Aircraft noise health impacts and limitations in the current research

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ABSTRACT

Continuous growth of the aviation industry draws attention to the consideration of health effects associated with aircraft noise exposure. The narrative literature review of aircraft noise health effects described herein sought to explore the latest scientific findings and consider what type of limitations are present in the studies that could negatively impact the validity of the research findings. The literature screen was initially conducted in June 2018 within the EU H2020 research project ANIMA (Aviation Noise Impact Management through Novel Approaches) and, for some of the outcomes, a second exercise was carried out in June 2019. This combined literature review gives a stronger evidence base for the health effects of aircraft noise exposure on the cardiovascular and metabolic system, sleep quality, cognitive functioning, mental health and well-being, as well as the extent to which these outcomes are associated with annoyance. The findings also show that various study limitations are present in the research. The quality of research and, consequently, its validity could be improved, if limitations in study design, participant selection, exposure assessment, outcome characterization and confounding were considered and addressed in more detail.

Keywords: aircraft noise, health impacts, study limitations

INTRODUCTION

Globally, the aviation industry experienced continuous growth until the advent of the pandemic, as shown in the annual 2018 Air Transport Statistical ICAO report. In 2017, a new record of 4.1 billion passengers carried by the aviation industry was reported, indicating an increase of 7.1% over the year 2016 [1]. The cargo air traffic, though less prominent than passenger traffic, had also shown a 3.8% global growth in terms of freight tonne kilometres towards the end of 2016 [2]. This suggests that, in the future, the propensity to travel by air will continue to grow. However, environmental awareness will have continuous and significant influence on the growth of the aviation industry [2]. One of the primary targets of environmental awareness with regard to the aviation industry is noise reduction, since well-being, quality of life and health are known to be negatively affected by noise [2, 3, 4, 5, 6, 7].

Health outcomes investigated in relation to aircraft noise exposure are noise annoyance, sleep disturbance, cognitive impairment, cardiovascular disease and metabolic disorders, adverse birth outcomes, hearing impairment and tinnitus, mental health and well-being [7, 8, 9].

Based on a number of comprehensive literature reviews [10, 11, 12, 13, 14, 15], the World Health Organization (WHO) recommended that average noise exposure to aircraft noise levels should be reduced to below 45 dB L_{den} and below 40 dB L_{night} during the night in order to prevent an occurrence of adverse health effects [7]. Still, the authors of these reviews emphasize that more and better quality studies are needed for the comprehensive assessment of aircraft noise effects on health. All research studies unavoidably have some limitations, knowledge of these limitations is essential in research progress to address how future studies could be improved [16]. Limitations present in the research might have been responsible for high levels of measurement error, residual and unmeasured confounding, threatening the validity of findings from these studies. It is also possible that such limitations could have prevented demonstration of the relationship between aircraft noise exposure and health effects [17]. With this narrative literature review of aircraft noise health effects, we wish to address the latest scientific findings and consider what type of limitations are present in the studies that could negatively impact the validity of the research findings.

METHODS

A systematic literature search of the databases MEDLINE (PubMed) and EMBASE (Science Direct) for original studies investigating adverse health effects of aircraft noise exposure was implemented in two steps. In the first step, a literature search was carried out within the EU Horizon 2020 research project ANIMA (Aviation Noise Impact Management through Novel Approaches). This search was limited to studies published after the end date of previous systematic reviews, commissioned by the World Health Organization (WHO) for the development of the new Environmental Noise Guidelines [7], and included studies published up to June 2018. General search terms applied were “environmental noise, exposure levels, transportation noise OR aircraft OR air traffic OR airport noise” in combination with the different search terms of health outcomes: noise annoyance, cardiovascular disease, adverse metabolic outcomes, sleep disturbances, cognitive impairment, mental health and well-being. The search strategy was adapted to the respective database and is presented in more detail in the ANIMA deliverable D2.3 “Recommendations on noise and health” [18]. In the second step, a literature search for the health outcomes of the cardiovascular system was repeated in June 2019.

