ANIMA
Aviation Noise Impact Management
through Novel Approaches

D2.3 Recommendations on noise and health

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[1] Use one of the following codes: R=Document, report (excluding the periodic and final reports)
DEM=Demonstrator, pilot, prototype, plan designs
DEC=Websites, patents filing,press & media actions, videos, etc.
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Table of Contents

1 Executive Summary

The air transport industry makes an important contribution to the economy, quality of life and well-being (e.g. through the supply of services in support of leisure, family/cultural links). However, like practically any (economic) activity it is also associated with some unwanted by-products, most notably a range of environmental impacts, one of the most significant of which for local communities, is noise intrusion.

This deliverable provides an overview of the considerable evidence collected by researchers investigating the health implications arising from aircraft noise exposure. Specifically, it reviews and updates the meta-analyses conducted on behalf of the WHO to inform their latest Environmental Noise Guidelines for the European Region (WHO, 2018). The WHO evidence base has been supplemented with a review of research published since the cut off for the WHO meta-analyses (circa 2014).

These reviews demonstrate associations between aircraft noise exposure (as measured using long-term aggregate averaged outdoor sound levels) and ischemic heart disease, annoyance, reading and oral comprehension as well as sleep disturbance during the night. For other health outcomes statistically significant associations were not observed, whether this is due to the lack of association or due to the unresolved uncertainties in the research is still unknown; leading to the conclusion that future studies should focus on addressing these limitations.

Drawing on their evidence base, the WHO has identified sound exposure levels "above which the GDG [Guideline Development Group] is confident that there is an increased risk of adverse health effects" (WHO, 2018:20). In turn they have given the highest priority to the avoidance of annoyance and sleep disturbance. Consequently, the WHO 'strongly recommends' that noise levels produced by aircraft should be reduced to below 45dBA L_{den} and 40dBA L_{night} (2018b:6) based on the percentages of the population reporting that they are a) 'highly annoyed' and b) 'highly sleep disturbed', respectively. The WHO regards these as important health outcomes in their own right as well as potential mediators of other long-term health impacts (Eriksson et al., 2018). **Significantly, in our review some associations were made between sleep disturbance, annoyance and certain long-term health outcomes, indicating that sleep disturbance and reported annoyance may be mediators of some adverse health impacts.**

At the most basic level these WHO recommendations require political processes to be established that allow for balancing the costs of achieving reductions in risks to health (in terms of the economic and social cost of constraining airport/aviation development) against risks to the health of populations exposed to noise.

Whatever the outcome of these broader deliberations, it is desirable that every effort is made to ensure effective and efficient use of any resources deployed to mitigate risks. With this in mind, **the WHO reviews, and the review conducted as part of this sub-task in ANIMA, highlight the importance of addressing reported annoyance and sleep disturbance as the most critical outcomes**; given that on the one hand they represent direct disturbance and irritation to residents living near airports, and on the other hand persistent annoyance and sleep disturbance have been linked to other adverse health effects through the stress mechanism. Consequently, it can be hypothesised that reducing reported annoyance and sleep disturbance would decrease adverse health effects of aircraft noise and improve well-being/quality of life.

An examination of the association between reported annoyance and health, and links with sleep disturbance (measured both physiologically and by self-report) suggests that mitigation efforts should focus on annoyance outcomes in addition to reduce noise exposure. ANIMA deliverable D2.4 provides evidence that, for such efforts to be enhanced, they must address the full suite of acoustic and non-acoustic contributions to noise annoyance. To date, management interventions and indeed impact studies have only partially addressed these contributions. Thus, **going forward, we need to encourage a more *comprehensive* approach both in the design and evaluation of noise interventions, and in the assessment of the long-term consequences arising from noise exposure**.

Such an approach will need to place additional emphasis on the *process* by which interventions are designed, decided upon and implemented to address all potential (significant) acoustic and non-acoustic contributions to annoyance.

This recommendation to adopt a more comprehensive approach to annoyance mitigation highlights the **need for research** to:

- Establish how interventions have influenced (and may influence in the future) annoyance outcomes and, by implication, well-being/Quality of Life (QoL) and thereby potentially mitigate long-term health risks (ST 3.1.2 addresses this requirement specifically)
- Assess the impact of engagement processes associated with noise management interventions for their ability to modify non-acoustic factors known to exacerbate the annoyance response (ST 3.2.1 is designed to establish the impact of such a communication intervention on attitudes to source, trust and annoyance levels)

From a health impact assessment perspective, this more comprehensive view of the determinants of reported annoyance and, in particular, the **wider *acoustic context* could be used to inform future epidemiological studies**, which would have added value if associations were made to a wider range of acoustic variables (e.g. attempts to take event noisiness; the numbers of those events, and the temporal distributions of those events in relation to other background noise sources present, into account) and also adjusted for influences on the noise actually experienced by individuals for which conventional long-time averaged outdoor measurements provide only a partial description. Various life-style factors such as the percentage of time spent outdoors, indoor sound sources, propensity to open windows, and time spent away from the area entirely, may be of greater or lesser relevance for different individuals in different situations.

2 Introduction

In this report, we begin by providing an outline of the context of a review on the relationship between aircraft noise and health. This is followed by a brief discussion of the approach taken, which includes the aim, guiding principles, and methods applied under them. It does so in a systematic, comprehensible, and – as far as possible – replicable way.

2.1 Context

This report 'D2.3' is the result of subtask 2.2.1 of Work package (WP) 2 of the **ANIMA** project. As such, it has some connections to other sub/tasks and WPs. The aim in this context was to minimise overlaps between different reports, where possible, while at the same time ensuring that each report is entirely comprehensible by itself.

This report therefore is intended to complement and in parts build on D2.4, 'Recommendations on annoyance mitigation and implications for communication and engagement', insomuch as, whilst both focus address the annoyance response to aircraft noise, D2.4 looks to a more psychological lens to discuss both acoustic and non-acoustic contributors of annoyance. D2.3 on the other hand, focuses very much on short-term physiological responses and long-term health associations.

Suggestions for how this deliverable can be further utilised as an informative aid and contribution to future studies can be found in the final section.

2.2 Approach of the Report

The main aim of this work is to systematically review scientifically well-founded evidence used to underpin noise and health impact assessments. With this in mind, the deliverable is guided by two core principles:

1. Firstly, this report is founded in evidence relating to the key health impacts arising from environmental noise exposure resulting from aircraft, acknowledging the most recent Environmental Noise Guidelines for the European Region (WHO, 2018).
2. Additionally, the report focuses on the degree of community health risk. Particular inherent challenges addressed within the discussion of such health risks include the extrapolation to long-term health impact predictions, and limitations of statistical association when considering specific causality of impact. This should help inform management responses and the development of a comprehensive rationale for the management of health risk (both positive and negative contributions associated with the airport).

Guided by these principles, we have taken a phased approach consisting of a literature review, a discussion of the basis of these risks and the management implications and associated research gaps.

The literature review starts by outlining the noise-health impact model. It introduces the areas of theoretical causation, statistical associations and the types of evidence used to underpin assessed health impacts. Particular focus is paid to the distinction between short-term physiological response and long-term health impacts.

Through the course of section 3, a study review of specific key health impacts arising from aircraft noise exposure is systematically outlined and discussed, addressing all health impacts identified by the World Health Organisation (WHO).

Section 4 summarises the community health risks and acknowledges inherent uncertainty in the evidence base. The key risks that underpin the recent WHO recommended noise exposure levels are highlighted.

Section 5 addresses the question of how a responsible industry should respond to these risk thresholds when encouraging a more comprehensive approach to annoyance mitigation. Associated research priorities are identified in support of effective and efficient noise management interventions and more refined assessments of health impacts.

It is important to note that some sections are more derivative and some more literature based. Sections that focus on substantive health impacts are heavily founded in literature, the review of which can be found in sections 3.1 to 3.8. These sub-sections are introduced by an overview of the exposure response model (Section 3), which is arguably the basis of all concerns about the impacts relating to initial exposure, and pathways to impact. The literature search process and a list of core search engines can be found in Annex 7.1 “Approach to research”.

Sections 4 and 5, however, take a slightly different approach, focusing on efforts by the industry to effectively mitigate the noise impacts evidenced in previous sections. They pose further questions about what the industry could do in light of a more comprehensive view and therefore systematic approach.

As indicated above, the methodological approach to undertaking each of the component reviews in this report is described in Annex 7.

3 Substantive Health Impact Reviews

Exposure to noise levels below those known to cause hearing impairment can result in annoyance, sleep disturbance, cognitive impairment, physiological stress reactions, endocrine imbalance, and cardiovascular disorders (Babisch, 2011). Lately, other health outcomes have been associated with noise exposure, such as metabolic disorders, and adverse birth outcomes (Basner et al., 2014). Observational field studies and epidemiological studies play an important role in explaining the effect of environmental noise exposure on health experimental laboratory studies. Field studies show that whilst high noise levels have an acute effect, relatively low environmental noise levels can also have an acute effect if concentration, relaxation or sleep is disturbed (Münzel et al., 2014; Eriksson and Pershagen, 2018).

A general stress-response model is used as the rationale behind the health response to noise exposure, as noise is a known bio-psychosocial stressor that can affect physiological functioning (Babisch, 2003; Basner et al., 2014, Eriksson and Pershagen, 2018).

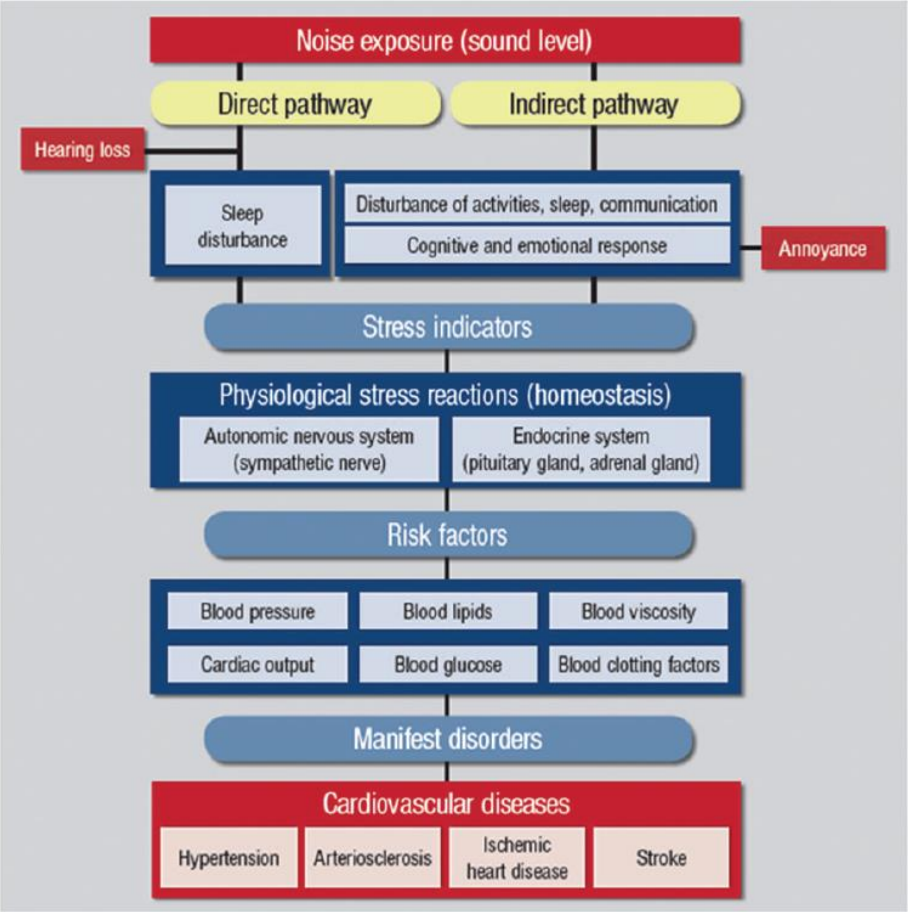


Figure 1: Noise reaction model (Münzel et al., 2014 from Babisch, 2002 and Babisch, 2014)

As Figure 1 illustrates, the noise reaction model identifies two principal pathways relevant to the development of adverse health effects due to noise exposure (Job, 1996; Babisch, 2002). This refers to the 'direct' and 'indirect' arousal and activation of the organism (Babisch et al., 2013). 'Direct' pathways of noise reaction refer to the instantaneous unconscious interaction of the acoustic nerve with different structures of the central nervous system. 'Indirect' noise reaction pathways refer to the conscious cognitive perception of the sound, its cortical and subcortical structure activation and related hormonal and conscious emotional responses. This is why it is assumed that noise annoyance plays an important role in modifying effects (Babisch, 2002; Münzel et al., 2014).

Although people tend to habituate to noise exposure, the degree of habituation differs across individuals and is rarely complete (Basner et al., 2014). Both reaction pathways can initiate physiological stress reactions, a so-called acute short-term response (Babisch, 2002, 2006; Ndrepepa and Twardella, 2011; Babisch et al., 2013; Basner et al., 2014). In the daytime, when subjects are awake, the predominant source of stress reactions is assumed to be the 'indirect' pathway through conscious experience, whereas in sleeping individuals, during the night, the non-conscious 'direct' pathway is assumed to be the predominant mechanism of impact even at low noise levels (Babisch, 2002; Rylander, 2004). This means that both the unconscious neural processing of sound exposure and the conscious perception determine the impact of noise on neuroendocrine homeostasis (Babisch, 2002; Münzel et al., 2014). Physiological stress reaction initiates a fight or flight response, activating the subcortical regions of the brain like the hypothalamus. The hypothalamus in turn activates the autonomic nervous system, the endocrine system, and the limbic system, causing a secretion of catecholamine’s (adrenaline and noradrenaline) and cortisol. These hormones cause changes in a number of physiological functions, like homeostasis of several organs, which can be seen as short-term changes in blood pressure, cardiac output, blood lipids (cholesterol, triglycerides, free fatty acids, phosphatides), carbohydrates (glucose), electrolytes (Mg, Ca), thrombosis/fibrinolysis and other (Chrousos and Gold, 1992; Henry, 1992; Lundberg, 1999; Spreng, 2000; Münzel et al., 2014). These are well known risk factors for the development of diseases such as cardiovascular, metabolic and other stress-related diseases (Babisch, 2002).

Generally, the stress response (fight/flight reaction and its physiological stress response) is meant to be acute or at least of a limited duration. The time-limited nature of this process renders its accompanying anti-anabolic, catabolic, and immunosuppressive effects temporarily beneficial and of no adverse consequences (short-term effects). Long-term noise exposure is assumed to cause chronicity and excessiveness of stress system activation. This effects metabolism and the cardiovascular system, which in turn may increase established cardiovascular disease risk factors such as blood pressure, blood lipid concentrations, blood viscosity, and blood glucose concentrations (Chrousos and Gold, 1992; Henry, 1992; Eriksson and Pershagen, 2018). These changes may increase the risk of hypertension, arteriosclerosis, and may be related to severe events, such as myocardial infarction and stroke (Chrousos and Gold, 1992; Lundberg, 1999; Ising and Braun, 2000; Ising and Kruppa, 2004; Basner et al., 2014). Given the different acoustic characteristics of different noise sources (sound level, frequency spectrum, time course, sound level rise time, and psycho-acoustic measures) noise levels from different noise sources cannot be merged into one indicator of decibels. Different exposure–response curves are needed for different noise sources (Basner et al., 2014).

The question that public health is facing is no longer whether noise exposure causes health effects; rather there is a question as to what is the magnitude of these effects, and where is the onset or possible threshold of the increase in risk (health hazard) (Babisch, 2011).

3.1 Cardiovascular Diseases

Over the last twenty years, there has been a substantial shift of the major risk factors that contribute to the global burden of disease. Previously, important risks presented communicable childhood diseases, which were with substantial advances from that period and aging of a population in Western societies, replaced with non-communicable adulthood diseases. While the shift is not equally visible in the whole World because of different socioeconomic status, this stands true for Western Europe (WHO, 2007). Globally, of all-cause diseases and mortality, cardiovascular risk factors (arterial hypertension and smoking) and diseases (ischemic heart disease and cerebrovascular disease) represent the top four causes of death and reduced life quality due to illness (disability-adjusted life years, or DALYs) in humans. Among those, high blood pressure is the leading risk factor for all-cause mortality and has the most pronounced impact on life years spent with significant illness and disability in the population worldwide (Münzel et al., 2018).

Although the strength of the association varies significantly across studies, there is substantial evidence of the adverse effects from environmental noise exposure on the cardiovascular system (Münzel et al., 2018a; Münzel et al., 2014; Münzel et al., 2017; van Kempen et al., 2018). Studies of chronic traffic noise exposure are investigating the relationship with cardiovascular health outcomes such as elevated blood pressure, hypertension, ischaemic heart disease (including myocardial infarction), stroke, heart failure, and atrial fibrillation (Münzel et al., 2018a; Münzel et al., 2014). Also, some of the studies have evaluated the health burden of medical and economic implications from environmental noise (Münzel et al., 2014; Harding et al., 2013).

The aim of this section is to present key risks to the cardiovascular system arising from aircraft noise exposure. First, we will present the WHO’s position on the exposure-response relationship between diseases of the cardiovascular system and exposure to aircraft noise. We then present supporting conclusions of the studies, which have not yet been included in the WHO review.

3.1.1 Brief summary of the WHO review on the impact of aircraft noise on cardiovascular system

In 2018, the WHO commissioned a new systematic review to evaluate the latest studies on the impact of environmental noise (noise from air, road and rail traffic and wind turbines) on the cardiovascular and metabolic system. The purpose of this review was to provide input to the new environmental noise guidelines for the European Region, as the new guidelines should be based on the latest scientific knowledge (van Kempen et al., 2017; van Kempen et al., 2018).

The WHO review included studies with an observational study design that were published in the period between 2000 to August 2015. The main cardiovascular health effects under investigation were hypertension, ischaemic heart disease and stroke. In order to retain the link with the European Environmental Noise Directive 2002/49/EC (END) and for the meta-analysis implementation, all non-L_{den} metrics from the evaluated studies were transformed into L_{den} (European Parliament and Council of the European Union, 2002).

