 2009). However, these increases in hyperactivity symptoms, whilst statistically significant, are extremely small and most likely not of clinical relevance. Aircraft noise exposure does not appear to be causing children to develop hyperactivity problems.

There have been fewer studies of aircraft noise effects on adult psychological health. The HYENA study, found that a 10dB increase in day-time (LAeq 16 hour) was associated with a 28% increase in anxiety medication use: similarly, a 10dB increase in night-time (Lnight) aircraft noise was associated with a 27% increase in anxiety medication use. However, day-time and night-time aircraft noise exposure were not associated with sleep medication or anti-depressant medication use (Floud et al., 2011). Anxiety medication is prescribed for individuals experiencing levels of anxiety and worry that interfere with their ability to function effectively: they can also be prescribed for sleeping problems. A sub-study of the HYENA study found that salivary cortisol (a stress hormone which is higher in people with depression) was 34% higher for women exposed to aircraft noise > 60dB LAeq 24 hour, compared to women exposed to less than 50dB LAeq 24 hour (Selander et al., 2009). However, no association between aircraft noise and salivary cortisol was found for men.

Diseases Associated with long time exposure to Aircraft Noise.

1. The Effects of Noise on Low Birth Weight and Prematurity

Low birth weight and prematurity have been the outcomes most examined in relation to environmental noise. Two recent reviews have been published, (Hohmann, Grabenhenrich, Kluizenaar, et al. 2013) and (Ristovska, Laszlo, Hansell, 2014). No consistent associations were found between chronic noise exposure and pregnancy outcomes, but the studies included in both of these reviews varied in study design and measurement of exposure, confounding factors and outcomes. Occupational noise levels assessed in these studies range from above 78 dBA, to 85 dB L eq8h, to above 90 dBA. In the aircraft noise studies, levels are lower with high noise exposure defined as above 65 and 87 dBA. Assessment methods for noise exposure varied using dosimetry, assessments by occupational hygienists, questionnaires and aircraft noise contour maps. The second review found some suggestive evidence of an association between environmental noise and low birth weight but certainly no definitive evidence, (Hohmann, Grabenhenrich, Kluizenaar, et al. 2013). Modelled road traffic noise exposure has been linked to low birth weight in a Canadian study of 70,000 administrative birth records, (Gehring, Tamburic, Sbihi H, et al. 2014). This association remained after adjustment for air pollution exposure, suggesting that noise has an effect on low birth weight, independent of air pollution. Road traffic is a source of both noise and air pollution both of which have been implicated in health effects. Air pollution is usually measured in terms of gases such as nitrogen dioxide and particulate emissions of different sizes, e.g. PM2.5 and PM10. A small significant risk was also found for noise and gestational age but not pre-term birth. There is scope for further studies in this area using standardized measures of noise exposure and birth outcomes.

2. Endocrine Responses to Noise Exposure

In adults, the mechanism for noise effects on health is thought to be related to the stress hypothesis where noise exposure increases physiological arousal through repeated stimulation of the endocrine system and autonomic nervous system, (Babisch 2002). It is likely that the same mechanism pertains to children as well. Catecholamine and cortisol secretion have been studied as indicators of chronic stress in children exposed to aircraft and road traffic noise. Levels of adrenaline and noradrenaline were raised in both cross-sectional and longitudinal reports from the Munich Study in relation to aircraft noise exposure above 68 dBA and increases in aircraft noise exposure to 62 dBA around the newly opened Munich Airport, (Evans, Hygge, Bullinger 1995) and (Evans, Bullinger, Hygge 1998). This is strong evidence of effects in children because of the longitudinal nature of the study and the increased hormone levels with lengthening duration of noise exposure. However, urinary catecholamines were not raised in the aircraft noise-exposed sample from the West London Schools Study (high noise group >63 dBA, low noise group <57 dBA) (Haines, Stansfeld, Brentnall, et al. 2001), albeit a cross-sectional study, and there are insufficient studies to be certain whether noise exposure is related to increased catecholamines. None of these studies have consistently showed a relationship between aircraft noise and urinary cortisol exposure.(Evans, Hygge, Bullinger 1995), (Evans, Bullinger, Hygge 1998) and (Haines, Stansfeld, Brentnall, et al. 2001) There is undoubtedly a need for further studies in this area where perhaps measures of prolonged raised cortisol might be appropriate.