Studies were included if the following set of criteria were met:

1. Noise exposure assessment implemented with noise measurements or noise modelling.
2. Noise from aircraft or airports, measured or modelled separately from other noise sources.
3. Studied health impacts that fall into categories of cardiovascular disease, adverse effects of metabolic system, sleep disturbance, cognitive impairment, mental health or well-being and health and noise annoyance.
4. Analysis of the relationship between above mentioned health impacts and aircraft noise exposure.

Extraction of the data from the reviewed articles is presented in more detail in the above mentioned ANIMA report [18].

In the final part of this literature review, we provide insights into the limitations to the research approach present in the reviewed studies, as they were identified by the studies' authors themselves. We placed the identified limitations into five groups; study design, participant selection, exposure assessment, outcome characterization and confounding.

RESULTS AND DISCUSSION

Cardiovascular disease and adverse effects on metabolic system and aircraft noise

The latest findings on the cardiovascular effects of aircraft noise exposure are consistent with those identified in the previous systematic reviews [14, 19, 20, 21, 22]. New studies showed that the association between aircraft noise and hypertension was particularly significant when subjects were exposed to noise for longer periods (5-year exposure window prior to diagnosis), when they were exposed to a combination of traffic noise sources [23], and when they were also exposed to noise during the night [24]. Zeeb and collegues [25] observed that the association with hypertension arose only in patients with subsequent hypertensive heart disease. Research on ischaemic heart disease (IHD) demonstrated that aircraft noise exposure was associated with myocardial infarction [26, 27]. In a study where people were exposed to aircraft noise, with events exceeding a maximum sound level of 50 dB(A), an increase in risk (HR 1.074 (95% CI; 1.020 – 1.127) for ischaemic stroke was observed [27]. No association was observed for haemorrhagic stroke [27, 28]. The adverse effects on the metabolic system associated with aircraft noise exposure were diabetes type II and obesity or overweight. Eze and coworkers [29] observed a strong statistically significant association between aircraft noise exposure and type II diabetes, with an estimated risk RR 1.71 (95% CI; 1.02 – 2.88). Previous comprehensive reviews could not provide such strong conclusions to the effect of aircraft noise exposure on diabetes type II [14, 30]. Pyko and collegues [31] and Foraster et al [32] observed inconclusive results regarding the association between aircraft noise exposure and markers of obesity and overweight, stronger association was observed for females and subjects exposed to aircraft noise for longer periods. Based on the limited evidence, previous comprehensive reviews similarly resolved that there are some indications for the association between aircraft noise exposure and markers of obesity [14].

Sleep quality and aircraft noise exposure

The WHO states that environmental noise is a major factor which negatively influences sleep quality and sleep duration [33]. The current review includes 13 studies investigating the effect of aircraft noise exposure on physiological measures of sleep (via polysomnography and actimetry) and psychological measures such as sleep quality and sleep disturbances (self-reported measurements). Four studies used physiological measurements to assess the effect of aircraft noise exposure on sleep. In two studies by DLR (German Aerospace Centre), the effect of noise on sleep was measured via polysomnography. Müller and collegues [34] found an association between the night flight ban at Frankfurt Airport and decreased number of awakenings. The number of awakenings associated with aircraft noise declined from 2.0 to 0.8 after the implementation of the night flight ban for those participants, who went to bed between 22:00-22:30 and got up early between 06:00-06:30.

Basner and coworkers [35] compared the awakenings per night for participants exposed to aircraft noise versus participants of a control group, indicating no difference in awakenings between the groups. Müller et al [36] measured participants' motility during sleep as an indicator for sleep quality. Results indicate more body movements in participants exposed to higher sound pressure levels.