Hypertension is an important medical condition, which is also a significant risk factor for other cardiovascular diseases and is the leading cause of cardiovascular mortality (WHO, 2013). In their review, the WHO observed that though increased risk for hypertension was associated with increased exposure to road traffic noise, no significant increase of the risk associated with increased aircraft noise exposure was observed. They stated that other meta-analysis came to similar conclusions. On the other hand, they assessed the quality of evidence supporting estimated associations between hypertension and environmental noise to be very low, meaning this estimate of effect is very likely to be changed in the future (van Kempen et al., 2018).

From the reviewed studies, the WHO observed that the increased risk for **ischaemic heart disease** (IHD, also known as coronary artery disease) was statistically associated with increased exposure to aircraft noise. It was observed that aircraft noise was associated with the prevalence, incidence and mortality caused by IHD. However, only the association with the incidence of IHD was found to be statistically significant. The review authors conclude that even though the evidence of this finding is considered as very low quality - and as such these estimates are very likely to be changed in the future - these findings are consistent with recent longitudinal studies, which report positive associations between aircraft noise and mortality due to IHD (van Kempen et al., 2018).

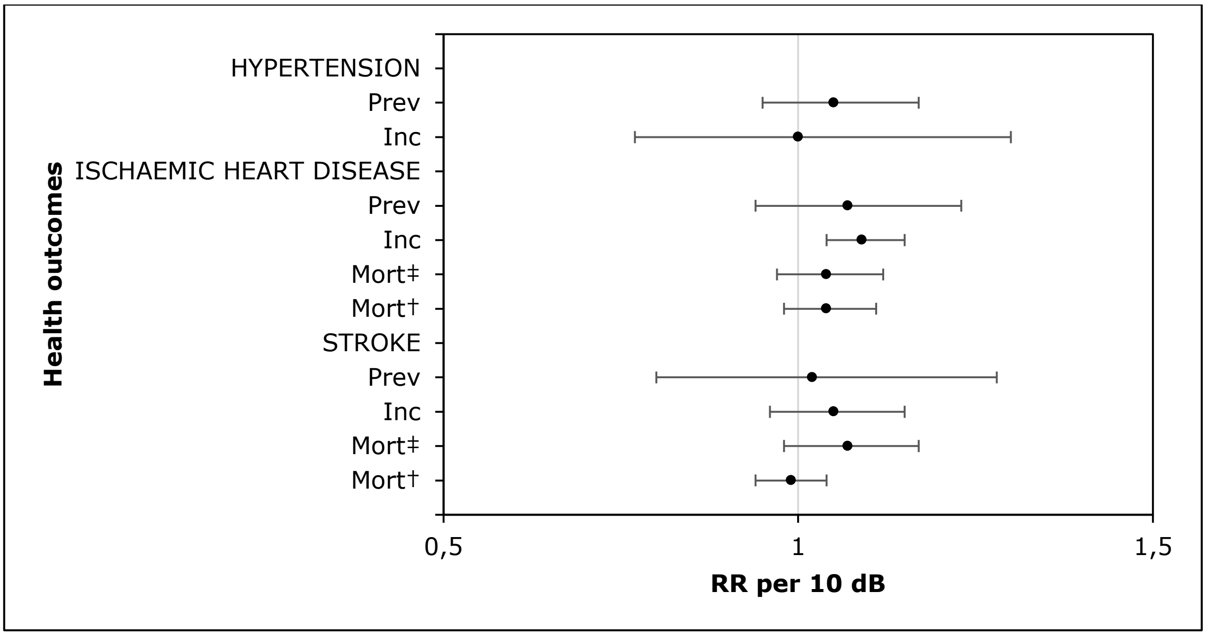
Stroke was identified to be associated with an increase in both prevalence and incidence of stroke. None of these associations seen in ecological and cross-sectional studies were statistically significant. The observations found the prevalence and the incidence of stroke were supported only by the results of the ecological studies on the association between air traffic noise and mortality due to stroke. No such association was observed in the evaluated cohort study. These results are consistent with recent longitudinal studies, which showed no clear indications of association (van Kempen et al., 2018).

The evaluated estimates for the investigated cardiovascular health outcomes are presented in Table 1 and Figure 2.

Outcome		No. of studies/ Design	RR per 10dBA (95% CI)	No. of participants (cases)	QoE*
Hypertension	Prev	9 CS	1.05 (0.95 – 1.17)	60,121 (9,487)	++
	Inc	1 CO	1.00 (0.77 – 1.30)	4,721 (1,346)	++
Ischaemic Heart Disease	Prev	2 CS	1.07 (0.94 – 1.23)	14,098 (340)	+
	Inc	2 ECO	**1.09 (1.04 – 1.15)**	9,619,082 (158,977)	+
	Mort	2 ECO	1.04 (0.97 – 1.12)	3,897,645 (26,066)	+
		1 CO	1.04 (0.98 – 1.11)	4,580,311 (15,532)	++
Stroke	Prev	2 CS	1.02 (0.80 – 1.28)	14,098 (151)	+
	Inc	2 ECO	1.05 (0.96 – 1.15)	9,619,082 (97,949)	+
	Mort	2 ECO	1.07 (0.98 – 1.17)	3,898,645 (12,086)	+
		1 CO	0.99 (0.94 – 1.04)	4,580,311 (25,231)	+++

Bold *– stat. significant association; Prev – prevalence; Inc – incidence; Mort – mortality; CS – cross-sectional; CO – cohort; ECO – ecological; QoE – quality of evidence; RR – relative risk; * – GRADE Working Group of evidence, ++++ – high quality, +++ – moderate quality, ++ – low quality, + – very low quality.*

Table 1: Aircraft noise exposure and the risk of cardiovascular disease as estimated by van Kempen et al. (2017, 2018)



Prev – prevalence; Inc – incidence; Mort – mortality; ‡ - from ecological study; † - from cohort study

Figure 2: Pooled exposure-effect estimates of aircraft noise exposure on cardiovascular diseases from van Kempen et al., (2017, 2018)

3.1.2 Updated review on aircraft-noise related cardiovascular disease

A detailed description of the approach to the literature search used in the current review in relation to cardiovascular disease is described in Annexes 7.1.1. and 7.1.2.

For the purpose of this review, we evaluated 10 studies investigating the impact of aircraft noise exposure on the risk of different cardiovascular health outcomes. Table 2 presents the main characteristics of the evaluated studies of the current review. The estimated risks for the observed health outcomes of evaluated studies are presented in the Table 3 and Table 4.

Due to the wide variety of different cardiovascular diseases investigated in the evaluated studies, we sorted studies depending on the group of cardiovascular disease under observation. These groups are hypertensive heart disease, ischaemic heart disease (including myocardial infarction), other forms of heart disease and cerebrovascular disease (including stroke).

In general, evaluated studies observed a positive association between exposure to aircraft noise and increased risk of mortality due to cardiovascular disease (Evrard et al., 2015; Heritier et al., 2017). Heritier et al (2017) observed that the effects of aircraft noise exposure on the cardiovascular system were less pronounced than those observed for other traffic noise sources. They attributed this to the ban on night-flights and the possibility that people who may not have been able to cope with aircraft noise may have moved away.

Empirical evidence illustrates a link between aircraft noise exposure and risk of mortality due to cardiovascular disease.

Study, pub. Year	Design, Period and location	Population	Outcome (ICD-10)	Noise assessment Noise indicator; noise range	Follow-up	Analysis	Adjustments	Description of the expos-resp relationship (dBA)
Evrard et al., 2015	ECO (2007-2010); France	Total = 1.9 million	CVD (I00-I52), Ischaemic heart disease (I20-I25), Myocardial infarction (I21-I22), Stroke (I60-I64, excluding I63.6);	Modelling (INM); L_{den} AEI; 42.0 – 64.1dBA	n/a	Poisson regression (MRR)	A, G, SES, lung cancer mortality, NO_2	Trend per 10dBA
Seidler et al., 2016a	CC (2005-2010); Germany	Total/cases = 1,026,670	Acute myocardial infarction (I21);	Digital landscape model; $L_{pAeq24h}$; $L_{pAeq,night}$; 40 – 65dBA	n/a	Logistic regression (OR)	A, G, SES	Trend per 10dBA and Noise categories (reference: 24-hour continuous noise level <40dBA)
Seidler et al., 2016b	0); Germany	Total/cases = 1,026,670	Heart failure (I50); Hypertensive heart disease (I11, I13.0, I13.2); Insurance billing register	Digital landscape model; L_{Aeq24h}; 40 – 65dBA	n/a	Logistic regression (OR)	A, G, SES	Trend per 10dBA and Noise categories (reference: 24-hour continuous noise level <40dBA)
Zur Nieden et al., 2016a	ECO (2012-2014); Germany	Total/cases = 844/132	Hypertension (I10); Physical examination of the subject	Field meas.; $L_{pAeq,18\text{-}06h}$	n/a	Logistic regression (OR)	A, G, SES, S, PA	Noise categories
Zur Nieden et al., 2016b	ECO (2012-2014); Germany	Total = 844	Systolic and diastolic blood pressure; Physical examination of the subject or laboratory measurement	Field meas.; $L_{pAeq18\text{-}06h}$	n/a	Logistic regression (OR)	A, G, SES, S, PA	Noise categories

CO-cohort study; CS-cross-sectional study; CC-case control study ECO-ecological study; CVD-cardiovascular diseases; AEI – average energetic index; INM; Integrated Noise Model; A-age; G – gender; S-smoking; SES-socio-economic status; NO_2- nitrogen dioxide; PA-physical; OR – odds ratio; MRR - mortality rate ratio

Table 2: Study characteristics of the updated review

Study	Design	Population	Outcome (ICD-10)	Noise assessment	Follow-up	Analysis	Adjustments	Noise categories (dBA)
Dimakopoulou et al., 2017	CO (2013); Greece	Total = 420	Hypertension (I10), Cardiac arrhythmia (I49.9), Myocardial infarction (I21-22), Stroke (I60-64)	Modelling (INM); L_{Aeq16h}, L_{night}; 30 – 60dBA	9 yrs; HYENA study	Multiple Logistic regression (OR)	A, G, S, BMI, E, PA, Al, Sa	Trend per 10dBA
Evrard et al., 2017	ECO (2013); France	Total = 1244;Male	Prev. of hypertension (I10);	Modelling (INM); L_{den}, L_{Aeq16h}, L_{night}; 50 – 60dBA	4 yrs; DEBATS Longitudinal study	Multiple Logistic Regression (OR)	A, G, BMI, PA, E, Al	Trend per 10dBA
Heritier et al., 2017	CO (2000-2008); Switzerland	Total/cases = 4.41 million	All CVD (I00-I99), IHD (I20I25); Stroke (I60-I64), Isch. stroke (I63), Hemorr. stroke (I60-I62), MI (I21-I22), Heart failure (I50), BP related death (I10-I15)	Modelling FLULA2; L_{den}; 30 - 60dBA	8 yrs; SiRENE project	Cox Proportional Hazards model (HR)	G, SES, MS, E, MT, N, NO_2	Trend per 10dBA
Zeeb et al., 2017	CC (2005-2010); Germany	Total/cases = 1,026,670/ 137,577	Morb. for hypertension (I10), Hypersensitive heart disease (I11)	Digital landscape model; $L_{pAeq24h}$; L_{night}; 40 - 60dBA	n/a	Logistic Regression (OR)	G, A, E, SES	Trend per 10dB and Noise categories (reference: 24-hour contin. noise level <40dBA)
Seidler et al., 2018	CC (2005-2010); Germany	Cases/controls = 25,495/ 827,601	Prim. hosp. discharge/ osec. diagnosis of stroke: I61-intracerebral haemorr. I63 –cerebral infarct. I64- stroke not specified as haemorr. or infarct.	Modelled: $L_{pAeq24h}$; $L_{pAeq,night}$; 40 - 70dBA	n/a	Logistic Regression (OR)	G,A, E, J, REB	Trend per 10dBA And Noise categories (reference contin. sound pressure level below 40dBA)

CO-cohort study; CC-case control study ECO-ecological study; CVD – cardiovascular diseases; IHD – Ischemic heart disease; MI – myocardial infarction; BP – blood pressure; INM – Integrated Noise Model; A – age; G – gender; S – smoking; SES – socio-economic status; J – job title; REB – local proportion of people receiving unemployment benefits; MT – mother tongue; N – nationality; BMI – body mass index; E – education; NO_2 – nitrogen dioxide; Sa – salt intake; PA – physical activity; MS – marital status; Al – alcohol.

Table 2(continued): Study characteristics of the updated review

3.1.2.1 Hypertensive diseases

We, like the WHO, found that there are clear indications from the evaluated studies that aircraft noise exposure may increase the risk of hypertension (van Kempen et al., 2018).

Zur Nieden (2016b) observed a small, non-significant association between systolic blood pressure and aircraft noise exposure $Lp_{Aeq,18h-6h}$. However, the same population did not demonstrate increased risk of hypertension due to increased aircraft noise exposure (zur Nieden et al., 2016a, 2016b). Contrary to the findings of zur Nieden et al (2016a), Dimakopoulou et al (2017) did find an elevated risk for hypertension with increasing aircraft noise exposure levels and that the risk for hypertension in this follow-up study is higher than the initial HYENA study (Hypertension and Exposure to Noise near Airports, conducted by Babisch et al in 2013). The authors suggest that the reason for this discrepancy may lie in the study design, as the previous HYENA study was more prone to biases, and also in the fact that the population in this cohort is now older and have lived much longer in the vicinity of the airport (Dimakopoulou et al., 2017).

Evrard et al (2017) observed a rise in OR (odds ratio) of hypertension with increasing exposure for day-evening-night aircraft noise exposure (L_{den}) and for night-time noise exposure (L_{night}) in men, but not in women. No such trend was observed for daytime noise exposure (L_{Aeq16h}). A significant increase in diastolic and systolic blood pressure was also observed only among men. In women, a significant increase in systolic but not in diastolic blood pressure was observed for L_{den} and L_{Aeq16h} (Evrard et al., 2017). Observed gender differences might be due to unmeasured confounding factors, which are more prevalent among men than women.

On the contrary, Zeeb et al (2017) did not observe any association between continuous air traffic noise exposure (per 10dB $L_{pAeq24h}$) and hypertension, but observed a significantly increased risk for individuals exposed to aircraft noise levels of 50-54dB $L_{pAeq24h}$. Zeeb et al (2017) also observed significant positive associations in people with an initial hypertension diagnosis and subsequent hypertensive heart disease. Aircraft noise exposure showed the highest increase in risk in comparison to other traffic noise sources (13.9% per 10dB $L_{pAeq24h}$). The authors debated whether noise exposure is associated with more severe forms of sustained hypertension, or whether non-differential disease misclassification for hypertension without complications in the insurance data obscures exposure-disease association (Zeeb et al., 2017).

Seidler et al (2016b) observed that cases with hypertensive heart disease showed a statistically significant association in the highest noise category of aircraft noise exposure between 55 to <60dB L_{Aeq24h} (OR 1.26; 95% CI 1.18 – 1.35) (Seidler et al., 2016b).

Evaluated studies indicate that aircraft noise exposure may increase the risk of hypertension.

Outcome; ICD-10 classification		**Noise exposure**	**Assessed Risk (Per 10dBA increase in noise levels)**		**No. of partic. /cases**	**Study**
Diseases of the circulatory system (ICD-10; I00 – I99)						
All Cardiovascular disease; I00-I99	Mort	L_{den}	**1.18 (1.11-1.25)** 0.994 (0.985-1.002)	RR (95% CI) HR (95% CI)	1,900,000/ 7,450 4,410,000/ 142,955	Evrard et al., 2015 Heritier et al., 2017
Hypertensive diseases (ICD-10; I10 – I15)						
Blood pressure; I10-I15	Mort	L_{den}	1.012 (0.985-1.039)	HR (95% CI)	4,410,000/ 13,438	Heritier et al., 2017
Heart failure and hypertensive heart disease; I50, I11, I13.0, I13.2	Inc	L_{Aeq24h}	**1.016 (1.003-1.030)**	OR (95% CI)	1,030,000/ 104,145	Seidler et al., 2016b
Hypertension; I10	Tot	L_{Aeq16h} L_{night}	**1.45 (1.05-1.99)** **1.69 (1.01-2.82)**	OR (95% CI)	420/265	Dimakopoulou et al., 2017
	Inc	L_{Aeq24h} L_{Aeq16h} L_{night}	0.997 (0.985-1.010) 1.46 (0.89-2.39) **2.63 (1.21-5.71)**	OR (95% CI)	1,030,000/ 137,577 420/71	Zeeb et al., 2017 Dimakopoulou et al., 2017
	Prev	L_{den} L_{Aeq16h} L_{night}	**1.48 (1.00-1.97)†** 1.34 (0.90-1.79) † **1.34 (1.00-1.97) †**	OR (95% CI)	1230/426	Evrard et al., 2017
Hypertensive heart disease; I11	Inc	L_{Aeq24h}	**1.139 (1.090-1.190)** **1.126 (1.107-1.146)**	OR (95% CI)	1,030,000/ 7,031 1,030,000/ 50,681	Zeeb et al., 2017 Seidler et al., 2016b

Tot - incident and prevalent cases; MI – myocardial infarction; † - in men. RR – risk ratio; HR – hazard ratio; OR – odds ratio

Table 3: Exposure to aircraft noise and the assessed risk for cardiovascular diseases from epidemiological studies (bold are statistically significant associations)