3. Blood Pressure Responses to Noise Exposure

There have now been a number of studies investigating the association between road traffic and aircraft noise exposure and blood pressure in children. Whilst it is premature to examine cardiovascular risk in children, studies from adults suggest that repeated elevation of blood pressure in relation to noise exposure might have pathological effects on health in the long term. (Munzel, Gori, Babisch, et al. 2014). Thus, it is appropriate to examine whether noise might be having an effect on blood pressure in children. A recent review (Paunović, Stansfeld, Clark, et al. 2011) found small positive relationships between aircraft noise and blood pressure in children. In this review, road traffic noise studies, although methodologically diverse, showed a stronger relationship with systolic blood pressure. The studies varied in methodology and control for confounding factors. In one study, traffic noise exposure was classified in terms of traffic volume; children whose bedrooms were facing a street with low traffic had the lowest blood pressure readings, whilst the highest readings were found in the group where the children's bedrooms were facing a street with high, or extremely high traffic volume. The difference in blood pressure between the two groups was 1.8 mmHg, (95 % confidence interval (CI) 0.1–3.5, P = 0.036) for systolic and 1.0 mmHg (95 % CI −0.4–2.4, P = 0.148) for diastolic blood pressure (Babisch, Neuhauser, Thamm, et al. 2009). These sorts of differences are not unlike those seen in other studies of road traffic noise, although in some studies, the differences were as great as 4–5 mmHg, (Belojevic, Jakovljevic, Stojanov, et al. 2008). Diastolic blood pressure was related to a 5-dBA increase in L den and L night in 10-year-old children from the GINI-plus, LISA-plus studies adjusting for nitrogen dioxide and three types of particles including PM 2.5, (Babisch, Neuhauser, Thamm, et al. 2009). In adjusted analyses, road traffic noise, ranging from 27–86 dBA, measured in front of the child's bedroom, was independently and positively associated with blood pressure, whereas air pollution was not, (Liu, Fuertes, Tiesler, et al. 2014). In contrast, another study of 12-year-old children found associations between long-term exposure to nitrogen dioxide and PM 2.5 and diastolic blood pressure but no association with noise exposure, although there were trends with diastolic blood pressure (Bilenko, Rossem, Brunekreef, et al. 2013). This could be because traffic noise levels were quite low (45–70.5 dBA L den) with a limited range of exposure in this study. Also, noise measurements made only at the façade of the building may not accurately assess noise exposure in bedrooms at the back of the dwelling. Future studies could adopt a more standardized methodology, but overall, there is increasing evidence of associations between transport noise and blood pressure. Even if these associations are small, the long-term consequences of these blood pressure increases across the life course are unknown and should be studied.