With regard to self-reported sleep outcomes, studies used different scales and questionnaires to assess the impact of aircraft noise exposure on sleep quality or sleep disturbances. Five studies assessed sleep disturbances due to aircraft noise [34, 37-40]. Other studies measuring psychological sleep outcomes assessed sleep insufficiency, insomnia, tiredness, and sleep quality [35-36, 41-45]. Kwak and collegues [44] found a significant difference in reported sleep disturbance between a control group and a low and high aircraft noise exposure group. Holt et al [45] did not find a significant difference in sleep insufficiency when comparing groups of participants with different lower and higher noise levels.

Measures of sleep differed greatly between these studies. Nevertheless, eleven of twelve papers found an effect of aircraft noise on self-reported sleep measures, i.e. participants reporting more sleep disturbances, a poorer quality of sleep, as well as tiredness due to nocturnal aircraft noise.

Mental health and well-being

In this section, different outcomes for mental health and well-being were examined. Seven studies were included assessing the impact of aircraft noise exposure on self-reported quality of life and well-being [46-49], self-reported depression, anxiety or (other) psychological symptoms [43, 50], and interview measures of diagnosed unipolar depression [47].

Two studies on self-reported quality of life and well-being included short-term measures, e.g. happiness; two studies assessed long-term quality of life. In a new approach, an experience sampling method was used in a study linking current data on happiness with noise contour data from the exact position of participants showing higher levels of aircraft noise exposure associated with lower levels of happiness [48]. In another study on short-term well-being, the rated well-being for one day was linked to noise contour data [49] indicating negative associations between daytime noise exposure and well-being rates. Two sub-studies from the NORAH study examined long-term quality of life in children [46] and adults [47]; both indicating that higher levels of aircraft noise exposure are linked to poorer mental quality of life.

Two studies were identified examining self-reported depression and psychological symptoms. Hiroe and collegues observed differences in depression scores between a high aircraft noise exposure group and a control group at a major Japanese airport, but no exposure-response relationship could be shown [43]. In the French DEBATS study the impact of aircraft noise exposure on self-reported psychological symptoms were observed. Baudin and coworkers reported no association between exposure to aircraft noise and psychological distress regarding different noise levels and two types of psychological distress assessment [50].

Regarding diagnosed depression, Seidler et al [51] examined the health insurance data of residents in the vicinity of Frankfurt Airport. Results show a relationship between aircraft noise exposure and diagnosed unipolar depression in an inverted u-shape with a peak of risk increase at 50-55 dB(A) [51].

Recent studies indicate that aircraft noise exposure has an impact on quality of life measures. The evidence for an association of aircraft noise exposure with psychological symptoms and disorders are inconsistent. Different outcome measures in the scope of mental health and well-being make it difficult to compare the found evidence. Thus, it is important to examine standardised concepts and measures.

Annoyance and health outcomes

In line with the general stress-response model, noise annoyance and sleep disturbances are considered both as health outcomes, as well as mediating factors contributing to the development of other health effects [52-53]. The WHO highlights noise annoyance and sleep disturbances to be potential mediators of other long-term health impacts [6]. In order to shed light on the relationship between aircraft noise annoyance and other health outcomes, a narrative literature review was conducted to condense findings. This publication focused on eight studies investigating the relationship between noise annoyance and other health outcomes that included underlying noise data.

For cardiovascular diseases, two studies found noise annoyance to be associated with hypertension [54-55], whereas one study found no significant association between blood pressure levels and aircraft noise annoyance [56]. The link between noise annoyance and sleep measures was investigated in two studies, showing that annoyance was related to poorer sleep quality [57] and more reports of sleep disturbances [58]. Further, for mental-health and wellbeing related measures, noise annoyance was shown to be related to psychological distress [50] and a negative association between noise annoyance and mental-health related quality of life was found [47]. Physical activity, defined as behaviour with generally restorative functions and contributing positively to health, was found to decrease with long-time aircraft noise annoyance [59].

Due to the small number of studies and the differing measures, the evidence is not sufficient to draw consistent general conclusions. Thus, results indicate that aircraft noise annoyance might be an important mediator for health outcomes and, therefore, along with sleep disturbances, may contribute to the effect of aircraft noise on various health outcomes.