Outcome; ICD 10 classification		Noise exposure	Assessed Risk (Per 10dBA increase in noise levels)		No. of partic. /cases	Study
Ischaemic heart diseases (ICD-10; I20 – I25)						
Ischemic heart disease; I20-I25	Mort	L_{den}	0.991 (0.987-1.003) **1.24 (1.12-1.36)**	HR (95% CI) RR (95% CI)	4,410,000/ 60,327 1,900,000/ 7,450	Heritier et al., 2017 Evrard et al., 2015
Myocardial infarction; I21-I22	Tot	L_{Aeq16h} L_{night}	1.03 (0.55-1.92) 0.83 (0.31-2.20)	OR (95% CI)	420/34	Dimakopoulou et al., 2017
	Inc	L_{Aeq16h} L_{night}	0.69 (0.29-1.63) 0.37 (0.10-1.42)	OR (95% CI)	420/18	Dimakopoulou et al., 2017
	Mort	L_{den} L_{Aeq24h}	**1.28 (1.11-1.46)** **1.027 (1.006-1.049)** 0.993 (0.966-1.020)	RR (95% CI) HR (95% CI) OR (95% CI)	1,900,000/ 7,450 4,410,000/ 19,313 1,030,000/ 19,632	Evrard et al., 2015 Heritier et al., 2017 Sidler et al., 2016a
Other forms of heart diseases (ICD-10; I30 – I52)						
Cardiac Arrhythmia I49.9	Tot	L_{Aeq16h} L_{night}	1.28 (0.85-1.94) **2.09 (1.07-4.08)**	OR (95% CI)	420/68	Dimakopoulou et al., 2017
	Inc	L_{Aeq16h} L_{night}	1.33 (0.80-2.21) 1.88 (0.85-4.19)	OR (95% CI)	420/44	Dimakopoulou et al., 2017
Heart failure; I50	Inc	L_{Aeq24h}	0.974 (0.958-0.990)	OR (95% CI)	1,030,000/ 70,012	Seidler et al., 2016b
	Mort	L_{den}	**1.056 (1.028-1.085)**	OR (95% CI)	4,410,000/ 12,345	Heritier et al., 2017
Cerebrovascular diseases (ICD-10; I60 – I69)						
Stroke; I60-I64	Tot	L_{Aeq16h} L_{night}	0.84 (0.36-1.95) 1.30 (0.32-5.31)	OR (95% CI)	420/12	Dimakopoulou et al., 2017
	Inc	L_{Aeq16h} L_{night} $L_{pAeq24h}$	1.02 (0.30-3.54) 1.99 (0.23-17.2) 0.976 (0.953-1.000)	OR (95% CI) OR (95% CI)	420/5 25,498/ 827,601	Dimakopoulou et al., 2017 Seidler et al., 2018
	Mort	L_{den}	1.08 (0.97-1.21) 1.013 (0.993-1.033)	RR (95% CI) HR (95% CI)	1,900,000/ 7,450 4,410,000/ 22,444	Evrard et al., 2015 Heritier et al., 2017
Haemorrhagic stroke; I60-I62	Inc	$L_{pAeq24h}$	0.945 (0.884-1.011)	OR (95% CI)	3236/ 827,601	Seidler et al., 2018
	Mort	L_{den}	0.991 (0.951-1.032)	HR (95% CI)	4,410,000/ 5,354	Heritier et al., 2017
Ischemic stroke; I63	Inc	$L_{pAeq24h}$	0.982 (0.957-1.008)	OR (95% CI)	3236/ 827,601	Seidler et al., 2018
	Mort	L_{den}	**1.074 (1.020-1.127)**	HR (95% CI)	4,410,000/ 2,991	Heritier et al., 2017

Tot - incident and prevalent cases.

Table 3 (continued): Exposure to aircraft noise and the assessed risk for cardiovascular diseases from epidemiological studies (bold are statistically significant associations)

3.1.2.2 Ischaemic heart diseases

Evrard et al. (2015) observed a positive statistically significant association between weighted average exposure (dBA L_{den}) to aircraft noise and mortality from ischaemic heart disease (RR 1.28; 95% CI 1.11 – 1.46). The estimated risk was higher than the risk estimated in the WHO review (see previous chapter). In the WHO review, statistical significance was reached only for the risk of incidence of ischaemic heart disease (van Kempen et al., 2018).

The evaluated studies mostly investigated aircraft noise regarding the association with myocardial infarction. Evrard et al (2015) observed a positive association between weighted average exposure to aircraft noise and mortality for myocardial infarction. The risk was higher for men than for women (Evrard et al., 2015).

Seidler et al (2016a) also found indications for the relationship between exposure to traffic noise and the occurrence of a myocardial infarction. They observed that the risk indicators tend to be more pronounced for road and rail traffic noise than for aircraft noise. In their study, they observed that the risk for myocardial infarction starts rising at an aircraft noise level of 55dB LpAeq24h. In the highest noise exposure category (>60dB LpAeq24h), OR rises to 1.42 (95% CI; 0.61 – 3.25). The small number of people exposed to high noise levels (>60dB LpAeq24h) might be responsible for inability to reach statistical significance. In their analysis, they observed that the most sensitive noise exposure time is between 5.00 to 6.00 a.m. (Seidler et al., 2016a). On the contrary, Dimakopoulou et al. (2017) did not find an increase in the risk of myocardial infarction with increasing aircraft noise exposure.

The relationship between aircraft noise exposure and risk of myocardial infarction or mortality from ischaemic heart disease needs cautious interpretation. Further research is required on this theme.

3.1.2.3 Other forms of heart diseases

Dimakopoulou et al (2017) observed an elevated non-significant risk between aircraft noise exposure and arrhythmia during the night. Seidler et al (2016b) observed that heart failure was associated with aircraft noise only in the presence of hypertensive heart disease.

3.1.2.4 Stroke

Dimakopoulou et al (2017), like the WHO, observed an elevated non-significant risk for stroke associated with aircraft noise exposure. The association was stronger during the night, but it still did not reach statistical significance, which might have happened due to the small number of people exposed to high aircraft noise levels (Dimakopoulou et al., 2017; van Kempen et al., 2018).

Seidler et al (2018) did not observe an increase in the risk of stroke with increasing aircraft noise levels, but they were faced with the same problems as Dimakopoulou et al (2017), i.e. a small number of cases in the high exposure categories. On the other hand, they observed that nightly maximum sound pressure levels exceeding

50dB L_{max} led to increased disease risk for aircraft noise exposure, even if continuous sound pressure levels were below 40dB $L_{pAeqnight}$, which indicated possible relevance of the maximum aircraft noise level at night on the cardiovascular system (Seidler et al., 2018).

When the elevation of the risk for stroke due to aircraft noise exposure was investigated separately for the ischemic and haemorrhagic stroke, Heritier et al (2017) observed that possible increased risk for ischemic stroke but not haemorrhagic stroke was associated with elevation of aircraft noise levels.

	Noise exposure		**Effect estimate OR (95% CI)**	**No. of cases/controls**	**Study**
Outcome /ICD-10	**Indicator**	**Categories**			
Hypertensive diseases (ICD-10; I10 – I15)					
Hypertension/ I10	$L_{pAeq24h}$	40 – 44dBA	0.99 (0.97-1.02)	13,319/55,561	Zeeb et al., 2017
		45 – 49dBA	0.99 (0.97-1.03)	7,100/29,488	
		50 – 54dBA	**1.07 (1.02-1.12)**	3,014/11,819	
		55 – 59dBA	0.96 (0.89-1.05)	813/3,575	
		≥ 60dBA	0.68 (0.33-1.40)	9/56	
Hypertension/ I10	L_{night}	40 – 44dBA	**1.02 (1.00-1.03)**	23,217/60,309	Zeeb et al., 2017
		45 – 49dBA	1.00 (0.97-1.02)	10,648/29,711	
		50 – 54dBA	1.01 (0.97-1.05)	4,071/11,087	
		55 – 59dBA	0.81 (0.67 – 0.97)	176/591	
Hypertensive heart disease/ I11	L_{Aeq24h}	40 – 44dBA	**1.18 (1.15-1.21)**	15,895/197,474	Seidler et al., 2016b
		45 – 49dBA	**1.24 (1.21-1.28)**	8,684/106,497	
		50 – 54dBA	**1.19 (1.14-1.24)**	3,302/42,620	
		55 – 59dBA	**1.26 (1.18-1.35)**	979/12,744	
		60 – 64dBA	0.86 (0.45-1.65)	10/172	
Heart failure and hypertensive heart disease/ I50, I11, I13, I13.2	L_{Aeq24h}	40 – 44dBA	1.01 (0.99-1.03)	30,463/197,474	Seidler et al., 2016b
		45 – 49dBA	**1.07 (1.04-1.09)**	16,604/106,497	
		50 – 54dBA	1.00 (0.96-1.03)	6,113/42,620	
		55 – 59dBA	1.03 (0.98-1.09)	1,802/12,744	
		60 – 64dBA	0.97 (0.61-1.53)	24/172	
Ischaemic heart diseases (ICD-10; I20-I25)					
Myocardial infarction/ I21-I22	$L_{pAeq24h}$	40 – 44dBA	1.01 (0.97-1.05)	5,839/249,666	Seidler et al., 2016a
		45 – 49dBA	1.00 (0.95-1.05)	3,029/134,464	
		50 – 54dBA	0.97 (0.91-1.04)	1,151/52,923	
		55 – 59dBA	1.06 (0.95-1.18)	376/15,845	
		60 – 64dBA	1.42 (0.62-3.25)	6/196	
Myocardial infarction/ I21-I22	$L_{pAeqnight}$	40 – 44dBA	0.99 (0.95-1.04)	3,319/140,511	Seidler et al., 2016a
		45 – 49dBA	0.95 (0.89-1.01)	1,382/65,738	
		50 – 54dBA	1.07 (0.98-1.17)	623/24,693	
		55 – 59dBA	0.99 (0.66-1.49)	24/1,142	
Myocardial infarction - fatal/ I21-I22	$L_{pAeq,24h}$	40 – 44dBA	**1.06 (1.01-1.12)**	3,121/24,966	Seidler et al., 2016a
		45 – 49dBA	**1.08 (1.01-1.15)**	1,649/134,464	
		50 – 54dBA	1.03 (0.94-1.12)	605/52923	
		55 – 59dBA	1.09 (0.94-1.27)	198/15845	
		60 – 64dBA	**2.70 (1.08-6.74)**	5/196	
Myocardial infarction - fatal/ I21-I22	$L_{pAeqnight}$	40 – 44dBA	**1.07 (1.01-1.13)**	1,813/140,511	Seidler et al., 2016a
		45 – 49dBA	1.00 (0.92-1.08)	717/65,738	
		50 – 54dBA	**1.14 (1.01-1.28)**	348/24,693	
		55 – 59dBA	1.24 (0.73-2.13)	14/1,142	

Table 4: Exposure to aircraft noise and the assessed risk for the incidence of cardiovascular diseases from epidemiological studies by noise categories (bold are statistically significant associations)

Outcome /ICD-10	Noise exposure		Effect estimate OR (95% CI)	No. of cases/controls	Study
	Indic.	Categories			
Other forms of heart diseases (ICD 10; I30 – I52)					
Heart failure/	L_{Aeq24h}	40 – 44dBA	0.96 (0.93-0.98)	4,664/40,861	Seidler et al., 2016b
		45 – 49dBA	1.02 (0.99-1.05)	19,886/197,474	
		50 – 54dBA	0.92 (0.89-0.96)	10,844/106,497	
		55 – 59dBA	0.93 (0.87-1.00)	3,852/42,620	
		60 – 64dBA	1.12 (0.67-1.88)	1,094/12,744	
Cerebrovascular diseases (ICD-10; I60 – I69)					
Stroke; I61, I63-64	$L_{pAeq24h}$	<40dBA, Max ≥50dBA	**1.07 (1.02 – 1.13)**	10,595/325,613	Seidler et al., 2018
		40 – 44dBA	0.98 (0.95-1.01)	7304/247,877	
		45 – 49dBA	1.02 (0.98-1.06)	3973/133,244	
		50 – 54dBA	0.97 (0.92-1.03)	1470/52,507	
		55 – 59dBA	0.86 (0.77-0.95)	413/15,792	
		60 – 64dBA	1.62 (0.79-3.34)	8/195	
	$L_{pAeqnight}$	<40dBA, Max ≥ 50dBA	1.01 (0.98-1.04)	6707/220,495	Seidler et al., 2018
		40 – 44dBA	1.02 (0.98-1.04)	4209/139,373	
		45 – 59dBA	1.00 (0.98-1.05)	1804/65,201	
		50 – 54dBA	0.99 (0.91-1.07)	741/24,541	
		55 – 59dBA	1.00 (0.68-1.46)	28/1131	
Ischemic stroke; I63	$L_{pAeq24h}$	<40dBA, Max ≥ 50dBA	**1.06 (1.00-1.12)**	1465/52, 373	Seidler et al., 2018
		40 – 44dBA	0.99 (0.96-1.03)	6392/247,876	
		45 – 49dBA	1.04 (0.99-1.09)	3489/133,244	
		50 – 54dBA	1.06 (0.92-1.04)	1273/52,507	
		55 – 59dBA	0.85 (0.76-0.95)	356/15,792	
		60 – 64dBA	1.41 (0.62-3.22)	6/195	
Haemorrhagic stroke;	$L_{pAeq24h}$	<40dBA, Max ≥ 50dBA	**1.16 (1.02-1.33)**	256/52,373	Seidler et al., 2018
		40 – 44dBA	0.90 (0.82-0.99)	874/247,876	
		45 – 49dBA	0.94 (0.84-1.05)	470/133,244	
		50 – 54dBA	0.99 (0.85-1.16)	192/52,507	
		55 – 59dBA	0.91 (0.69-1.21)	53/15,792	
		60 – 64dBA	3.22 (0.79-13.1)	2/195	

Table 4(continued): Exposure to aircraft noise and the assessed risk for the incidence of cardiovascular diseases from epidemiological studies by noise categories (bold are statistically significant associations).

3.1.3 Conclusions

As the WHO review illustrated, the current review shows, that there are some new indications that aircraft noise exposure may increase the risk for cardiovascular diseases, such as hypertension, ischaemic heart diseases, stroke and some other forms of heart diseases.

In some of the evaluated studies it was suggested that the night is a particularly sensitive time for the development of cardiovascular diseases (Dimakopoulou et al., 2017; Seidler et al., 2016b). These findings are supported by suggestions that sleep disturbance due to aircraft noise could mediate the effect of aircraft noise on health, especially cardiovascular diseases (Greiser et al., 2007; Haralabidis et al., 2008).

Though the evidence supporting the association between aircraft noise exposure and cardiovascular health outcomes is substantial, there is still heterogeneity among studies in estimating the effect size (risk in present case). There are many reasons for heterogeneity among epidemiological studies due to different study designs, differences in exposure of observed populations and differences in exposure, confounder and outcome assessment.

Especially unfavourable for the evaluation of the evidence of noise effects exposure is the use of different noise metrics, as the quantification of the noise exposure requires a common unit. The question, regarding which noise indicator is the most relevant in describing the relationship between aircraft noise exposure and health effects, is a recurring theme.

Even though cardiovascular risk estimates for aircraft noise are found to be much lower than the ones found for known individual life-style risk factors for the development of cardiovascular diseases, individual life-style risk factors can be influenced by individual behaviour, and therefore, are not comparable. Also, protection from health consequences of traffic noise exposure is a governmental and management task and an individual does not have a direct influence over it.

As there are still uncertainties in scientific evidence, precautionary principle is recommended. Decisions can be made based on the best available data and future studies should also focus on vulnerable groups, effect modifiers, sensitive hours of the day, coping mechanisms, differences between noise sources, possible confounding with air pollution and differences between objective (noise level) and subjective (noise perception) exposure.

Aircraft noise exposure may increase the risk of cardiovascular diseases, although the evidence available may currently be contested. Subjective and objective factors may influence individual response to aircraft noise. It is through further research that better understanding of the relationship between noise exposure and cardiovascular disease risk and mortality may be revealed.

3.2 Sleep Disturbance

A good night's sleep is essential for a wide array of vital functions. Sleep plays a critical role in, for example, cognitive and neurobehavioral functioning (van Dongen et al., 2003), memory consolidation (Tononi & Cirelli, 2014), the immune system (Gomez-Gonzales et al., 2012), and mood regulation (Minkel et al., 2012). Interruption or deprivation of sleep can interfere with these processes: an insufficient amount of sleep has been linked to illnesses such as cardiovascular diseases (Wang et al., 2012; Meier-Ewert et al., 2004), obesity and depression (Nakata, 2011).

According to the WHO (Fritschi et al., 2011), one major factor negatively influencing sleep quality and sleep duration is environmental noise. There is a vast number of studies examining the effects of environmental noise, such as road and rail traffic noise, on sleep and there are different methods to measure sleep. The most comprehensive methodology to physiologically assess sleep is polysomnography (PSG), which encompasses various measurements including electroencephalogram (EEG), electrooculogram (EOG), electrocardiogram (ECG), as well as electromyogram (EMG). A less invasive method for participants is actigraphy, which is the measurement of a person's body movements via a single device worn on the wrist. In recent studies, authors attempted to use the combination of actigraphy and ECG measurements in order to detect awakenings in a less costly way than by means of PSG (Basner et al., 2008; McGuire et al., 2014). Next to physiological measurements, there is also the option to ask participants about their experience of sleep disturbances or sleep quality, i.e. a psychological assessment of sleep. The items used for this type of assessment can refer to the last night's sleep or a participant's experience of sleep over a longer period of time.

The latest WHO review regarding the effects of environmental noise on sleep concludes that transportation noise, e.g. aircraft noise, has an influence on - physiologically and psychologically measured – sleep (Basner & McGuire, 2018). A brief summary of main results of the WHO review is given in section 3.2.1.

This review aims to summarise and evaluate new studies, which have not been discussed in the recent WHO review, on the effects of aircraft noise on sleep, and these provide an overview of the current state of the art. Effects of noise on sleep, such as tiredness and a decreased performance level, can be understood as short-term effects. Experiencing sleep disturbances over a long period of time can result in long-term effects and can include other health-related outcomes such as cardiovascular diseases. These are discussed in sub-section 3.2.5 as well as in sub-section 6.5 of the deliverable D2.4, Recommendations on annoyance mitigation and implications for communication and engagement.

3.2.1 Brief summary of results of the WHO review on the impact of aircraft noise on sleep

In their WHO review on the impact of environmental noise on sleep, Basner and McGuire (2018) reviewed 74 studies published in the period between 2000 and 2015. Ten studies refer to aircraft noise-related sleep disturbance. Of these, one study measured sleep quality physiologically with polysomnography. In nine studies, sleep disturbance was assessed in surveys by self-report, either using questions that explicitly refer to aircraft noise (seven studies), or questions to operationalise sleep quality without any attribution to aircraft noise (two studies).