4. Annoyance

Children may be annoyed by environmental noise in the same way as adults. In the cross-sectional multi-country RANCH study, a curvilinear exposure response relationship was demonstrated between exposure to aircraft noise at school and severe annoyance in children adjusting for confounding factors. (van Kempen, van Kamp, Stellato, et al. 2009). The percentage of severely annoyed children increased from about 5.1 % at 50 dB to 12.1 % at 60 dB. Similar associations were found with exposure to aircraft noise at home. In the same study, a linear relationship was found between road traffic noise exposure and annoyance responses. In general, children were less annoyed than their parents at levels above 55 dB, but the shapes of the exposure response relationships were comparable to those in their parents. These associations have also been demonstrated longitudinally in a South African study, where aircraft noise exposure was related to increased levels of annoyance in children over time, (Seabi, 2013). Generally, it seems that children are less annoyed by road traffic noise than adults. In a large German study, 7.3 % of 8- to 10-year olds were annoyed by road traffic noise during daytime (yes on a dichotomous scale) compared to 16.4 % of 11- to 14-year olds (collapsed 5-point scale), (Babisch, Schulz, Seiwert, et al. 2012). This may partly be because of different time activity patterns of children and adults, but also various types of environmental noise may have a different meaning for children and adults. For instance, in this German study, noise from neighbours and noise from family were reported as more annoying for children than road traffic noise. Additionally, children of lower socioeconomic status were more annoyed by road traffic and also those who lived in larger agglomerations of more than 100,000 inhabitants.

5. Noise-Induced Hearing Loss

Environmental noise does not usually reach levels that are likely to affect hearing in the community. Tinnitus, often associated with hearing loss, has been reported in community surveys of young people associated not only with occupational noise exposure but also with other sources of noise exposure, (Park, Choi, Lee, et al, 2014). For young people, the risks to hearing are more likely to result from leisure noise from clubs and rock concerts, and recently, there has been concern over sound levels from personal listening devices. Over the last 20–30 years the number of young people with social noise exposure has tripled to around 19 %, (European Commission 2008). Recently, the sales to young people of personal electronic devices for listening to music have increased enormously. The risks of noise-induced hearing loss from these devices have been compared to the European Noise at Work Regulations recommending an equivalent noise exposure level to 80 dBA for an 8-h working day. The equivalent sound pressure levels of personal electronic devices at maximum volume range from about 80–115 dBA with a mean exposure time ranging from 1 to 14 h a week. On average, it has been estimated that the sound exposure levels from personal electronic devices range from 75 to 85 dBA, so for the majority of personal electronic device users, the risk to hearing is minimal. However, approximately 5–10 % of listeners are considered to be at higher risk due to listening at high level and the long duration of their listening, (Twardella, Perez-Alvarez, Steffens, et al. 2013). There may be differences in effects by country, and a much greater prevalence of audiometric notches was demonstrated in the USA than in

Germany, although this could also relate to methodological differences between studies, (Twardella, Perez-Alvarez, Steffens, et al. 2013). However, it would be fair to say that the risk of hearing loss from these devices is as yet uncertain, and further research will be needed in the future when there is greater experience with these devices. Suffice it to say, there is a need for monitoring hearing over time in young people to check for hearing loss as, although there may be no risk of hearing impairment, if there were a risk it could involve large numbers of young people.

6. Noise and Sleep Disturbance in Children

Surprisingly, there have been relatively few studies on environmental noise and sleep in children, although children have been identified as a group vulnerable to the effects of sleep disturbance, (Pirrera, De Valck, Cluydts, 2010). Prolonged sleep disturbance in children may result in tiredness, difficulties in focussing attention, increased irritability and lowered frustration tolerance, (World Health Organization Europe. 2009). A cross-sectional study of 12-year-old children found a moderate exposure response relationship between road traffic noise exposure at night and sleep quality and problems with sleepiness during the day, but no significant association with difficulties falling asleep, (Ohrstrom, Hadzibajramovic, Holmes, et al, 2006). The level of noise exposure at the least exposed façade of a dwelling, perhaps more associated with levels of noise exposure within bedrooms, than noise exposure on the most exposed façade, has been associated with difficulties falling asleep and sleeping problems in a recent community study, (Tiesler, Birk, Thiering, et al. 2013). However, night-time aircraft noise exposure did not increase the risk of cognitive impairment beyond the effects of day-time noise exposure in the RANCH and Munich studies. (Stansfeld, Hygge, Clark, et al. 2010). Vulnerable young people may be more at risk of sleep disturbance: ill children in hospital were both more likely to have disturbed sleep before admission, probably related to existing illness and were also found to be woken by noise such as alarms, and attention of hospital staff, potentially disturbing their recovery, (Herbert, de Lima, Fitzgerald, et al 2014).