Cognitive impairment and aircraft noise exposure

Only one recent study investigating the impact of aircraft noise exposure on children's cognition was identified. In this study, a significant association between exposure to aircraft noise and children's reading, well-being at school and annoyance was observed. A 20 dB(A) increase in aircraft noise exposure was associated with a two months delay in reading and oral comprehension [46]. Similar conclusions were observed in the WHO review [12], where a one month delay in reading and oral comprehension in children was observed when aircraft noise levels exceeded 55 dB L_{den}. For future studies, Klatte and collegues [46] recommended inclusion of information on socio-economic status and the number of books at home.

Limitations of the current research in defining the relationship between aircraft noise exposure and health impacts

Our evaluation of the epidemiological studies on the relationship between aircraft noise exposure and health outcomes showed that several limitations in the implementation of the studies might have influenced the estimation of the association between exposure and outcome of interest. Careful consideration of the limitations that can occur during the research would significantly improve the quality of studies, providing a higher quality of evidence.

Table 1: List of limitations observed in the evaluated studies

Categories	**Limitations**
Study design	retrospective design
	unknown temporal relationship
	ecological fallacy
Participant selection	low response or participation rate
	selective non-response
	self-selection
Exposure assessment	non-acoustical measurements of noise exposure
	lack of information on indoor acoustical properties
	long-term average noise indicators
	small number of people exposed to high noise levels
Outcome characterization	self-reporting and non-differential disease misclassification
	lack of a more detailed differentiation between diseases
	no health data available on smaller spatial scale
	lack of information on cause-specific mortality
Confounding	lack of adjustment for basic confounders
	no personal lifestyle data
	lack of information on the period of residence at location

Study design

The role of the study design on the results of the epidemiological research was discussed in detail in 2010 [60]. Each study design has its strengths and weaknesses, demonstrating temporality is regarded as an important indicator when causality is being considered. For this reason, prospective instead of retrospective studies are encouraged, as the former allow us to reduce reverse causality by studying exposure before the occurrence of an outcome [61]. An ecological exposure assessment approach is also prone to measurement error as such assessed exposure is not applicable for an individual's exposure (ecological fallacy). Prospective longitudinal cohort studies including a good follow-up, as well as interventional studies, are considered best suited for examining causation [61-63].

Participant selection

One of the challenges in participant selection is the continuous decline in study participation in recent years, as a high response rate is crucial for an estimation of the exposure impact valid for the underlying population [64]. Fincham (2008) recommends that the goal for researchers should be a 60% response rate [65]. On the other hand, the representativeness of the study results was not affected, if the non-response/-participation was random, but this is usually difficult to assess [64]. Another challenge frequently observed in aircraft noise impact studies is that, along with a high response rate, a selective non-response was present [66]. Some of the evaluated studies [24, 66] had a small number of participants and low number of outcomes of interest. Such small studies are prone to large standard errors, with wide confidence intervals and imprecise estimates of the effect; they may also produce false-positive results, or over-estimate the magnitude of an association. In the implementation of such studies, firm conclusions about the risk factor should not be made/should be made with caution [67].

Exposure assessment and application of noise metrics

Exposure data obtained through questionnaires (using non-acoustical measures of noise exposure, like percentage of highly annoyed from aircraft noise exposure) is highly unreliable and should not be equated with sound measurements or modelling. Most of the studies measure individuals' noise exposure at the most exposed façade of their home. This measurement method may pose two causes of exposure misclassification. The first one is participants' day-time mobility, as during the day they are more likely to be outside their home [29, 66]. The second one is that such a method does not account for acoustic properties of participants' homes (orientation of bedroom, noise insulation of windows), the use or implementation of other noise protection measures or individuals' coping strategies, such as window opening and closing behaviour. There might be differential attenuation of noise penetrating indoors due to building characteristics and coping behaviour. In other words, most of the studies do not have any information on indoor noise levels, which might be a more reliable assessment of one's true exposure, as especially in the vicinity of many airports with high noise levels airports subsidize the installation of sound-proofed windows [29, 31, 68, 69]. The use of more detailed exposure models considering building noise insulations and indoor noise characteristics can improve the knowledge of the association. Difficulties in drawing stronger conclusions could also be attributed to the small number of people exposed to high aircraft noise levels [31].