In their systematic review, Basner and McGuire (2018) conducted meta-analyses of the exposure-response relationship for environmental noise-related sleep disturbances. For aircraft noise, they presented two exposure-response functions:

1. For the probability of additional awakenings due to aircraft noise based on polysomnographic measurements, i.e. for the probability of sleep stage transitions to S1 (light sleep) or Wake, related to the event-specific maximum sound level L_{Smax} (OR per 10dB L_{Smax} = 1.35 [1.22 – 1.50] for the unadjusted model):

   $$\textit{Prob. of Wake or S1} = -3.0918 - 0.0449 \ast L_{Smax} + 0.0034 \ast (L_{Smax})^2$$

2. For the percentage of highly sleep disturbed persons (%HSD) based of self-reports on survey questions that explicitly refer to aircraft noise, related to aircraft night sound level L_{night} (OR per 10dB L_{night} = 1.94 [1.61 – 2.33]):

   $$\%HSD = 16.7885 - 0.9293 \ast LA_{night} + 0.0198 \ast (L_{night})2$$

For %HSD based on responses to questions that did not refer to aircraft noise, no exposure-response function was presented as the results of the meta-analysis indicate a non-significant relationship (OR per 10dB L_{night} = 1.17 [0.54 – 2.53]).

3.2.2 Updated review on aircraft-noise related sleep disturbance

A detailed description of the approach used in this literature search, including the excluded papers after the full text review, can be found in Annex 7.1.3. Table 5 shows all 13 articles included in the current review on the effects of aircraft noise on sleep.

It is important to note that the studies are sorted according to the measurements used to assess sleep, i.e. physiological measurements or self-report. Some studies used both physiological and subjective measurements of sleep, so they are discussed in both sections. Some basic information of the included articles, such as sample size, measurements and outcomes, is summarised in Table 5 and 6 as well.

Outcome: physiological measurements of sleep								
No.	**Author**	**N =**	**Country**	**Airports**	**Measurements**	**Confounder**	**Noise metric**	**Outcome**
1.*	Basner et al., 2017	79 (control=40)	USA	Philadelphia International Airport	Sleep fragmentation index (ECG, actimetry)	Age, gender, BMI	L_{ASmax}, L_{Aeq}	No significant difference for sleep fragmentation index
2.	Janssen et al., 2014	418	The Nether-lands	Amsterdam Schiphol Airport	Actimeters measuring motility	Sleep period time, age, gender	L_{Amax}, L_{Aeq}	Exposure response function for probability to awake due to an aircraft noise event. Association between the number of events above 60dBA and increased motility
3.*	Müller et al., 2017	64 & 49	Germany	Cologne/Bonn & Frankfurt Airport	Polysomnography		L_{ASmax}	Exposure response function for probability to awake due to an aircraft noise event. Participants at CGN slept significantly less than participants at FRA
4.*	Müller et al., 2016	49	Germany	Frankfurt Airport	Polysomnography		L_{ASmax}	Association between night flight ban and decreased number of awakenings

*This article is an additional paper.

Table 5: Summary of Recent Sleep Disturbance Studies utilising Physiological Measurements

Table 6: Summary of recent Sleep Disturbance Studies utilising Subjective Measurements

		Outcome: self-reported sleep						
No.	**Author**	**N =**	**Country**	**Airports**	**Measurements**	**Confounder**	**Noise metric**	**Outcome**
1.*	Basner et al., 2017	79 (control = 40)	USA	Philadelphia International Airport	PROMIS Sleep Questions, Pittsburgh Sleep Quality Index (PSQI)	Age, gender, BMI	L_{ASmax}, L_{Aeq}	Compared to control group: poorer sleep quality on PSQI (p=0.018); no significant difference for morning sleep assessment
5.	Douglas & Murphy, 2016	208	Ireland	Dublin Airport	bothered, disturbed or annoyed during past 12 months on 5- and 11-point scale; whether noise interfered, e.g. with sleeping		L_{Aeq}, L_{Amax}, L_{A90}	Compared to other noise sources, participants report the highest mean level of sleep disturbance close to the airport
6.*	Hiroe et al., 2017	3,659	Japan	Narita International Airport	International Classification of Sleep Disorder (ICSD), Diagnostic and Statistical Manual of Mental Disorders (DSM-5), International Statistical Classification of Diseases and Related Health Problems (ICD-10)	demographic variables, socioeconomic status, lifestyle factors, including smoking, alcohol consumption, and physical activity, personal medical history in terms of sleep disturbances, cardiovascular diseases, anxiety, depressive disorders, medication use, and finally annoyance due to noise exposure.	$L_{Aeqnight(22\text{-}07)}$	Association between insomnia and $L_{Aeqnight(22\text{-}07)}$ (p<.05)
7.	Holt et al., 2015	745,868	USA	Nationwide	Sleep insufficiency: "During the past 30 days, for about how many days have you felt you did not get enough rest or sleep?"	Age, sex, race/ ethnicity, educational attainment, smoking, obesity (BMI)	Day-night average sound levels	No significant effect
2.	Janssen et al., 2014	418	The Netherlands	Amsterdam Schiphol Airport	11-point scale	Sleep period time, age, gender	L_{Amax}, L_{Aeq}	No effect of the number of events found on sleep quality
8.	Kim et al., 2014	1,005	South Korea	Kunsan Airport (military)	PSQI	Sex, occupational class, current smoking status, doctor-diagnosed chronic disease	WECPNL (daily level of aircraft noise)	Significant difference between exposure groups regarding prevalence of sleep disturbance (>80

								WECPNL with 77,1% ; 60-80 WECPNL 77,1% and control 45,5% at <60 WECPNL)
9.	Kwak et al., 2016	3,308	South Korea	Gimpo International Airport	Insomnia severity index (ISI), Epworth Sleepiness Scale (ESS)	Age, sex, education level, residency period, smoking, drinking, exercise, medical history	WECPNL	Significant difference between exposure and non-exposure group regarding ISI and ESS
4.*	Müller et al., 2016	49	Germany	Frankfurt Airport			L_{ASmax}	Reduction of self-reported sleep quality by 5% in 2012 and 11% in 2013.
10.	Nassur et al., 2017	1,244	France	Paris-Charles de Gaulle, Lyon-Saint-Exupéry and Toulouse-Blagnac	Total sleep time (‘At what time do you usually got to bed to sleep on a weeknight?’, ‘At what time do you usually get up on a weeknight ?’; self-reported feeling while awakening after usual night’s sleep	Age, gender, education, marital status, smoking habits, alcohol consumption, physical activity, self-reported health, BMI, self-reported anxiety and depression, noise sensitivity, monthly household income, work schedule, physical tiredness, nervous tiredness, cardiovascular disease, hypertension, annoyance	L_{den}, $L_{Aeq24hr}$, $L_{Aeq6hr-22hr}$, and L_{night}	Shorter TST when higher L_{den} ; no significant effect regarding feeling while awakening; significant association between short TST or feeling of tiredness while awakening for all noise indicators.
11.*		1,286	Vietnam	Hanoi Noi Bai International Airport	5-point verbal scale		$L_{Aeqnight}$	Higher levels of sleep disturbance under arrival route, but no significance test
12.*	Röösli et al., 2017	5,592	Switzerland	Military airfield and three international civil airports	Self-reported sleep disturbance		Intermittency ratio (IR); $L_{Aeq08hnight}$	A higher IR is associated with higher values of %HSD
13.*	Schreckenberg et al., 2016	3,508	Germany	Frankfurt Airport	3 items: disturbances falling asleep, while sleeping an in the early morning, 5-point verbal scale (similar to ICBEN)	Noise sensitivity, judgment of air traffic as useful, comfortable and environmentally harmful, demographics, survey mode	$L_{pAeq22-06h}$	Sleep disturbances reduced after night curfew, not for while falling asleep or in the early morning

3.2.3 Physiological measurements of sleep and aircraft noise

A total of four papers were selected in which the effects of aircraft noise on participants' sleep were assessed using physiological measurement tools such as polysomnography or actimeters. Four studies are discussed in these papers:

- The STRAIN (Study on human specific Response to Aircraft Noise) study;
- The NORAH (Noise-Related Annoyance, Cognition, and Health) study;
- A study conducted near Philadelphia International airport;
- A study from The Netherlands.

The STRAIN study was conducted by the German Aerospace Center (DLR) and took place at Cologne/Bonn airport in Germany that has no night time restrictions and processes many cargo flights during the night. The effects of aircraft noise on sleep were measured polysomnographically (PSG), including electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG), electro-cardiogram (ECG), respiratory movements, finger pulse amplitude, position in bed and actigraphy, in a total of 64 residents completed the study in the years 2001/2002.

The NORAH sleep study was also carried out by DLR and focused on residents' sleep around Frankfurt Airport (Müller et al., 2017). This study had a similar acoustical and polysomnographic methodology as the STRAIN study, except that participants at Frankfurt Airport had specific bed time regulations. In the NORAH study, three measurement waves were conducted. The first took place in 2011, before the opening of the new runway and the implementation of a night flight ban from 23:00 to 05:00. In both 2012 and 2013, after the airport expansion and the introduction of the night flight ban, additional measurement waves followed. Here, participants' sleep was measured for three consecutive nights. Müller et al. (2016) found that the number of aircraft noise associated awakenings per night declined from 2.0 awakenings in 2011 to 0.8 in the following year for those who went to bed "early" between 22:00-22.30 and got up early between 06:00-06.30. Further, an exposure-response curve for the probability of awakening due to an overflight was calculated, taking into account, among others, the maximum sound pressure level and the duration of the aircraft noise event. The difference of the awakening probability for an overflight with the same maximum sound pressure levels between 2011 and 2012 was not statistically significant.

Müller et al (2017) compared aircraft noise-related sleep outcomes at Cologne/Bonn Airport with Frankfurt Airport using data from the STRAIN and NORAH (data from measurement wave in 2012) study. The major difference between these two airports is that Frankfurt Airport has a night flight ban between 23:00 and 05:00 in contrast to Cologne/Bonn Airport, which has no night flight restrictions and many flight operations (mostly cargo) during the night. The researchers found that participants living near Cologne/Bonn Airport slept significantly less than participants at Frankfurt Airport and woke up more often due to aircraft noise events (i.e. overflights). In line with this, participants' sleep efficiency (total sleep time divided by the time spend in bed) was, on average, worse for those living near Cologne/Bonn Airport. Moreover, results indicate that these participants also experienced significantly less deep sleep.

The U.S. pilot study conducted by Basner et al (2017) used self-administered devices for measuring sleep outcomes. The sample consisted of 39 individuals, who were exposed to aircraft noise, and 40 controls. The participants wore a device at night that measured body movements and recorded an electrocardiogram (ECG) during sleep. This method being validated with the polysomnograhy data from the NORAH study, the researchers calculated the number of awakenings per night for each participant by means of the ECG and motility data. The total sleep time was measured and was used, in combination with the number of awakenings per night, to calculate the sleep fragmentation index. There was no significant difference between the exposure and control group regarding the sleep fragmentation index, implying that participants exposed to aircraft noise did not statistically awake more often than participants who are not exposed to aircraft noise. However, the study by Basner and colleagues was a pilot study designed to test devices and procedures, which may explain the non-significant results.

The last study that was identified and used physiological measures of sleep is a Dutch study by Janssen et al (2014). Janssen and colleagues also used actimeters to measure participants' motility during sleep (2014). Motility was then used as an indicator for sleep quality. It was found that the mean sound exposure level (indoor) is positively associated with the average motility during sleep. Participants, who were exposed to higher average sound levels, exhibited a higher degree of body movements, i.e. had a poorer sleep quality.

3.2.3.1 Comparison of studies

In general, observational studies such as these should be interrater-reliable, meaning that the assessment procedure should be standardized in such a way that at least two independent researchers come to a similar result. Unfortunately, the number of raters as well as the interrater-reliability are seldom reported. All four studies described measured sleep by physiological means. However, the measurements used differ regarding the advantages they offer: the use of actimeters, for instance, is quite easy and low-priced, but they only assess body movements during sleep. Polysomnography, on the other hand, requires more preparation time and monetary resources, but allows for a more comprehensive assessment of participants' sleep.

The NORAH study examined the effects of a night time curfew on residents' sleep and found a significant decrease of aircraft noise associated awakenings (Müller et al., 2016, 2017). Compared to data collected in the STRAIN study, participants living around Frankfurt Airport experienced fewer awakenings and more episodes of deep sleep (Müller et al., 2017).

Janssen and colleagues used actimeter measurements and found participants exposed to nocturnal aircraft noise to experience significantly worse sleep quality, operationalised as more body movements (2014). The results from these three studies contradict the findings of Basner et al (2017), who did not find a significant effect of aircraft noise on awakenings.

These studies do indicate that exposure to nocturnal aircraft noise affects participants' sleep as indicated by more awakenings compared to no aircraft noise exposure. In line with this, participants experienced fewer awakenings when one of the airports implemented a night flight curfew. However, the effects on participants' sleep of the bundled amount of flight movements late in the evening (e.g. 10pm-11pm) or early in the morning (e.g. 5am-6am) need further examination.

3.2.4 Self-reported sleep outcomes and aircraft noise

Twelve of the identified papers measured sleep outcomes for aircraft noise by means of self-reports. The measured sleep outcomes vary between the different studies as do the items used for assessing these sleep outcomes. Five studies assessed sleep disturbances due to aircraft noise. The remaining seven studies used sleep insufficiency, insomnia, tiredness, and sleep quality as sleep outcome and did not specifically refer to aircraft noise as the source of any abnormal sleep patterns.

In the NORAH study (Schreckenberg et al., 2016; Müller et al., 2016) and a Japanese study (Nguyen et al., 2017) participants were asked to score their sleep disturbances on the 5-point verbal ICBEN scale. Schreckenberg and colleagues calculated an aircraft noise-related sleep disturbance score on the basis of three items, asking about disturbances when falling asleep, when sleeping during the night and in the early morning (2016). The category 'highly sleep disturbed' included participants rating the upper two answer options. The percentage of highly sleep disturbed (%HSD) people decreased in 2012 and 2013, after the implementation of the night flight ban at Frankfurt Airport. However, due to the night flight ban, $L_{Aeq22\text{-}06h}$ mainly consists of noise events occurring in the hours of 10pm-11pm and 5am-6am. The decrease is mainly explained by less sleep disturbances during the night. There is no difference regarding %HSD when falling asleep and an upward shift of the exposure-response curve for %HSD in the early morning. Although physiological measurement showed less aircraft associated awakenings during the three measurement waves (2011, 2012, and 2013) of the NORAH sleep study due to the night flight ban, participants' perceived sleep experience significantly decreased in quality from the first to both the second (reduction by 5%) and third wave (reduction by 11%). This is independent of the aircraft noise exposure level and despite the implementation of a night flight ban (Müller et al., 2016) and maybe due to an excess reaction because of the change situation at Frankfurt airport in those years.

Nguyen et al (2017) conducted three measurement waves and compared sleep disturbances of participants who live under an arrival route with participants who live under a departure route, i.e. are exposed to different noise levels. The self-reported sleep disturbances indicate that participants living under an arrival route are more sleep disturbed than participants living under a departure route in all three waves. However, the authors do not mention any significance tests for these differences.

Röösli et al (2017) used the Intermittency Ratio (IR) as an additional metric for aircraft noise exposure as it represents the "eventfulness" (Röösli et al., 2017:2) of a noise situation. They found that a higher IR is associated with a higher percentage of highly sleep disturbed (%HSD) participants.

In a study by Douglas and Murphy (2016), the level of night-time disturbance was measured with two items by asking participants about the degree of disturbances by any specific transportation noise (including aircraft noise), indicated on a 11-point scale, as well as whether aircraft noise interferes with activities such as sleep. 61.1% of participants living near Dublin airport, exposed to a minimum of 40dBA $LA_{eqnight8h}$, reported night-time disturbances compared to 1.9% of participants living at a control location (a 'quiet' area).

As mentioned above, seven of the twelve studies assessed sleep without linking possible disturbances specifically to aircraft noise. In other words, they asked about either the quality of participants' last night's sleep or the sleep quality of the last couple of days/weeks/months.

This approach was utilised in the French DEBATS (discussion on the health effects of aircraft noise) study (Nassur et al., 2017). They measured the total sleep time (TST) with two items and defined ≤6 hours of sleep per night as "short TST" and more than 6 hours as "normal and long TST"; sleep quality was assessed by asking participants about their feelings while awakening after a usual night sleep. The answers to the latter were categorised into "well/rather rested" and "rather/very tired". There was a significant association between aircraft noise and a short TST as well as the feeling of tiredness.

In addition to the physiological measure of sleep, Basner et al (2017) assessed participants' sleep quality with the Pittsburgh Sleep Quality Index (PSQI). Results show that participants living in the vicinity of the Philadelphia International Airport scored lower on the PSQI, indicating a poorer sleep quality ($p<0.02$), compared to the control group.

One study investigated the association between military aircraft noise and sleep quality of participants living near a military airfield in South Korea (Kim et al., 2014). Sleep quality was also measured with the PSQI and two exposure groups were defined. As noise metric, the researchers used the so-called WECPNL, an index of the daily aircraft noise level. The low exposure group was exposed to noise levels between 60 and 80 WECPNL, the high exposure group to above 80 WECPNL and the control group to less than 60. The resulting exposure-response curve showed that the prevalence of low sleep quality in mentally healthy adults was 2.61-fold higher in the low and around 3.5 times higher in the high exposure group compared to the control group.

In the Dutch study, one item was used to assess sleep quality ("How well did you sleep last night?"), which was rated on an 11-point scale (Janssen et al., 2014). Mean sound exposure level (SEL) was significantly associated with self-reported sleep quality. There was no effect of the number of aircraft noise events found on self-reported sleep quality in the Dutch study conducted at Schiphol Airport (Janssen et al., 2014).

Another study, conducted by the Narita International Airport Corporation (Hiroe et al., 2017) in the vicinity of Narita International Airport, assessed, among other aspects, insomnia and its relation to aircraft noise. The score for participants' reported insomnia was based on several items from the International Classification of Sleep Disorder (ICSD), the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), as well as the International Statistical Classification of Diseases and Related Health Problems (ICD-10). Insomnia was significantly associated with night-time aircraft noise exposure ($p<0.05$).