7. Noise and Psychological Health in Children

a. Quality of Life and Well-being: There have been several studies examining well-being or quality of life in children assessing less severe aspects of psychological disturbance than psychiatric disorder. In Munich, children living in areas exposed to high aircraft noise had lower levels of psychological well-being than children living in quieter environments, (Evans, Hygge, Bullinger 1995). The longitudinal data from around Munich showed that after the inauguration of the new airport, the newly noise-exposed communities demonstrated a significant decline in self-reported quality of life, measured on the Kindl scale, after being exposed to the increased aircraft noise for 18 months, compared with a control sample, (Evans, Bullinger, Hygge 1998). These studies suggest that noise does not influence children's mental health, though it may affect their stress responses and sense of well-being.

b. Psychiatric Disorders and Noise Exposure: Anxiety and depression (measured with psychometrically valid scales) were not associated with chronic aircraft noise exposure adjusting for socioeconomic factors in the Schools Health & Environment Study around the Heathrow Airport, (Haines, Stansfeld, Job, et al. 2001), although road traffic noise at the least exposed façade has been associated with a small increased risk of emotional symptoms on the Strengths and Difficulties Questionnaire (SDQ), (Tiesler, Birk, Thiering, et al. 2013) (Goodman, 1997). In a further study of children's health around Heathrow Airport—the West London Schools Study, (Haines, Stansfeld, Brentnall, et al. 2001). An association was found between aircraft noise exposure levels and increased scores on the hyperactivity subscale measured by the SDQ. These analyses were revisited in the RANCH Study of 2844, 9- to 10-year-old children living around the Schiphol Airport in the Netherlands, Barajas Airport in Spain and Heathrow Airport in the UK, (Stansfeld, Berglund, Clark, et al. 2005). There were no overall effects of aircraft noise or road traffic noise on children's mental health, measured by the SDQ, but a small association was found with increased hyperactivity subscale scores as in the earlier West London Schools Study, (Stansfeld SA, Clark C, Cameron RM, et al. 2009). Recent German studies of road traffic noise exposure in 10-year-old children have also shown an association between noise exposure measured as L den at the most exposed façade and increased scores on the hyperactivity subscale of the SDQ, (Tiesler, Birk, Thiering, et al. 2013), suggesting that this is not an isolated finding. Overall, there is reasonable evidence that noise impairs quality of life in children but does not cause more serious mental health problems. The mechanism by which noise exposure might influence hyperactivity deserves further attention.

c. Noise and Cognitive Impairment in Children: Studies suggest that the evidence of the effects of noise on children's cognition has grown stronger over recent years, with over 20 studies showing detrimental effects of noise on children's memory and reading outcomes, (Evans, Hygge, 2007). Recent advances include the use of larger samples, longitudinal studies, the examination of exposure-effect relationships and more thorough assessment of a range of relevant confounding factors, (Hohmann, Grabenhenrich, Kluizenaar, et al. 2013). Social deprivation is often associated with high levels of noise exposure; it is also associated with poorer cognitive achievement. Thus, there is considerable potential for confounding in these associations and measures of socioeconomic position must be adjusted for in analyses of noise exposure and cognition and health.