There is an ongoing debate on the relevance of long-term average noise indicators in describing the relationship between aircraft noise exposure and health effects. The use of amendments to the L_{den} has been previously discussed [70,71]. Researchers have been encouraged to consider noise metrics that more efficiently characterize the temporal variation of the sound and its emergence, instead of only considering averaged exposure levels [72]. Such additional event related indicators are, for example, the number of events exceeding a certain L_{Amax} level [26, 66]. Some of the reviewed studies [27, 69] used a complementary noise metric intermittency ratio (IR), introduced in the SiRENE project [72, 39], reflecting short-temporal variations of transportation noise exposure. In these studies, the IR was found to be associated with several health outcomes, however, in a complex and inconsistent way, depending on the outcome and noise source. Noise metrics should reflect individual time periods, and be used corresponding to the activities people are doing at that time. For example, noise metrics individually reflecting the night-time period, when people are sleeping. It has been observed that noise disturbance during the night is considered relevant for the development of many types of cardiovascular disease [21, 28, 31, 73].

Outcome characterization

Non-differential disease misclassification may occur when health data concerning the outcome of interest are obtained through self-reports and not through differentiated/specific diagnoses by qualified health personnel. This may cause an under- or over-reporting of a disease [63, 74]. In health outcome characterization it is also important to consider that the lack of differentiation between outcomes could be responsible for the underestimation of the risk for a specific disease [22]. An example of this was found in the current review, where an association was observed for ischaemic stroke, but no association was observed when all cases of stroke were considered. Health data obtained from health databases present another issue, as they usually lack information for smaller spatial scales. Therefore, linking health data with local, if not address-related noise exposure data is difficult. Furthermore, if individual secondary health data (e.g. from health insurance organisations) are available, this data can be linked to individual exposure data, but it often lacks information on individual characteristics and behaviour that might be relevant confounding risk factors of the health outcome of interest.

Confounders and effect modifiers

Aircraft noise and health studies should adjust their study analysis for at least basic confounders and modifiers to ensure that associations in the analysis are not a result of an unadjusted or not efficiently controlled confounder. Various factors such as the physical environment and socioeconomic factors contribute to the pathogenesis of a disease. The social environment, for example, shapes lifestyle choices that significantly modify disease risk [75]. Basic potential confounders for environmental noise and health studies are age, gender, socioeconomic status, smoking, body-mass-index, physical activity, alcohol consumption, ethnicity, noise-sensitivity, decreased sleep quality due to exposure to noise at night, air pollution, family history of diabetes mellitus [53, 76]. In the majority of the studies included in this review, such data were missing or not all confounders were considered.

As it is anticipated that a certain time-period is needed for the occurrence of a disease, longer exposure windows prior to outcome occurrence and length of living in the vicinity of an airport should be considered in the association analysis [23-25].

CONCLUSIONS

This evaluation adds, to the available evidence from previous comprehensive reviews, a stronger basis for the relationship between aircraft noise exposure and risk for cardiovascular disease, adverse effects on the metabolic system, cognitive functioning in children, sleep quality, mental health and well-being and noise annoyance. Nonetheless, the research findings are still inconclusive and new studies of high quality are needed to obtain a more reliable estimate of aircraft noise health impact. The quality of the research studies could be improved, if limitations in study design, participant selection, exposure assessment, outcome characterization and confounding were considered and addressed.

CONFLICTS OF INTEREST

The authors declare that no conflicts of interest exist.

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