Kwak et al (2016) used scales for insomnia and daytime hypersomnia to assess sleep disturbance. The study area was divided into three groups: low-exposure group with 75 to 80 WECPNL, a high exposure group (80-90 WECPNL) and a control group. Participants in the low and high noise exposure group reported significantly more sleep disturbances (insomnia and hypersomnia) compared to the control group. However, there were no noise measurements available for the control group.

Holt et al (2017) used data collected within the scope of the State-based Behavioural Risk Factor Surveillance System (BRFSS) in the vicinity of 95 U.S. airports in 2008 and 2009. Sleep insufficiency was measured with a single item: "During the past 30 days, for about how many days have you felt you did not get enough rest or sleep?" (Holt et al., 2015). This item is part of the Healthy Days Core Module (CDC HRQoL–4), assessing health-related quality of life. The researchers grouped participants according to the exposed noise levels, i.e. ≥55dBA to <60dBA, 60dBA to 65dBA, and ≥65dBA (DNL; day/night average noise level) as well as outside of these three exposure zones. There was no statistically significant difference of sleep insufficiency between the four groups. It is noteworthy that the sample sizes of the three exposure groups (n = 7,799) differ to the sample size of the group outside the exposure zones (n = 738,069).

3.2.4.1 Comparison of studies

The studies included in this review using self-report measures differ greatly with regard to the assessed sleep outcome (sleep disturbances, insomnia etc.) and items used for this assessment, e.g. specifically referring to aircraft noise or not. Therefore, the possibility to compare the results of the various studies is limited.
Eleven of the twelve papers found an effect of aircraft noise on participants' self-reported sleep. Five of these studies directly addressed sleep disturbances due to aircraft noise.

Overall, participants reported more sleep disturbances, poorer sleep quality and tiredness when being exposed to nocturnal aircraft noise. Despite the various sleep measurements used, results indicate a negative relationship between nocturnal aircraft noise exposure and self-reported sleep outcomes.

3.2.5 Conclusions

Both studies using physiological measurements of sleep and studies assessing sleep by means of self-report reveal significant effects of nocturnal aircraft noise on participants' sleep. Three of the four examined studies using the former approach found a significant effect of nocturnal aircraft noise on awakenings. The majority of self-report studies also show a significant effect of aircraft noise on sleep. Self-report studies using items that directly connect the sleep outcome with aircraft noise as well as studies using items without mentioning aircraft noise found significant effects. There are mixed results for the latter case.

Basner and McGuire (2018) did not find significant effects of aircraft noise on sleep in studies where the wording of questions did not explicitly refer to the noise source. They attribute this to the possibility that attitudes to, or annoyance by the night time noise influence self-reported sleep outcomes. It is still unclear, though, whether and in what way annoyance and/or attitudes impact the physiological experience of sleep, i.e. whether highly annoyed people, for example, awake significantly more often due to aircraft noise than people who are not annoyed by this noise source.

Studies have shown that meaningful noises can catch one's attention easier than non-meaningful noises. For example, a person's own name can lead to more brain activation than when another name is said (Carmody and Lewis, 2006). The current results indicate that both self-reported and physiological measurements of people's sleep quality are important in order to capture the whole picture of the effects of nocturnal aircraft noise, as these seem to be manifold. Accordingly, in the updated WHO Noise Guidelines for the European Region (WHO, 2018) it is stated that even though self-reported sleep disturbance might differ considerably from physiologically measured sleep parameters, it constitutes a valid indicator in its own right, as it reflects the effects on sleep perceived by an individual over a longer period of time.

Minimising sleep disturbances and enabling good sleep quality are important goals of aircraft noise mitigation interventions and can help improve quality of life and reduce the risk of not only short-term effects, such as tiredness and decreased performance levels, but also of long-term health effects such as cardiovascular diseases or mental illnesses.

There seems to be a link between aircraft noise and people's self-reported and physiologically measured sleep quality. Appropriate aircraft noise mitigation interventions addressing sleep quality and disturbance may increase quality of life and lessen the risks of psychological and physiological health effects.

3.3 Cognitive impairment

Noise exposure has been considered in the research associated with impairment to cognitive function. Children have the propensity to be especially vulnerable as their cognitive functions are less automatised and, thus, more prone to disruption in comparison to adults (Klatte et al., 2013). It is assumed that environmental noise exposure affects children's cognitive function through learned helplessness, teacher frustration, interruptions of classroom discourse and general inattention to auditory and auditory-verbal stimuli, resulting from over-generalisation of a strategy of tuning out unwanted sounds (Stansfeld et al., 2005). Some researchers also assume that the effects of noise exposure on reading are mediated by effects on phonological precursors of reading acquisition (Evans and Maxwell, 1997; Klatte et al., 2010).

The elderly could also be considered as susceptible population group, as a decline in cognitive functions is already considered to be a normal consequence of aging (Glinsky, 2007). A decrease in cognitive function in elderly, in addition to the expected decrease from aging, is assumed to be associated with environmental noise exposure through noise annoyance (Lee et al., 2016).

3.3.1 Brief summary of the WHO review on the impact of aircraft noise on cognitive impairment

In 2018, Clark and Paunovic (2018) published an extensive evidence review on cognitive impairment and children in preparation of the WHO Noise guidelines (WHO, 2018). All studies identified through the review had child populations and most focused on aircraft noise exposure. In order to define the association between children's cognitive abilities and aircraft noise exposure, a range of cognitive domains was evaluated.

Clark and Paunovic (2018) identified 14 studies investigating the association between aircraft noise exposure and reading and oral comprehension. From these studies, 10 demonstrated a statistically significant association between increased aircraft noise exposure and poorer reading comprehension, 2 showed only a trend of an association.

Aircraft noise exposure in the association with impairment assessment through standardised assessment tests (SATs) was investigated in the 7 studies, 3 were intervention studies. From these 7 studies, 4 showed statistically significant association between noise exposure at school and poorer SATs scores. Three intervention studies suggested that sound insulation was associated with improvement in SATs. Other 3 showed no significant association, which Clark and Paunovic (2018) attribute to the small sample size and low power of the studies.

The association of aircraft noise exposure on children's long-term and short-term memory was investigated in 11 studies, 1 of which was intervention study of airport closure/relocation. Of these studies, 6 found an association of aircraft noise exposure and children's memory whilst 5 studies did not. Four of the studies that were able to find an association were based on the data from the RANCH (Road traffic and Aircraft Noise Exposure and Children's Cognition and Health) project.

Attention and aircraft noise exposure were investigated in 10 evaluated studies, 5 of them showed significant association and the other 5 did not. One of the studies unable to find an association of aircraft noise exposure and attention was intervention study.

None of the identified 9 studies investigating the association between aircraft noise exposure and executive function (working memory), observed a significant association. Description of the approach used in this literature search can be found in Annex 7.1.4.

3.3.2 Updated review on aircraft noise related cognitive impairment

Our updated review identified only one new study investigating the association between aircraft noise exposure and cognitive impairment in children (Klatte et al., 2016). Klatte et al (2016) published a study of aircraft noise exposure, cognition and quality of life of elementary school children in Germany, based on the results of the NORAH study (Noise-Related Annoyance, Cognition, and Health). Children's exposure to aircraft noise did not exceed 59dBA and was much lower in comparison to the exposure in some other studies. They found a linear exposure-effect association between aircraft noise exposure and children's reading, well-being at school, physical and mental well-being, and annoyance after adjustments. Even though there were differences in exposure levels in some other studies, the effect found in this study is comparable to the previously published studies. Study authors observed a 20dBA increase in aircraft noise exposure associated with 2 months' delay for the whole sample, and with 3 months' delay in the subsample of non-migrant children. The authors of the studies conclude that for the evaluation of the noise effect, other factors impacting reading should also be considered, especially socioeconomic status (SES) and the number of books at home (Klatte et al., 2016).

There was no study investigating the relationship between cognitive functioning in elderly and aircraft noise exposure. Nonetheless, we identified three studies investigating the relationship with road traffic noise exposure. These studies supported previous studies' findings, that long-term noise exposure may negatively impact on older people's cognitive function, resulting in cognitive impairment additional to normal cognitive aging (Tzavian et al., 2015; Tzavian et al., 2016a; Tzavian et al., 2016b).

3.3.3 Conclusions

Clark and Paunovic (2018) showed that there are indications that aircraft noise exposure could cause cognitive impairment in children. These indications appeared for some cognitive domains stronger than for others. Sound insulation of schools proved to be an effective intervention method in some studies evaluated in the Clark and Paunovic review (2018). The study found in our updated review showed further support to the association between aircraft noise exposure and reading comprehension. Additionally, we have observed that some of the recent studies indicated that exposure to environmental noise might not only affect children's cognition but also cognitive functioning in elderly.

3.4 Mental Health and Well-Being

According to the definition of the WHO, well-being is an important element of health. Impaired mental health is a major health issue in Western countries, for example, indicated by lifetime prevalence for mental disorders of 25% in Europe (Bruffaerts et al., 2011). These conditions are often accompanied by poorer quality of life and negative impacts on social and occupational domains. It has been shown that poor mental health also contributes to and can be associated with other physiological diseases and symptoms like diabetes (e.g. (Gilsanz et al., 2015), risk of stroke (Pan et al., 2010), or other cardiovascular diseases (Ladwig et al., 2017).

Although early research indicates an association between aircraft noise and mental health outcomes (Tarnopolsky, et al., 1980), the impact of environmental noise on mental health has not been in the focus of noise research for many years.

Mental health is often studied as part of health-related quality of life (HQoL) as a subject area (see D3.1). HQoL, again, is part of the quality of life (QoL), which in addition includes other aspects such as material living conditions, productive or main activity, education, leisure and social interactions, economic and physical safety, governance and basic rights, natural and living environment, and overall life satisfaction (e.g. EUROSTAT, 2017). HQoL is viewed as a multidimensional concept as it incorporates a person's physical health and psychological state "in a complex way" (WHO, 1995). Moreover, the WHO (1995) suggests health-related QoL to be the "individual's perception of his/her position in life in the context of the culture and value systems in which he/she lives in". The concepts of both well-being and HQoL are often used interchangeably, as they look at a person in his/her social environment, but they actually differ in that the concept of well-being focuses more generally on positive affect and satisfaction (Meiselman, 2016). Mental health, however, is well-being in a psychological manner, corresponding to emotional and cognitive functioning.

This review aims to identify relevant studies and research papers regarding the impact of aircraft noise on health-related quality of life, well-being and mental health. The following literature search was conducted giving an overview of the recent progress from 2014, and builds on the latest research, as represented in the review by Clark and Paunovic (2018). Starting with a summary of the latest systematic review on noise and mental health by Clark and Paunovic (2018) in section 3.4.1, section 3.4.2 gives an overview of the findings since 2014 regarding different aspects of mental health in terms of specific outcomes and different measuring methods.

3.4.1 Brief summary of results of the systematic review on noise and mental health by Clark and Paunovic for the WHO (2018)

The systematic review on the impact of environmental noise on health-related quality of life, well-being and mental health was performed by Clark and Paunovic (2018) with the aim of providing updated information for the revision of the WHO environmental noise guidelines. It includes studies on noise from aircraft, rail traffic, and road traffic and wind turbines.

Studies with different kinds of measurement methods such as self-reported and interview measures were included. Literature published before 2005 had already been reviewed in existing systematic reviews, meaning that the WHO literature review of Clark and Paunovic (2018) focused on searches between 2005 and 2015. The studies were selected based on AMSTAR criteria: Assessing the Methodological Quality of Systematic Reviews (Shea et al., 2007). Due to methodological differences and the small number of studies found, a narrative systematic review was performed. The quality of examined studies and accompanying results were rated using the GRADE approach (Guyatt et al., 2008).

Overall, ten studies considering the impact of aircraft noise on mental health or quality of life outcomes were rated sufficiently according to AMSTAR criteria. Results reveal inconsistent findings. While five studies found no association between aircraft noise and poor self-reported QoL and health as well as well-being, respectively (Clark et al., 2012; Schreckenberg et al., 20101; Schreckenberg et al., 20102; Stansfeld et al., 2005; van Kempen et al., 2010), only the results of one study indicate an association between aircraft noise and lower mental health scores (Black et al., 2007).

Regarding medication use, one study found an association between daytime noise and prescription of anxiolytics but not for antidepressants (Floud et al., 2011). For measures of depression, anxiety and other psychological symptoms, no studies were available for self-reported measures; for interview measures, one study indicated an association between high aircraft noise exposure and anxiety disorders. The examined studies on emotional and conduct disorders also show no association with aircraft noise (Clark et al., 2012; Clark et al., 2013; Crombie et al., 2011; Stansfeld et al., 2005). Evidence for an association of aircraft noise exposure and hyperactivity in children is also inconsistent, with only two studies showing an association and one indicating no association (Crombie et al., 2011; Stansfeld et al., 2009).

Throughout the review, all evidence for associations and no associations were rated as being of low or very low quality. Estimates of risk cannot be drawn from the results of the review. The authors emphasise the difficulty in drawing conclusions from the studies for several reasons: the small number of studies, the differing study designs, and the wide variation of methods for both noise measures and outcome measurements. All these aspects hamper the comparability. They also state that studies do not consider confounding factors such as history of mental well-being, and other factors.

3.4.2 Updated review on aircraft noise and mental health since 2014

This review gives an overview of published studies since 2014 examining the relationship of aircraft noise exposure and mental health outcomes. The approach of the underlying literature search is described in Annex 7.1.5.

Table 8 gives essential information about the seven studies that met the inclusion criteria, showing a wide variation in terms of used exposure measures and outcome assessments. The studies are presented including sample size, country of implementation, utilised outcome measures and noise metrics as well as confounders and the information about a change situation. The latter is defined as a change in the noise situation occurring due to e.g. a constructional change at the noise source such as a new runway (van Kamp & Brown, 2013).

Most studies are implemented in the European region. In comparison to Clark and Paunovic (2018), no new studies considering emotional and conduct disorders in children, hyperactivity symptoms in children or studies examining medication intake or treatment of anxiety and depression, were found. Due to the small number of studies identified, this review is of a narrative nature.

Table 8: Description of aircraft noise and mental health studies since 2014

Outcome: self-reported (health-related) quality of life and well-being						
Author(s)	**N =**	**Country**	**Measurements**	**Confounder**	**Noise metric**	**Change**
Klatte et al, 2017	1,243	GER	Parents and children's ratings of quality of life Parents rating: KINDL-R (Fragebogen zur Erfassung et al, 1998) One subscale with 6 items for child mental well-being Children's rating: Well-being at school with 5 items	age, gender, SES (socio-economic status), classroom insulation, road-traffic noise, railway noise at school	$L_{AeqS08\text{-}14h}$ $L_{AeqA06\text{-}18h}$	Opening of new runway Night flight ban
Schreckenberg et al, 2017	3,508	GER	Mental health-related quality of life using SF-8	Mode of survey, gender, age, occupancy, hours out of home, ownership, sociooeconomic status, migration background, noise sensitivity, body mass index, physical activity, noise levels for road and railway	L_{Aeq24h}	Opening of new runway Night flight ban
Fujiwara et al, 2017	Approx. 12,000	GB	Experience sample method Measure: well-being in two dimensions stating how happy and relaxed participants are Continuous scale from « extremely » to « not at all » with a slider	Land cover, distance from the coast, region and day of the week	Noise contours for aircraft noise above 57dBA (to 72dBA)	-
Lawton and Fujiwara, 2016	189,058	GB	4 ONS well-being questions - Life satisfaction «Overall, how satisfied are you with your life nowadays?» - Worthwhile «Overall, to what extent do you feel the things you do in your life are worthwhile?» - Happiness «Overall, how happy did you feel yesterday?» - Anxiety «Overall, how anxious did you feel yesterday?» Measured on an 11-point scale from 0-10 «not at all» to «completely»	Ethnicity, household income, health status, marital status, employment status, housing status, gender, age, geographic region, religion and education	L_{Aeq16h} L_{night} (above 55dBA for daytime noise, and 50dBA for night time noise)	-

Outcome: Self-reported depression, anxiety and psychological symptoms						
Author	**N =**	**Country**	**Measurements**	**Confounder**	**Noise metric**	**Change**
Hiroe et al., 2017	3,659	JAP	Total Health Index (THI) with 130 items; summing up to 12 subscales for mental health: - Mental instability - Depression - Nervousness 5 derived scores: e.g. - Schizophrenics	Age, sex, noise sensitivity	L_{den}	Relaxation of restrictions
Baudin et al, 2018	1,244	FRA	- Single item: depressive symptoms (past 12 months) - General Health Questionnaire (12 items)	Age, country of birth, gender, occupational activity, alcohol consumption, smoking, number of stressful life events, income, antidepressant use	L_{den} L_{Aeq24h} $L_{Aeq06-22h}$ L_{night}	-
Outcome: Interview measures of depression and anxiety disorders						
Author	**N =**	**Country**	**Measurements**	**Confounder**	**Noise metric**	**Change**
Seidler et al, 2016	1,026,670	GER	Diagnosed unipolar depression (ICD-10)	Sex, age, urban living environment, unemployment benefits, SES	$L_{pAeq24h}$ $L_{pAeqnight}$	-

3.4.2.1 Self-reported health-related quality of life and well-being

Four studies assessed self-reported HQoL and well-being. Two of these assessed HQoL - one in children (Klatte et al., 2017), the other in adults (Lawton and Fujiwara, 2016). The other two studies investigated mental health-related QoL (Schreckenberg et al., 2017) and the effect of aircraft noise exposure on well-being (Fujiwara et al., 2017).

Fujiwara et al (2017) conducted a survey using the experience sampling method (ESM) examining momentary subjective well-being in and around British airports. In this study, data from a spatial positioning experience sampling (Mappiness) was merged with noise contour data from the GPS position of the participant. Results show that high levels of aircraft noise are associated with lower levels of happiness, with a significant negative association between aircraft noise at 66dBA (L_{eq}) and happiness and relaxation, respectively. Exposure to aircraft noise at 72dBA (L_{eq}) is also negatively associated with happiness ratings, but in a very small sub-sample.