Studies have shown that children exposed to chronic aircraft or road traffic noise at school have poorer reading comprehension and memory than children who are not exposed. A study of 9- to 10-year-old children from rural Alpine areas. (Haines, Stansfeld, Brentnall, et al. 2001), (Haines, Stansfeld, Job, et al. 2001) (Cohen S, Krantz DS, Evans GW, et al, 1981) and (Lercher, Evans, Meis, 2003) found that modest levels of ambient community noise (train and road traffic noise above 60 dBA) were associated with poorer memory performance, but not with performance on a test of attention. Several studies have suggested that the effects of noise on children's cognition are not uniform across all cognitive tasks: tasks which involve central processing and language comprehension, such as reading, problem solving and memory appear to be most affected by exposure to noise, (Cohen, Evans, Stokols, et al 1986) and (Hygge, Evans, Bullinger, 2002). Robust evidence for noise effects on children's cognitive performance comes from intervention studies and natural experiments where changes in noise exposure have been accompanied by changes in cognitive performance, such as the Munich Airport study, (Evans, Hygge, Bullinger 1995), (Evans, Bullinger, Hygge 1998) and (Hygge, Evans, Bullinger, 2002). Prior to the relocation of the airport in Munich, high noise exposure was associated with deficits in long-term memory and reading comprehension in children of 10 years of age. Two years after the airport closed, these cognitive impairments were no longer present, suggesting that effects of noise on cognitive performance may be reversible if noise stops. Furthermore, in a new cohort of noise-exposed children living around the newly opened airport, impairments in memory and reading comprehension developed over the following 2 years. The Munich study remains one of the few longitudinal studies in the field, providing important evidence for a cause-effect relationship between noise exposure and cognitive deficits.

Demonstrating exposure-effect relationships between aircraft noise exposure and children's cognition and learning is important for confirming causal associations between noise and cognition, as well as for identifying thresholds for the effects that can be used by policy makers. The RANCH study found a linear exposure-effect relationship between chronic aircraft noise exposure experienced at school, but not road traffic noise exposure, and impaired reading comprehension and recognition memory, after adjusting for a number of relevant socioeconomic and confounding factors including mother's education, long-standing illness, the extent of classroom insulation against noise, and acute noise during testing, (Stansfeld, Berglund, Clark, et al. 2005). A 5-dB LAeq16 increase in aircraft noise exposure at school was associated with a 2-month delay in reading age in the UK and a 1-month delay in the Netherlands, (Clark, Martin' van Kempen' et al. 2006), this association remained after adjustment for aircraft noise annoyance and other cognitive abilities including episodic memory, working memory and attention, as well as air pollution. (Clark, Crombie, Head, et al. 2012). The RANCH study suggests that reading comprehension begins to fall below average at aircraft noise exposure greater than 55 dB LAeq16, but as the association is linear, any reduction in aircraft noise exposure should improve reading comprehension. Long-term exposure to road traffic noise was not associated with cognitive performance. The exception to this was conceptual recall and information recall, which unexpectedly demonstrated better performance in school pupils exposed to higher levels of road traffic noise. Attention and working memory were not consistently influenced by either aircraft noise or road traffic noise. The development of cognitive abilities such as reading is important not only in terms of educational achievement but also for subsequent life chances and adult health, (Kuh, Ben-Shlomo 2004), however, few studies have examined the effects of persistent noise exposure throughout the child's education. The UK sub-sample of the RANCH study was followed up longitudinally to examine the associations of aircraft noise exposure at primary school on children's reading comprehension at secondary school. This 6-year follow-up of 461 children aged 15 to 16 years, who attended primary and secondary schools around London Heathrow Airport, found that aircraft noise exposure at primary school was associated with a nonsignificant decrease in reading comprehension at follow-up, (Clark, Head, Stansfeld 2013). There was also a weak nonsignificant association between aircraft noise at secondary school and reading comprehension after adjustment for sociodemographic factors. This was a small-scale study, where the small sample size could potentially limit and influence the power to detect significant effects. Further longitudinal life course studies of noise exposure at school and educational outcomes should be conducted.