Lawton and Fujiwara (2016) conducted a study using data from the national annual population survey (APS) in the UK to link well-being measures with aviation noise using noise contour data. In order to adapt the approach of experience sampling method, respondents were asked to rate their experienced well-being of the whole day. Significantly negative associations of daytime aircraft noise above 55dBL_{eq16hr} and all well-being measures were found, but with all confounders held constant each additional dB in daytime noise resulted in a marginal decrease of well-being measures. For nighttime noise levels no significant association was found.

In the section concerning self-related QoL, two sub-studies from the German NORAH study are included, one from the quality of life substudy and the other from the children sub study. In a longitudinal survey, Schreckenberg et al (2017) examined the association of aircraft noise exposure, annoyance and mental HQoL. Mental HQoL was assessed using the short form of the SF-36, the SF-8 (mental composite score, MCS). Results of the mental HQoL measures indicate that higher levels of aircraft noise are linked to poorer mental quality of life. A weak but significant impact of aircraft noise exposure on mental HQoL was revealed. They further investigated the causal relationship between noise exposure, noise annoyance and mental health-related quality of life (see D3.1).

The NORAH children study (Klatte et al., 2017) found small but significant effects of aircraft noise exposure on children's quality of life (measured with subscales of the standardised instrument KINDL) in a sample of 1,243 second-graders. Children's quality of life was assessed both via parents' ratings and children's ratings. Aircraft noise exposure was associated with less positive judgment of children's mental well-being and well-being at school.

The results of the examined studies suggest small negative effects of aircraft noise on self-reported QoL and well-being, for happiness and well-being only for people in high exposure areas. The two NORAH sub-studies show a decrease of health-related QoL with increasing aircraft sound levels.

In the studies by Lawton and Fujiwara (2016) and Fujiwara et al (2017), noise contour data were merged with other independent survey data to analyse the effects of aircraft noise on well-being measures. A benefit of this non-typical noise research method is that there is no anticipation of study objective in participants that might result in response bias. On the other hand, well-being and happiness are not standardised concepts used in noise research that can be compared to other results. Besides, in these studies only the current state of well-being is assessed, whereas in noise research usually long-term measures are used (e.g. annoyance is rated referring to the last 12 months) to predict long-term effects rather than acute effects of (aircraft) noise. In comparison, standardised scales (the SF-8 for adults and sub scaled of the KINDL for children) were used in the two NORAH studies; all of the studies analysed cross-sectional data.

In comparison to these reviewed studies, the studies analysed by Clark and Paunovic (2018) indicate that there is no association between aircraft noise exposure and measures of self-reported quality of life or health overall; this conclusion is based upon only one study out of six showing signs of an association.

In summary, the studies reviewed above suggest associations between aircraft noise exposure and mental health outcome measures, taking into account that these associations are weak.

3.4.2.2 Self-reported depression, anxiety and psychological symptoms

This particular literature search identified two studies assessing self-reported depression, anxiety and psychological symptoms.

To assess health effects in the vicinity of a major Japanese airport, Hiroe et al (2017) carried out a questionnaire survey in a sample of 3,659 residents using the Total Health Index (THI) questionnaire. The THI measures perceived physical and mental health via 130 items, which are added up to sub-scores (e.g. mental instability and depression referring to mental health). Results show a significant difference regarding depression scores between high exposure groups and the control group, but no exposure-response relationships between aircraft noise exposure and mental effects were found.

The French DEBATS study (Discussion on the health effects of aircraft noise) was performed to investigate the effect of long-term noise exposure from various noise sources on human health. The included sub-study assessed self-reported psychological symptoms using the General Health Questionnaire (GHQ) (12 items allowing identification of participants with psychological ill health) and one single item asking for depressive symptoms in the past 12 months. Baudin et al (2018) report no association between exposure to aircraft noise and psychological distress regarding different noise levels and two types of psychological distress assessment.

The two studies reveal opposing effects for the impact of aircraft noise on psychological symptoms, but they also differ in used instruments operationalizing psychological symptoms. Baudin et al (2018) operationalized psychological health with a questionnaire using scores to group those with psychological ill-health and those with normal health, whereas Hiroe et al (2017) investigated psychological symptoms with a questionnaire deriving sub-scores for symptoms of depression and mental instability. In contrast to Hiroe et al (2017), Baudin et al (2018) focus on psychological distress in general. In comparison to Baudin et al (2018), who included a wide range of confounding factors, Hiroe et al. (2017) performed statistical adjustments for only a few potential confounders, namely noise sensitivity, age, sex and body-mass-index.

In the systematic review by Clark and Paunovic (2018) no studies addressing these outcomes have been identified.

3.4.2.3 Secondary data analysis of depressive and anxiety disorders

One of the NORAH sub-studies investigated depressive and anxiety disorders using secondary data, Seidler et al (2017) examined health insurance data of 1,026,670 residents living in the vicinity of Frankfurt International Airport. They analysed data regarding a relationship between aircraft noise exposure and diagnosed unipolar depressions. Due to the billing system in the German health care system, health insurance data only contains disorders and diseases diagnosed by specialists (psychotherapists and physicians). In this large case-control study, the authors found a relationship between aircraft noise exposure and diagnosed unipolar depression in an inverted u-shape with a peak of risk increase at 50-55dBA.

Since 2014, only one study that met the inclusion criteria examined risk for depression depending on aircraft noise exposure. Study results by Seidler et al (2017) contradict the findings in the study reviewed by Clark and Paunovic (2018) indicating no association between aircraft noise exposure and increased depression risk (Hardoy et al., 2005). Although in both studies trained physicians assessed a medically diagnosed depression disorder, the studies differ in terms of study quality; the main differences include the sample size and noise metrics.

The study carried out by Hardoy et al (2005) lacks a definition of the noise metric used, and the sample size is quite small. The study by Seidler et al (2017) however, shows that noise metrics are well defined and the sample size is large and controlled, which is seen to be a major strength. The study has its limitations however: only persons over the age of 40 years participated in the study, making applicability to younger people difficult.

3.4.3 Conclusions

The results of this review support the findings of the initial WHO review by Clark and Paunovic (2018) indicating inconsistent evidence for the influence of aircraft noise on mental health outcomes.

The small number of studies does not allow the derivation of exposure-response relationships and risk estimates, respectively. The variation in outcome measures limits the comparison of results and especially measures to assess HQoL. Moreover, psychological symptoms have to be differentiated from those detecting manifest disorders, as they do not necessarily lead to the development of severe disorders.

All the studies addressing self-reported HQoL reveal weak but significant associations providing evidence that health-related quality of life is impaired due to aircraft noise. One study sheds light on the link between aircraft noise and a diagnosed mental disorder, although no causal relationship can be established based on the data.

Mental health outcomes should be further addressed in aircraft noise research considering the association between annoyance due to aircraft noise and mental health outcomes that has been found in various studies (e.g. Baudin et al., 2018; Schreckenberg et al., 2017; D2.4 Section 4.4). Since it can be said that rising noise levels may lead to an increase in aircraft noise annoyance, it can be hypothesised that increasing annoyance levels might contribute to a decrease of QoL or increase in poor mental health. This seems to be particularly true at airports where residents expect negative changes in noise exposure, for example, due to an airport expansion (Schreckenberg et al., 2017).

To date, only little reliable evidence is found that considers the impact of absolute aircraft sound levels on mental health related outcomes. This might be different for the impact of (anticipated) relative changes in aircraft noise exposure on mental health. For now, other outcome measures should be addressed by noise mitigation and should be incorporated in intervention planning; preferably those that are related to mental health outcomes in order to potentially have an impact on those as well.

There is a dearth of studies exploring aircraft noise and mental health. The available evidence is relatively weak and further research would improve understanding of exposure-response relationships and risk estimates.

3.5 Hearing Impairment and Tinnitus

Exposure to excessive noise levels, usually over a long period of time, is an important cause of hearing problems and hearing impairment (Olusanya et al., 2014). Tinnitus, such as ringing in the ears, often follows acute or chronic noise exposure and persists in a high proportion of the affected people for extensive periods (Fritschi et al., 2011; Sliwinska-Kowalska and Zaborowski, 2017). Recently 'hidden' hearing loss has been discussed and may manifest as difficulties in understanding speech, especially in noisy environments and not as an audiometric threshold shift (Sliwinska-Kowalska and Zaborowski, 2017). The main factors determining the development of noise induced hearing loss or increase in the threshold of hearing sensitivity are the intensity of noise, length of exposure, impulsiveness of noise and individual susceptibility (Sliwinska-Kowalska and Zaborowski, 2017).

A number of initiatives to prevent hearing loss and other hearing problems have focused in the occupational noise setting, as noise induced hearing loss can be caused by a one-time exposure to an intense impulse sound, or by chronic noise exposure with sound pressure levels higher than 75–85dBLA for an 8-hour period at work (Basner et al., 2014; Stansfeld and Matheson, 2003). On the other hand, the levels of environmental noise exposure, with the focus on traffic noise exposure, are much lower than those from occupational setting, and as such risk of hearing impairment related to environmental noise exposure in general population is still not fully acknowledged. However, exposure to loud music with personal listening devices, as it is possibly the most harmful of the environmental noise exposures, especially for young people, was lately considered with greater attention (Sliwinska-Kowalska and Zaborowski, 2017).

3.5.1 Brief summary of the WHO review on the impact of aircraft noise on hearing impairment and tinnitus

The association between hearing loss and aircraft noise exposure was mostly investigated in the older studies, published 20-30 years ago but the findings were not consistent across studies. Some of the studies found significantly worse standard pure-tone average, high pure tone average and threshold at 4kHz in children with frequent exposure to aircraft noise. On the other hand, more recent studies did not find significant association between excessive aircraft noise exposure and hearing impairment (Sliwinska-Kowalska and Zaborowski, 2017). The WHO report does not mention tinnitus in relation to aircraft noise so we assume there is no evidence to show such association.

3.5.2 Updated review on aircraft noise related hearing impairment and tinnitus

In our literature review, we have not identified new studies that would investigate the association between aircraft noise exposure and hearing impairment outcomes or tinnitus.

The approach of the underlying literature search is described in Annex 7.1.6.

3.5.3 Conclusions

Hearing impairment is mainly associated with exposure to environmental noise in case of very loud or persistent listening to the music and other leisure activities like fireworks, sport events etc. There is no convincing evidence that aircraft noise would cause hearing impairment in general public. However, more research is needed to verify the possible impact on children.

Extensive efforts to reduce aircraft noise exposure to prevent annoyance and sleep disturbance should further reduce the probability for risks of hearing impairment.

The evidence on aircraft noise exposure and hearing impairment and related effects is a few decades old and does not specifically explore impacts on people outside of occupational settings. Further research may increase knowledge of the relationship between aircraft noise exposure and hearing, although there is a suggestion that it is unlikely to be an important factor in hearing impairment amongst the adult population.

3.6 Adverse Birth Outcomes

There is growing recognition that the prenatal period plays an important role in the health and development of children through childhood and later in adult life. There has been widespread speculation about the factors that affect prenatal maternal health and research has focused on identifying the potential prenatal maternal influences on foetal and child development, such as maternal environment, and emotional and psychological state of the pregnant woman (DiPietro, 2012).

Pregnancy is defined as a physiological state, characterised by an increase in hypothalamus-pituitary-adrenal axis function and progressively increasing levels of serum concentrations of stress hormones including cortisol and adrenocorticotropic hormones (ACTH) after 12th week of gestation. Placental corticotrophin-releasing hormone (CRH), which is the principal regulator of the hypothalamic-pituitary-adrenal axis (HPA axis), has been proposed to directly modulate endocrine function of placental trophoblasts including the production of oestrogen, ACTH, and prostaglandin, and it is involved in the timing of parturition. An important notion is that the trajectory of CRH increase during pregnancy has been described to differ by ethnicity and socioeconomic factors (Nieuwenhuijsen et al., 2017).

The possible biological mechanism for adverse birth effects of noise exposure is based on the general stress response mechanism (Dzhambov et al., 2014; Nieuwenhuijsen et al., 2017). Psychological stress has a negative impact on pregnancy and foetal development and noise acts as an environmental stressor (Loomans et al., 2013; Littleton et al., 2010). We have explained the general stress response model to noise exposure in section 3 of this deliverable. Neurohormones, which are released to the general stress response (hormones released in the HPA axis) cause an increase of stress hormones such as CRH, ACTH and glucocorticoids (GCs). Release of maternal catecholamine (adrenaline and noradrenaline) cause an increase in blood pressure and uterine reactivity, both causing a decrease in placental functioning, and may lead to hypoxia of the fetus (Arroyo et al., 2016;

Hobel and Culhaney, 2003; Nieuwenhuijsen et al., 2017; Austin and Leader, 2000; Green et al., 2005; Shapiro et al., 2013; Entringer et al., 2015).

Maternal cortisol might pass through the placental barrier and interfere in the regulation of the fetal HPA axis, or stimulate the placenta to secrete CRH (DeWeerth and Buitelaar, 2005; Nieuwenhuijsen et al., 2017). Another study suggests that noise energy is able to affect the foetus directly (Gerhardt, 1990; Nieuwenhuijsen et al., 2017). Noise level of about 80dBA (L_{Max}) could increase the hematoencephalic barrier's penetrability (Dzhahmbov et al., 2015). Another possible mechanism underlying the association between noise exposure and pregnancy outcomes could be neurotropin nerve growth factor (NGF), which has a critical arbitrator role in stress responses and promotes 'cross-talk' between neuronal and immune cells and which could skew the immune response towards inflammation (Tometten et al., 2006; Nieuwenhuijsen et al., 2017).

However, we still do not know which measures of stress response are most strongly associated with adverse birth outcomes and whether there are critical time windows for the development of adverse birth effects. Most importantly, we still do not know what the cumulative effects of chronic stress and the roles played by different pathways in mediating associations between maternal stress and birth outcomes are (Shapiro et al., 2013).

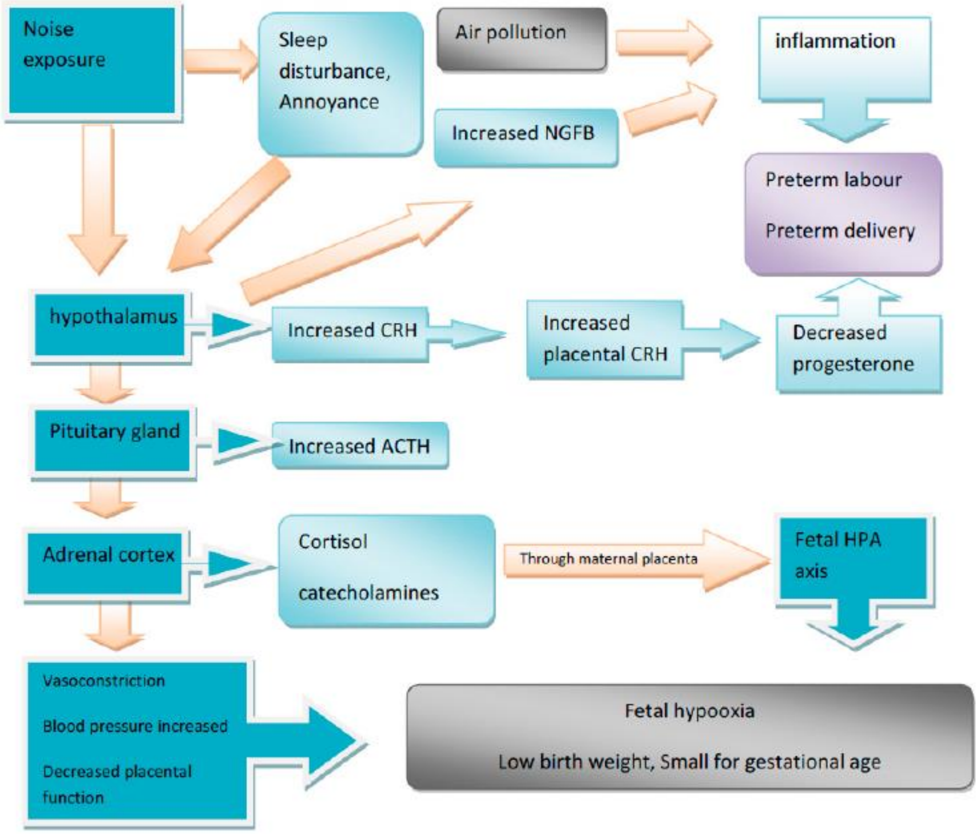


Figure 3: Detailed outline of possible biological mechanism for birth effects (Nieuwenhuijsen et al., 2017)

The World Health Organization (WHO) has prepared a figure for a pathway of possible mechanisms for developing birth outcomes due to noise exposure (Figure 3).

A number of researchers have investigated the relationship between environmental noise exposure and adverse birth outcomes, such as low birth weight, small size for gestational age, preterm birth, spontaneous abortion, and congenital malformations (Nieuwenhuijsen et al., 2017). In the following section, environmental noise, in the form of aircraft noise, and its relationship to adverse birth outcomes is discussed further.

3.6.1 Brief summary of the WHO review on the impact of aircraft noise on adverse birth outcomes

In 2017, Nieuwenhuijsen et al (2017) published an extensive evidence review investigating the effects of environmental noise exposure on adverse birth outcomes, in preparation of the WHO Environmental Noise Guidelines (WHO, 2018).

Nieuwenhuijsen et al (2017) found evidence supporting the association between aircraft noise exposure and preterm birth, low birth weight and congenital abnormalities. Chronic exposure to aircraft noise levels above 70-75dB (L_{den}) was associated with significantly higher risk for preterm birth and low birth weight. Exposure to aircraft noise levels below 65dB (L_{den}) did not show statistically significant association with the incidence of congenital malformations. Nevertheless, WHO assessed the evidence for adverse birth outcomes to be of very low quality, mostly due to the limitations of the study designs, inconsistencies across studies and because a lot of studies did not properly address confounding factors (Nieuwenhuijsen et al., 2017).

Furthermore, it should be noted that, from the collected evidence it cannot be concluded to what extent exposure to aircraft noise affects these birth outcomes. Similar findings were also found for other environmental noise sources, and, as in other health impacts, for which an association with aircraft noise was found, there is recognition of a need for new studies, to give provide a greater understanding of these subjects. The studies recognise the need for inclusion of potential modifiers and confounders, such as socioeconomic status, air pollution and noise sensitivity (Nieuwenhuijsen et al., 2017).

3.6.2 Updated review on aircraft noise related adverse birth outcomes

Studies, which have been published after the WHO publication did not specifically explore the association between aircraft noise exposure and birth outcomes, but mostly investigated the relationship with road traffic noise.

The approach of the underlying literature search is described in Annex 7.1.7.

3.6.3 Conclusions

Nieuwenhuijsen et al (2017) observed indications for the association between aircraft noise exposure and preterm birth, low birth weight and congenital abnormalities, but the evidence supporting these findings was assessed as of very low quality. Further investigation of the association is needed. Our updated review did not identify any new study investigating the association of aircraft noise and adverse birth outcomes.

Knowledge of the potential relationship between aircraft noise and adverse birth outcomes is deficient. Understanding of any connections between the two factors requires new research.

3.7 Metabolic Diseases

Recent scientific findings suggest that exposure to increasing noise levels may also be associated with increased risk of adverse metabolic health effects. It is assumed that noise acts as a stressor and may contribute to the adverse effects on metabolic system by activating the hypothalamic pituitary adrenal axis and increasing cortisol levels, which consequently inhibits the secretion of insulin as well as peripheral insulin sensitivity. In addition, disruptions of normal sleep patterns and chronic sleep deprivation can influence diabetes with increasing fasting glucose and appetite modulation, as well as general irregulation of the metabolic and endocrine functions (van Kempen et al., 2017; Eriksson and Pershagen, 2018). Adverse health outcomes of metabolic system associated with noise exposure are type II diabetes and obesity.

In 2018, van Kempen et al (2018) published a summary of an extensive systematic evidence review on the adverse effects of environmental noise exposure on cardiovascular and metabolic system. We implemented an updated review of adverse metabolic effects of aircraft noise exposure in order to include studies published after that period.

3.7.1 Brief summary of the results of the van Kempen et al., 2018 on the impact of aircraft noise on metabolic system diseases

Van Kempen et al (2018) observed that the effects of noise exposure on metabolic system have not yet been extensively studied and based on such a small pool of evidence no firm conclusions could be made. Nonetheless, van Kempen et al (2018) were able to estimate the risk for the occurrence of diabetes and obesity. The estimates of risks due to aircraft noise exposure are displayed in Table 9.

Evaluated studies showed that aircraft noise is non-significantly associated with the prevalence of diabetes, but the same was not observed for the incidence of diabetes. On the other hand, WHO reported that the results from one of the studies' gender-specific analysis suggested an increased risk of type II diabetes in women with RR 2.11 (95 % CI 0.76 – 5.88), suggesting that women are more prone to the occurrence of diabetes due to aircraft noise exposure.

In estimating the relationship and contributing risk for the development of obesity due to aircraft noise exposure markers of obesity, such as body mass index (BMI) and waist circumference were investigated. Van Kempen et al (2018) from the evaluated studies observed an association between an increase in traffic noise and increase in obesity markers. In some of the evaluated studies the occurrence of obesity markers appeared only in certain sub-groups. Increase in aircraft noise was significantly associated with increase in waist circumference. No clear increase in BMI in relation to the aircraft noise exposure per 10dBA was observed.

Outcome		**Study design**	**RR per 10 dBA (95% CI)**	**Participants (cases)**	**QoE**
Diabetes	Prev	1 CS	1.01 (0.78-1.31)	9,365 (89)	Very low
	Inc	1CO	0.99 (0.47-2.09)	5,156 (1,346)	Low
Outcome		**Study design**	**Change per 10 dBA**	**Participants**	**QoE**
Obesity	Δ BMI (kg/m^2)	1 CO	0.14 (-0.1- 0.45)	5,156	Low
	Δ waist circumference (cm)	1CO	3.46 (2.13-4.77)	5,156	Moderate

Table 9: Aircraft noise exposure and the risk of diabetes and obesity as provided by WHO (van Kempen et al., 2018; van Kempen et al., 2017).

3.7.2 Updated review

In our updated review we identified two additional studies that have not been included in the van Kempen et al (2018), and investigated the adverse effect of aircraft noise exposure on metabolic system.

One of the studies investigated the relationship between aircraft noise and the risk of type II diabetes. Eze et al (2017) found that there is a strong effect of aircraft noise, independent of other transportation noise sources on the occurrence of diabetes type II. The estimated risk in the study for aircraft noise exposure (L_{den}) was RR 1.71 (1.02 – 2.88). The estimated risk was adjusted to age, gender, education, socio-economic factor, smoking, alcohol and vegetables/fruits consumption, NO_2, physical activity, BMI, change in BMI, noise intermittency and traffic noise annoyance. Aircraft noise, which showed doubling of diabetes incidence per interquartile range (IQR), became more precise on accounting for noise intermittency, though noise intermittency itself was not associated with diabetes risk across single exposure models for aircraft noise (RR 0.88, 95% CI 0.68 – 1.13). Their findings present comprehensive and strong effect of aircraft noise on the occurrence of diabetes independent of the other transportation noise sources or NO_2.

Pyko et al (2017) in their study investigated the relationship between traffic noise (single noise sources and combined noise sources) and markers of obesity (waist circumference and BMI). During the follow up period they observed changes in weight (Δ BMI) and waist circumference in order to assess the risk for overweight (≥ 25 BMI) and central obesity (women ≥88 cm; men ≥102 cm) due to noise exposure. An association between exposure to aircraft noise and increase in waist circumference was observed. The average weighted waist circumference increase for aircraft noise was assessed at 0.16 cm/y (95% CI 0.14 – 0.17) per 10dB L_{den}. Assessed trend in incidence of central obesity in relation to aircraft noise exposure was IRR of 1.19 (95% CI: 1.14 – 1.24). Excess risk for central obesity related to aircraft noise exposure seemed to occur at noise levels lower than 50dB L_{den}. The observed increase in central obesity was highest for aircraft noise in comparison to other traffic noise sources. The risk increased to IRR of 2.26 (95% CI 1.55 – 3.29) in people exposed to all 3 transportation noise levels ($p< 0.001$).

As it was observed for changes in waist circumference, weight gain was associated with aircraft noise exposure and during the follow-up period changed with 0.03 kg/y (95% CI 0.01 – 0.04) per 10dB L_{den}. Aircraft noise was associated with an increased risk of overweight showing an IRR of 1.06 (95% CI 1.01 -1.12) per 10dB L_{den}. In relation to aircraft noise exposure, a statistically significant trend was observed for overweight in women only.

The approach of the underlying literature search is described in Annex 7.1.8.

Study	Design	Population	Outcome (ICD-10)	Noise assessment	Follow-up	Analysis	Adjustments	Noise cat. (dBA)
Eze et al., 2017	CO (2002 – 2011); Switzerland	Total = 2631	Diabetes	Modelling (FLULA2); L_{den}, L_{den}, L_n	Yes, SAPALDIA study (8 yrs)	Mixed Poisson regression model (RR)	A, G, E, SEI, S, Al, FV, PA, BMI, ΔBMI	Trend per 10dBA
Pyko et al., 2017	CO (1992 – 2006)	Total = 7949 (35-56 yrs)	Obesity markers (BMI-overweight, waist circumference-central obesity)	Airplane contours; L_{den}	Yes, 13 years	Linear regression model	A, G, PA, DH, PsyD, FD, O, SW, M, SD	Trend per 10dBA, Noise categories

A – age; G – gender; E – education; SEI – socioeconomic index; S – smoking; Al – alcohol; FV – fruit/vegetable consumption; PA – physical activity; BMI – body mass index; DH – dietary habits; PsyD – psychological distress; FD – family history of diabetes; O – occupational status; SW – shift work; M – martial status; SD – sleep disturbance;

Table 10: Study characteristics of the updated review

3.7.3 Conclusions

The literature review by van Kempen et al (2018) and our updated review showed that research on adverse metabolic effects of noise exposure is still not widely investigated. However, there is substantial evidence supporting the mechanism for development of metabolic effects due to noise exposure. Van Kempen et al (2018) in their review observed that there are indications for the association between increased noise levels and increased risk for adverse metabolic health effects and our updated review showed indications that **excessive risk for metabolic health outcomes could happen at relatively low noise levels.**

3.8 Annoyance and Health

3.8.1 Link between aircraft noise annoyance and health outcomes

The WHO states that noise annoyance leads to anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation or exhaustion, and sleep disturbance (WHO, 1999). Babisch (2002) describes in his noise effects reaction schema an epidemiological cause-effect chain [see introduction to this section 3 (Substantive Health Impact Reviews) for a more detailed description]. According to Babisch (2002), noise provokes - through the indirect pathway - disturbance, cognitive and emotional responses; summarised in the annoyance reaction. Underlying neuroendocrine and neural activations affecting the metabolic state of the organism might contribute to prolonged stress reactions. Due to the multi-dimensional structure of annoyance, it might be related to, or even contribute to, various health outcomes or even to manifest disorders.

Furthermore, it is suggested that health outcomes are linked to noise annoyance; or rather that noise annoyance contributes to the development of health outcomes. However, the causal pathway is not determined. Health outcomes can also be discussed as contributing to the manifestation of noise annoyance. In the pan-European LARES study (Large Analysis and Review of European housing and health Status), Niemann et al. (2006) investigate the impact of housing conditions on health in adults, children and the elderly in six European countries. Associations between the prevalence of medically diagnosed illnesses and traffic noise-induced annoyance and neighbourhood noise-induced annoyance respectively, were examined. Results revealed a significant association between strong annoyance by traffic noise and cardiovascular symptoms like hypertension (not for heart attacks), symptoms in the respiratory system (e.g. bronchitis) and diagnosed depressions. For most of the diseases and symptoms studied, there appeared to be a link between people’s propensity for noise annoyance and their risk of specific symptoms or conditions.

Unfortunately, annoyance due to different traffic sources had been pooled to one traffic noise annoyance variable, which was used to perform the analysis. Thus, it is not possible to derive the magnitude that is attributable to aircraft noise. Instead, it allows the conclusion that **traffic noise is a health risk**.

The relation of noise annoyance and health outcomes thus, leads to the question of the causal pathway between them, for example:

- Do high ratings of annoyance play a role in the development and maintenance of diseases?
- Are people who are suffering from any form of disease more bothered/annoyed/disturbed by aircraft noise?
- Is there an actual link or is it rather a mediation or moderator effect?

This review tries to shed light on these issues raised, and discusses research papers regarding the link between aircraft noise annoyance and various health outcomes, namely cardiovascular diseases, sleep parameters, and mental health outcomes. A literature search for published literature since 2014 was conducted in August 2018; the first section gives an overview of these findings. Subsequently, literature is discussed separately for different outcome segments. An outline of how this literature search was approached can be found in Annex 7.1.9.

3.8.2 Studies on aircraft noise annoyance and health outcomes: A review

Table 7 gives an overview of the studies including their sample size, country of implementation, utilised outcome measures, noise metrics and confounders. Studies are sorted by outcome.

Due to the relatively small number of studies found and a lack of comparable measures used, it is not possible to quantify reliable and generalisable results. This sub-section, therefore, reflects a narrative review of studies.

Table 7: Description of included studies

Outcome: Sleep					
Author(s)	**N =**	**Country**	**Measurements**	**Confounder**	**Noise metric**
Bartels, 2014	1,262	Germany Darmstadt	Aircraft noise annoyance • Verbal 5-point scale (Fields et al., 2001) Sleep quality 6 items rating on semantic differential (10 points) 1. Falling asleep (difficult – easy) 2. Quality of sleep (disturbed - calm) 3. Sleep depths (shallow – deep) 4. Sleep duration (short – long) 5. Restorative quality of sleep (low – high) 6. Tossing and turning (frequent – few)	-	LA_{eq} (derived from recordings at sleeper’s ear)
van den Berg et al., 2014	3,817	The Netherlands, Amsterdam	Aircraft noise Annoyance • ICBEN 11-point numerical scale referring to last 12 months Sleep disturbance • Question modeled after standard annoyance question (ICBEN)	-	-
Outcome: Mental Health					
Author	**N =**	**Country**	**Measurements**	**Confounder**	**Noise metric**
Baudin, et al., 2018	1,244	France Paris Lyon Toulouse	Psychological distress • General Health Questionnaire with 12 items covering mood, behaviour, current feeling, recent feelings, 4-point scale • Single Item Aircraft noise annoyance • ICBEN question with 5-point verbal scale	gender, age, country of birth, occupational activity, education, marital status, smoking habits, alcohol consumption, number of work-related stress and major stressful life events, household monthly income, sleep duration, antidepressant use, self-reported anxiety	L_{DEN} $L_{Aeq24hr}$ $L_{Aeq6hr-22hr}$ L_{night}
Beutel et al., 2016	15,010	Germany Mainz	Depression Patient health questionnaire (PHQ-9) Anxiety Two items of GAD-7 (Generalised Anxiety Disorder scale)	sex, age, socioeconomic status	-

			Aircraft noise annoyance "How annoyed have you been in the past x years by…"? (Felscher-Suhr et al., 2000), 5-point scale		
Dreger et al., 2015	1,185 (first to fourth grade)	Germany Bremen	Mental health Strengths and Difficulties Questionnaire for parents (SDQ) Aircraft noise annoyance ICBEN noise question with 5-point verbal scale	number of siblings, early biological risk (born prematurely before week 37 or had a low birth weight (under 2500g) or both), crowding, second-hand smoke at home, physical activity, single parenthood, parental education, parental unemployment, household equivalent income, migration background	-
Schreckenberg et al., 2017	3,508	Germany Frankfurt	Aircraft noise annoyance • ICBEN 5-point verbal scale Mental HQoL (health-related quality of life) • SF-8	mode of survey, gender, age, socio-economic status (SES), migration background, noise sensitivity, occupancy, ownership of residence, hours during the day not at home, body mass index (BMI), physical activities, and $L_{pAeq,24hrs}$ for road traffic and railway sound exposure,	$L_{pAeq24hrs}$
Outcome: Cardiovascular disease					
Author	**N =**	**Country**	**Measurements**	**Confounder**	**Noise metric**
Babisch et al., 2013	4,861	Germany Berlin	Aircraft noise annoyance Non-verbal 11-point 'ICBEN scale' ranging from 0 to 10 (Fields et al., 2001). Hypertension • Blood pressure measurements combined with information on diagnoses of hypertensive disease and medication	age, gender, BMI, alcohol consumption, school education, physical activity at leisure, study area (country/airport)	L_{den}
Carugno et al., 2018	400	Italy Orio al Serio International Airport (BGY)	Same questionnaire and methods as in HYENA study	gender, age, education, BMI, cigarette smoking, last occupation, airport-related job, annoyance score from traffic noise	L_{den}

Eriksson et al., 2010	4,721	Sweden Stockholm	Aircraft noise annoyance 4-grade scale • Never • A few times per month • A few times per week • A few times per day Blood pressure • Diagnose of hypertension • Blood pressure measure	age, socioeconomic status, body mass index, use of tobacco, family history of diabetes, physical activity, working in shifts, alcohol intake and road, rail and occupational noise annoyance, hormone replacement therapy/menopause status	L_{den}
Hahad et al., 2018	14,639	Germany Mainz	Aircraft noise annoyance “How annoyed have you been in the past x years by?” 5-point scale • During the day • During sleep Atrial fibrillation (AF) • Previous diagnosis of AF (self-reported) and/or • Documentation of AF on the study electrocardiogram (ECG)	Age, sex, medication use, smoking, family history of MI/stroke, dyslipidaemia, obesity, hypertension, diabetes mellitus, socioeconomic status (SES), night shift work, depression	-

3.8.2.1 *Noise annoyance and cardiovascular disease*

This section reviews the relationship between noise annoyance and cardiovascular diseases. For the association of noise exposure and cardiovascular diseases see section 3.1, above. For this section, a total of four papers were selected in which the relationship between aircraft noise annoyance and cardiovascular symptoms were assessed.

In the German Gutenberg health study, which aimed at gathering information about etymology, pathogenesis, and risk factors of common diseases, Hahad et al (2018) examined the association of atrial fibrillation (AF), a cardiac dysrhythmia disorder, and noise annoyance due to, among others, aircraft. Noise annoyance was assessed with the verbal 5-point ICBEN scale. Atrial fibrillation was assessed via electrocardiographic (ECG) and self-reported history of AF. Results show participants with high levels of total noise annoyance having a higher prevalence of AF in comparison with participants reporting no annoyance. Also, the results in this study indicate that other cardiovascular risk factors such as hypertension as well as blood pressure and heart rate were not modified by annoyance. Further, significant associations between atrial fibrillation and annoyance due to aircraft noise were detected for day and night time, but with rather small effects (day: OR 1.04, 95% CI 1.00–1.08; night: OR 1.14, 95% CI 1.05–1.13). The drawback of this study is the absence of underlying noise data.

In a longitudinal study investigating causes of diabetes, Eriksson et al (2010) examined in a subsample of 4,721 participants the association between noise annoyance and hypertension. They created a hypertension free baseline sample excluding participants with a history and indices of hypertension. Noise annoyance was assessed in the follow-up 8-10 years after baseline using a 4-point verbal scale; noise annoyance at baseline was estimated by the Miedema function (Miedema and Oudshoorn, 2001). Results indicate that the relative risk for hypertension among subjects reporting annoyance was significantly higher than in those not reporting annoyance (RR = 1.42 (1.11–1.82)). The authors conclude that participants annoyed by aircraft noise might be sensitive to noise related hypertension.

In the HYENA study (Hypertension and Exposure to Noise near Airports), conducted by Babisch et al (2013), an analysis examining noise annoyance as a potential effect modifier for noise levels on health effects, such as cardiovascular diseases, was performed. Overall, 4,861 people participated at six major European airports (London, Berlin, Amsterdam, Stockholm, Milan, and Athens). Noise annoyance was measured using the non-verbal 11-point ICBEN scale (Fields et al., 2001). Blood pressure measures were carried out during a home visit to assess hypertension diagnoses according to the criteria of the WHO. In addition, information on diagnoses of hypertensive disease and medication was assessed for an accurate classification. Logistic regression models revealed no significant association between either aircraft noise levels, or annoyance with risk of hypertension, also when controlling for confounders. A stratified analysis showed a stronger effect of noise levels on risk of hypertension with higher annoyance. The authors conclude that results do not show whether noise levels or noise annoyance is a better predictor for risk of hypertension but suggests a slight tendency that noise levels have a stronger impact in annoyed subjects than in less annoyed subjects.