Studies have also shown effects of noise on standardised achievement tests. Over 40 years ago, Bronzaft and McCarthy, (Bronzaft, McCarthy, 1975), demonstrated that children who were taught in classrooms on the noisy side of a school near a railway line had poorer performance on the school achievement tests than those taught in classrooms on the quiet side of the same school in New York. The mean reading age of children in the classrooms on the noisy side of the school was 3 to 4 months behind the children in the low noise-exposed classrooms. A more recent study of national standardized test scores (SATs) carried out around the Heathrow Airport, (Haines, Stansfeld, Head, et al. 2002), examined test scores for 11,000 11-year-old children in relation to aircraft noise exposure contours for their school. The results showed that there was an exposure-effect relationship between noise exposure and performance on reading and math tests, but that this was influenced by socioeconomic factors. There have been less studies that include assessments of the effects of noise exposure within classrooms as well as external noise exposure, although Shield and Dockrell found associations with both sources of noise at school in relation to national tests for primary school children aged 7–11 years. (Shield, Dockrell, 2008). Older children's performance was most affected by external noise. As the strongest association of test scores was with L Amax, this may be interpreted as individual noise events being important in effects on children's cognition.

The Federal Interagency Committee on Aviation Noise (FICAN) funded a study which assessed the relationship between aircraft noise reduction and standardized test scores in the USA, (Eagan, Anderson, Nicholas, et al 2004) (FICAN 2007). The study evaluated whether abrupt aircraft noise reduction within classrooms, caused either by airport closure or newly implemented sound insulation, was associated with improvements in test scores, in 35 public schools near three US airports in Illinois and Texas. The study relied on computed noise exposure metrics, which were converted to indoor values, making a comparison with other studies, which use outdoor exposure values, difficult. Overall, this study did find some evidence for effects of aircraft noise reduction and improved standardized test results, although it must be acknowledged that some associations were null and some associations were not in the direction hypothesised. This was a pilot study, and the authors stress that the airports and schools selected for the study may not be representative; that further, larger studies are required; that future studies should utilize airport data for noise exposure assessment; and that outdoor to indoor noise measurements at each school should be considered.

The findings of studies of noise effects on children's cognitive performance suggest that noise may directly affect reading comprehension or that noise effects could be accounted for by other mechanisms including teacher and pupil frustration, (Evans, Lepore 1993) learned helplessness (Evans, Stecker, 2004) and impaired attention. (Evans, Lepore 1993), (Cohen, Glass, Singer, 1973). Noise might interfere with the interactions between teachers and pupils. In the noisiest schools, teachers may have to stop teaching whilst aircraft fly over, and if this is frequent, it may contribute to interruptions in communication and fatigue in teachers and children and to a reduction of morale and motivation in teachers. Noise also causes annoyance, especially if an individual feels their activities are being disturbed or if it causes difficulties with communication. In some individuals, this annoyance may lead to stress responses. However, at present, there is little evidence to directly support the annoyance pathway as a mechanism for effects on cognition.

Another pathway is that of sleep disturbance caused by noise exposure at home. Where catchment areas for schools are fairly small, there is a strong correlation between home and school aircraft noise exposure, (Clark, Martin' van Kempen' et al. 2006). The consequences of sleep disturbance may include poorer well-being resulting in a range of responses: annoyance, irritation, low mood, fatigue and impaired task performance. (HCN 2004). Overall few studies have examined sleep disturbance as a mediator of noise effects on cognitive performance. A recent analysis of the cross-sectional Munich and RANCH datasets found that self-reported sleep disturbance did not mediate the association of aircraft noise exposure and cognitive impairment in children, (Stansfeld, Hygge, Clark, et al. 2010). Overall, several plausible pathways and mechanisms for the effects of noise on children's cognition have been put forward, but in general evidence for these mechanisms is fairly sparse.

Given the mounting evidence that environmental noise is related to impairment of school performance, the question of what can be done to reduce noise-induced learning impairments becomes salient. One possibility is a reduction of external sound in the classroom through sound insulation. Overall, few studies have examined the influence of noise abatement, via insulation schemes or airport relocation, on children's learning and cognition. Overall, these studies suggest that a reduction of noise exposure can eliminate previously observed cognitive deficits associated with noise but further studies in this area remain a priority.

Further knowledge about exposure-effect relationships would enhance decision-making concerning the design of physical, educational and psychological interventions for children exposed to high levels of noise. Such relationships can be assessed using either individually collected cognitive performance data or via standardized school test data. It may also be productive and informative to derive relationships for a range of additional noise exposure metrics, such as the number of noise events. Recent advances in noise modelling can only further enhance our knowledge about noise effects upon children's learning outcomes.

Ways of reducing the effects of noise

Aircraft noise can be disturbing to those who live around airports. For decades, the industry has been working to reduce noise, with significant progress: noise levels have halved in the past 10 years. It is estimated that the noise footprint of each new generation of aircraft is at least 15% lower than previous models.

a. Mandated decreases: In 2013, the International Civil Aviation Organization (ICAO), the United Nations' intergovernmental body on aviation, introduced Chapter 14, a new standard in noise reduction. It stipulates that new aircraft models need to be at least seven decibels quieter than those built to the previous Chapter 4 standard. This ensures the quietest technology will be used on future aircraft.

The certification was one of several measures to reduce engine noise. In fact, ICAO estimates that between 1998 and 2004, the number of people exposed to aircraft noise around the world was reduced by 35%.

ICAO advocates a balanced approach to noise reduction. This combines noise reduction at source with land-use planning and management, operational improvements and flight restrictions. The aim is to maximize the environmental benefit, while minimizing cost.

b. Technology: Research into noise reduction has been extensive, examining factors like the amount of air travelling through the engines, the size of the fan blades in the engine, the position of the engine on the aircraft body and even the size and number of flaps that help control the wing shape. The latest large aircraft, the Boeing 787 and Airbus A380, have remarkably small noise 'footprints'. The new Bombardier CSeries makes use of new Pratt & Whitney 'geared' turbofan engines, which further cut noise and emissions. The industry is working hard to make aircraft a further 50% quieter by 2020. There is a powerful incentive to continue tackling this issue, as concerns over noise pollution can – and do – affect the viability of airport expansion plans.

c. Air traffic management: Controlling where planes fly during take-off and landing has an important impact on noise pollution. The placement and use of runways is fundamental, for example, planes travelling at night can travel over seas or lakes to reduce the impact of noise.

Air traffic management maps out flight tracks that avoid the most densely populated areas. Recent developments in navigation performance mean that aircraft can now follow precisely designated tracks. This avoids track spreading and the resulting 'spaghetti' radar flight track maps but can mean that a smaller number of residents are subjected to a higher number of flyovers. Air traffic management therefore needs to be undertaken in close consultation with community groups. Issues such as the relative benefits of track concentration versus track dispersion need to be considered.

With support from the air navigation service providers and airport operators, airlines and pilots can implement noise reduction procedures, such as reduced thrust take-off, displaced landing thresholds and continuous descent operations.

Land-use planning: In parallel with aircraft noise reduction, land-use planning is crucial for minimising the number of people exposed to aircraft noise. Airports need to work with local authorities to implement zoning rules in affected areas. Effective land-use planning can discourage or prevent inappropriate new residential, health or educational developments, and encourage developments that are not sensitive to aircraft noise, such as light industry or storage areas. In some areas, sound insulation and ventilation is required for new or existing homes to reduce indoor noise levels.

Unfortunately, in most cases airport operators have no control over land-use planning off the airport site and can only encourage local government to consider airport noise when approving plans for residential and other noise sensitive land use. The industry encourages governments to take a long-term proactive planning approach to land use around airports to ensure that no future development will be negatively impacted by excessive aircraft noise.

A balancing act: In tackling environmental issues, some compromises need to be made. For example, the aviation industry and governments must choose between shortening routes to reduce fuel use and reducing noise, as sometimes the shortest route into an airport flies over communities. This is a delicate balancing act. (Aviation benefits beyond borders: 2020).

Control measures towards aircraft noise

The manual is being developed to provide a reference to airlines, airport operators, air traffic management and air traffic control service providers, airworthiness authorities, and environmental agencies, as well as other government bodies and interested parties. Its objectives are to:

- Document industry experience and the benefits, in terms of operational noise exposure resulting from optimizing the use of current aircraft and infrastructure, and the related benefits of technology and infrastructure improvements.
- Identify opportunities that could result in measurable noise impact reductions.
- Highlight emerging technology that, when used, could result in reductions in operational noise impacts.
- Demonstrate that a more efficient use of infrastructure is an effective means of reducing civil aviation noise impacts and therefore promote enhanced use of the capabilities inherent in existing aircraft, ground service equipment and infrastructure including airspace management.
- Highlight the importance of stakeholder collaboration to address operational changes that impact community noise exposure.

It is important to note that it may not be possible to realize the benefits from every opportunity at every airport; and for this reason, the document is not prescriptive and is not intended to be the basis for regulatory action. The choice of the operational procedures presented depends upon many factors other than noise benefits, as highlighted by the interdependencies section, and it may not be appropriate for certain of them to be implemented everywhere. For this reason, local issues need to be addressed locally, and this document is aimed at helping inform that process.

Conclusion

This paper has examined research evidence published in recent times, relating to transportation noise, in particular aircraft noise and the resulting impacts on various health endpoints. These included; the effects of noise on low birth weight and prematurity, endocrine responses to noise exposure, blood pressure responses to noise exposure, annoyance, noise-induced hearing loss, noise and sleep disturbance in children, noise and psychological health in children; and considered quality of life and well-being, psychiatric disorders and noise exposure and noise and cognitive impairment in children. The Research showing an association with aircraft noise and cardiovascular disease. There is emerging evidence to suggest that cardiovascular effects are more strongly linked with night time noise exposure as opposed to day or total (24hr) noise exposure. With regard to night noise and sleep disturbance, there is growing recognition that average indicators such as Lnight are insufficient to fully predict sleep disturbance and sleep quality and that use of number of noise events (LAmax) will serve to help understanding of noise-induced sleep disturbance. With regard to aircraft noise and its impact on health, further explorations of past studies have taken account of confounding factors not previously considered such as air pollution and concluded that these did alter the associations previously found. A number of studies, whilst reporting associations the impact of aircraft, discover that the effects do persist on workers exposed to the noise itself. There is a greater understanding of the importance of accounting for confounding factors, in particular air pollution, which is often highly correlated with aircraft noise exposure. With regard to future research there is an increased interest in incorporating the relative contribution of different transport noise sources and to also include the cumulative noise exposure in studies. The European Network of Noise and Health (ENNAH) has successfully drawn on European-wide expertise and research and has identified a number of gaps for future research considerations and will likely play a major role in this subject area going forward.

Recommendations

1. Earplugs – Insertable-type earplugs offer a very popular, inexpensive, effective, and comfortable approach to provide hearing protection. To be effective, earplugs must be inserted properly to create an air-tight seal in the ear canal. The wax impregnated moldable polyurethane earplugs provide an effective universal fit for all users and provide 30 to 35 dB of noise protection across all frequency bands.
2. Communication headsets – In general, headsets provide the same level of noise attenuation as earmuffs and are also more easily donned and removed that earplugs, but the microphone can interfere with the donning of an oxygen mask.
3. Active noise reduction headsets – This type of headset uses active noise reduction technology that allows the manipulation of sound and signal waves to reduce noise, improve the signal-to-noise ratios, and enhance sound quality. Active noise reduction provides effective protection against low-frequency noise. The electronic coupling of a low-frequency noise wave with its exact mirror image cancels this noise.
4. Combinations of protection devices – The combination of earplugs with earmuffs or communication headsets is recommended when ambient noise levels are above 115dB. Earplugs, combined with active noise reduction headsets, provide the maximum level of individual hearing protection that can be achieved with current technology.

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