Carugno et al (2018) conducted a aircraft cross-sectional study to investigate the relationship of noise levels and different non-auditory health effects in 400 participants aged 45-70 around Orio al Serio International Airport in Italy. The researchers grouped participants according to the exposed noise levels in three noise zones, <60A, 60-65dBA, and 65-75dBA$_{LVA}$, an Italian index of the daily aircraft noise level. According to the authors the same measurements and questionnaires as in the HYENA study were used. No differences in blood pressure levels depending on noise zones were detected. Also, the prevalence of hypertension did not differ across zones. Further analyses of the relationship between blood pressure and aircraft noise annoyance were performed, revealing no association between blood pressure and annoyance levels. The small sample size for each noise zone limits the applicability of the results.

Taken together, the studies do not show a consistent picture. While Carugno et al (2018) do not find a link between annoyance and blood pressure, other studies did find a positive association between annoyance and hypertension (Babish et al., 2013; Eriksson et al., 2010; Hahad et al., 2018). As all of these studies used cross-sectional research designs, no study allows for the derivation of causal pathways. It has to be noted that the comparability of the studies is impaired as the measurements of annoyance differ (i.e. 4- and 5-point verbal scale and 11-point numerical scale). Also, the studies of Hahad et al (2018) and Eriksson et al (2010) are more general health studies not explicitly designed to investigate the effects of aircraft noise. Thus, the evidence is not sufficient to draw consistent general conclusions.

3.8.2.2 Sleep and noise annoyance

There are multiple aspects in sleep that can be measured, starting by physiologically assessed measures like the number of awakenings, or self-reported disturbance or quality of sleep. The relationship between aircraft noise and sleep parameters is traced in Section 3.2. In this section, the link between aircraft noise annoyance and different aspects of sleep are reviewed in two studies, one by Bartels (2014) examining the link between annoyance and sleep quality and the other by van den Berg et al (2014), investigating the relationship between sleep disturbance and aircraft noise annoyance ratings.

For her dissertation, Bartels (2014) conducted a laboratory and field study to examine short- and long-term annoyance and its major determinants. In one part of the field study, she investigated the association of self-rated sleep quality, short-term annoyance and long-term aircraft noise annoyance in participants living in the vicinity of Cologne/Bonn Airport. Long-term noise annoyance was assessed for the past 12 months according to the recommended 5-point verbal rating scale by ICBEN (Fields et al., 2001). Sleep quality was rated with 6 items summed up to a sleep quality score, for example sleep depths, sleep duration, and restorative quality. Results showed that self-rated subjective sleep quality during four study nights was a significant predictor for long-term aircraft noise annoyance with an underlying negative association. Better-rated sleep quality accompanied a lower rating of long-term aircraft noise annoyance. The authors also state that the contribution of the average subjective sleep quality to long-term annoyance was equal to the contribution of the average short-term annoyance at daytime.

Van den Berg et al (2014) performed a study to examine the relationship between noise annoyance and sleep disturbance around Schiphol Airport. Both noise annoyance due to aircraft, and sleep disturbance were assessed with the standardised ICBEN question on a 5-point verbal scale, in case of the sleep disturbance in an adapted version (Fields et al., 2001). Sleep disturbance and noise annoyance strongly correlated in the examined sample, (for aircraft r = 0.83), also showing a strong linear relationship. Results raise the issue of whether it is redundant to ask both questions; the validity therefore, of the strong effect is questionable due to the strong correspondence of both used items. A problem in this study is that analyses have only been performed for people hearing the noise source; hence participants had to indicate whether they hear a noise source or not before rating the annoyance.

The two studies in this review use different self-report measures, one to assess sleep disturbances, the other to evaluate the quality of sleep. Therefore, the possibility to compare the results of the various studies is limited. Within these studies, noise annoyance was measured with the same standardised question (Fields et al., 2001). Altogether, the results indicate a possible association of self-reported sleep measures and noise annoyance.

3.8.2.3 Mental health and noise annoyance

Only a few studies examined the relationship between noise annoyance and mental health outcomes. For the association of mental health and noise exposure see section 3.4.

In this section, four studies are presented: two studies examine the link between mental health-related quality of life in adults and children (Dreger et al., 2015; Schreckenberg et al., 2017), one study examined psychological distress (Baudin et al., 2018) and one engaged in the analysis of manifest mental disorders (Beutel et al., 2016).

Dreger et al (2015) performed a longitudinal study to investigate the influence of environmental noise on mental health problems. The sample consisted of 1,185 school-aged children, first graders and four years later in a follow-up.

Mental health was assessed in terms of five sub-dimensions of the Strengths and Difficulties Questionnaire (SDQ, parental version): emotional symptoms, conduct problems, hyperactivity, peer relationship problems, and pro-social behaviour. Noise annoyance was measured using the recommended annoyance questions by ICBEN (Fields et al., 2001) with the 5-point verbal scale. The authors used the noise annoyance measure as an exposure variable. Results showed no associations between aircraft noise annoyance and any of the SDQ outcome variables. The authors argue that the study area is not highly exposed to aircraft noise, and that might contribute to the observed results. In addition, an objective noise exposure assessment is missing. Changes in annoyance ratings do not necessarily indicate changes in objective noise exposure.

Schreckenberg et al (2017) examined the relationship between aircraft noise annoyance and mental health-related quality of life (QoL) analysing longitudinal data from the German NORAH study (Noise-related annoyance, cognition, and health). Mental health-related QoL was assessed with the SF-8 questionnaire, an instrument conceptualised to assess health-related quality of life for the dimension mental well-being and physical well-being (Ellert et al., 2005). Aircraft noise annoyance was measured with the ICBEN item (Fields et al., 2001). In a cross-sectional analysis mental health-related QoL was found to decrease with the degree of annoyance due to aircraft noise. An analysis of the causal pathway revealed annoyance to mediate the effect of noise levels on mental health-related QoL. Results also indicate that annoyance and mental health-related QoL are reciprocally associated with each other. Moreover, mental health-related QoL seemed to negatively influence future annoyance ratings; higher QoL led to less annoyance.

In a sub-study of the French cross-sectional DEBATS study (Discussion on the health effects of aircraft noise), Baudin et al (2018) aimed to investigate the relationship between aircraft noise and psychological distress. Psychological distress was measured with the General Health Questionnaire (GHQ), which is used as a screening questionnaire to identify psychological distress, but not for clinical diagnoses. No association was found between noise exposure (independently of the indicator) and psychological distress, but a relationship was observed between psychological distress and aircraft noise annoyance. Furthermore, they observed that OR (odds ratios) for psychological distress strongly increased from 1.79 for people being slightly annoyed to 4.0 in people being extremely annoyed.

Only one study investigated the effect of traffic noise on manifest mental disorders. Beutel et al (2016) conducted a study using screening instruments (PHQ-9 and GAD-7) to identify disorders. Noise annoyance was measured with a slightly modified version of the German 5-point verbal ICBEN scale (Felscher-Suhr et al., 2000). Results showed that depression and anxiety scores as well as the prevalence of medically diagnosed depressions and anxiety disorders increased with the degree of annoyance. Adjusted for few socio-demographic factors, the odds ratio for anxiety and depression increased with the degree of noise annoyance compared to no annoyance. The drawback of the study is the use of the highest annoyance ratings of all categories as total noise annoyance. Although analyses show that aircraft is the source with the highest annoyance ratings among ratings on traffic noise in this sample, the reader cannot derive to which extent it accounts for the association of total noise annoyance and magnitude of scores or prevalence of diagnoses. Another drawback of the study is the lack of actual noise assessment.

In summary, while most studies do not establish a relationship between mental health measures and noise levels, they do show associations between mental health measures and noise annoyance. However, the sample characteristics varied between the studies, in that Dreger et al (2015), but not the others, addressed children. More importantly, also the outcome measures differed, with Schreckenberg et al (2017) investigating the mental health-related quality of life, Baudin et al (2018) aiming at psychological distress, Beutel et al (2016) covering manifest mental disorders (depression and anxiety), and Dreger et al (2015) addressing quality of life and well-being in children. Altogether, the results indicate that noise annoyance is associated both with mental health quality of life and psychological distress as well as to some extent with manifest disorders.

3.8.2.4 Physical activity and noise annoyance

A longitudinal study by Foraster et al (2016) shows that transportation noise annoyance is negatively associated with physical activity. 10-year noise annoyance due to aircraft noise was related to a decrease in moderate physical activity. Results indicate that noise annoyance might be detrimental in a two-fold impact on health. When annoyance leads to a decrease in physical activity accompanying restoration (in a physical and psychological manner) is prevented. Besides, the decrease in physical activity due to noise exposure resulting in noise annoyance might contribute to the development of long-term health outcomes such as cardiovascular disease risk, obesity, and diabetes. Longitudinal and cross-sectional results indicate a negative association of transportation noise annoyance and physical activity.

3.8.3 Conclusions

This review shows that **there are few studies regarding the links between aircraft noise annoyance and health outcomes.**

For cardiovascular diseases, three of the four examined studies found health outcomes to be associated with aircraft noise annoyance ratings. Regarding mental health, relationships of annoyance and quality of life, psychological distress and – to a lower extent – depression and anxiety have been shown. Moreover, different kinds of sleep measures and the amount of physical activity are also linked to noise annoyance.

Overall, most parts of the evidence result from cross-sectional studies, and thus do not allow for exploring underlying causal pathways.

It can be argued that the individual appraisals of noise, more than noise levels themselves, contribute to the effect on health outcomes. In some studies, noise annoyance is discussed as a mediator between noise exposure and health outcomes. However, in line with the stress theory and regarding the little but significant evidence found, it seems that annoyance might (at least partly) mediate the effect of noise levels on health outcomes. This leads to the assumption that interventions aiming at the reduction of noise annoyance might be accompanied by a reduction of negative health outcomes. Noise annoyance and influencing factors on its magnitude are more extensively discussed in D2.4, section 6.

This summary is based on very few studies, some of which do not primarily address aircraft noise annoyance. Therefore, this review has a narrative character, and generalisations are not yet possible.

While there is a paucity of studies of aircraft noise annoyance and health outcomes, there may be an apparent link between subjective noise annoyance and cardiovascular disease, as well as mental health and quality of life. Further research would need to be undertaken to establish any causal pathway between annoyance and health outcomes.

4 Community Health Risks

In the previous sections the evidence of the impact of aircraft noise on human beings was reviewed for several health outcomes. Associations with average aircraft sound levels were reported and interpreted for:

- Cardiovascular diseases
- Sleep disturbance
- Annoyance
- Cognition

- Mental health
- Hearing impairment
- Other adverse effects – including birth effects and metabolic diseases

In this Section we aim to discuss the health risks that emerge from exposure to aircraft noise and thus the position of the latest WHO Environmental Noise Guidelines and how that can inform the comprehensive goal of aviation industry to be responsible corporate citizen and act to improve residents' quality of life in general.

For this deliverable, acute effects of aircraft noise (e.g. aircraft-noise related awakenings) as well as associations between aircraft sound exposure and long-term effects such as cardio-vascular diseases are discussed. The general stress-model described in at the start of Section 3 is the theoretical background for the assumed link between acute psychological and physiological responses of individuals to aircraft noise exposure and long-term health impacts. **The evidence presented in the preceding reviews of health impacts demonstrates that researchers have been able to measure short-term physiological (and psychological) responses to noise exposure with reasonable accuracy and confidence.**

To address long-term effects, researchers rely primarily on epidemiological studies, which by their very nature introduce some sources of uncertainty (e.g. confounders and co-variants) that researchers have attempted to address with varying degrees of success (it is worth noting that these challenges are no different to those faced in establishing health risks from other environmental factors). **Further, such studies are also constrained by data quality (e.g. narrow descriptors of the noise environment[3]) and limited to statistical associations, which do not necessarily imply causality. Therefore, further studies are needed to investigate such causalities.**

Meta-analyses of epidemiological studies undertaken on behalf of the WHO and summarised in preceding sections have shown positive associations between aircraft noise exposure and ischemic heart disease, annoyance, reading and oral comprehension and sleep disturbance during the night. For other health outcomes statistical significant associations were not observed, whether this is due to the lack of association or due to the unresolved uncertainties in the research is still unknown, future studies should focus on addressing these limitations.

The position of the WHO appears to be that whilst the evidence supporting the associations between aircraft noise exposure and health impacts is of ‘moderate quality’, future research may improve this quality and result in firmer associations.

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[3] In practically all cases the measure used for quantifying noise exposure is some form of outdoor A-frequency weighted dB Level Equivalent with the most common being dB L_{den} and L_{night}

It is worth noting that our review of studies, published since the 2014 deadline for inclusion in the recent WHO reviews, paints a similar picture of inconsistent outcomes generally pointing to positive statistical associations with the main health impacts identified by the WHO.

In determining recommended noise exposure thresholds the WHO has defined sound exposure levels "above which the GDG [Guideline Development Group] is confident that there is an increased risk of adverse health effects" (WHO, 2018:20). In turn the WHO have given the highest priority to the avoidance of annoyance, with the key threshold defined as the onset of 10% highly annoyed people, and sleep disturbance the threshold of which is defined as onset of 3% highly sleep disturbed (for aircraft noise 11% highly sleep disturbed in order to avoid extrapolation to sound levels lower than the range of validity of the evidence). The WHO 'strongly recommends' that noise levels produced by aircraft should be reduced to below 45dBA L_{den} and 40dBA L_{night} (2018b:6) based on the percentage of highly annoyed and highly sleep disturbed people, respectively. The WHO regards these as important health outcomes in their own right as well as potential mediators of other long-term health impacts (Eriksson et al., 2018). Significantly, also in our review some associations were made between sleep disturbance, annoyance and some long-term health outcomes, indicating that sleep disturbance and annoyance may be mediators of some health impacts.

Health outcomes are however only one important segment of more comprehensive assessments of the health impacts of policies, plans and projects in diverse economic sectors using quantitative, qualitative and participatory techniques. The air transport industry makes an important contribution to the economy, job creation, quality of life and well-being (i.e. through the supply of services in support of leisure, family/cultural links) and in so doing helps reduce for example unemployment and low socio-economic status that may have negative impacts on health (Winkleby et al., 1992; WHO, 2013; and Stringhini et al., 2017). Indeed, in their commentary accompanying the latest Environmental Noise Guidelines, the WHO [World Health Organization] acknowledges some of these ‘transportation goods’ (WHO, 2018a: 73).

5 Implications and Recommendations

At the most basic level these WHO recommendations require political processes to be established that allow for the balancing of the costs of achieving reductions in risks to health (in terms of the economic and social cost of constraining airport/aviation development) against those borne in terms of risks to the health of populations exposed to noise. Comment on this broader political risk management challenge is beyond the scope of this ANIMA deliverable.

Though, whatever the outcome of these negotiations to build consensus on what constitutes a socially acceptable response to the challenge of health risk reduction, it is desirable that every effort is made to ensure effective and efficient use of any resources deployed to mitigate risks. With this in mind, **the WHO reviews, and that conducted as part of this sub-task in ANIMA, highlight the importance of addressing annoyance and sleep disturbance as the most critical outcomes**; given that on the one hand it represents direct disturbance and irritation of residents living near airports and on the other hand persistent annoyance has been linked to other adverse health effects through the stress mechanism. Consequently, it can be hypothesised that reducing annoyance and sleep disturbance will decrease adverse health effects of aircraft noise and improve well-being/quality of life.

Consequently, if efforts to mitigate these health risks are to be optimised they should focus on annoyance outcomes in addition to conventional attempts to reduce noise exposure. ANIMA deliverable D2.4 provides evidence that, for such efforts to be enhanced, they must address the full suite of acoustic and non-acoustic contributions to noise annoyance. To date, management interventions and indeed impact studies have only partially addressed these contributions. Thus, **going forward we need to encourage a more *comprehensive* approach both in the design and evaluation of noise interventions and in the assessment of the long-term consequences arising from noise exposure (see for example WP3, sub-tasks 3.1.2 and 3.2.1)**.

Such an approach will need to focus on the *process* by which interventions are designed, decided upon and implemented to address all potential (significant) acoustic and non-acoustic contributions to annoyance.

From an operational standpoint, this implies processes that:

- Allow for the identification and description (through the noise metrics used) of important (from the perspective of effected communities) acoustic attributes – we expect these to extend beyond conventional dBA L_{eq} representations to include a range of decibel and non-decibel acoustic features that describe meaningful aspects of the *acoustic context* (see D2.4 Section 6 for a detailed explanation of the range of attributes contributing to the acoustic context). In this way a common (comprehensible) language for defining noise exposure can be used to inform dialogue with key stakeholders.
- Harness this 'common language' in the provision of engagement opportunities throughout the whole course of noise management interventions from inception through design, decision-making, implementation and evaluation. Thereby addressing key non-acoustic contributions to annoyance through transparency, accountability, empowerment and involvement in decision-making (see D2.4

Section 7 for a list of contributors to the *non-acoustic context* of noise annoyance). In turn this should help build trust, demonstrate fairness, improve attitudes to source and alleviate perceptions of powerlessness/inability to influence outcomes.

From a research standpoint, this recommendation to adopt a more comprehensive approach to annoyance mitigation highlights the need to:

- Establish how interventions have influenced (and may influence in the future) annoyance outcomes and by implication well-being/QoL and thereby potentially mitigate long-term health risks (ST 3.1.2 addresses this requirement specifically)
- Assess the impact of engagement processes associated with noise management interventions for their ability to modify non-acoustic factors known to exacerbate the annoyance response (ST 3.2.1 is designed to establish the impact of such a communication intervention on attitudes to source, trust and annoyance levels)

From a health impact assessment perspective, this more comprehensive view of the determinants of annoyance and in particular the **wider *acoustic context* could be used to inform future epidemiological studies**, which would have added value if associations were made to a wider range of acoustic variables (e.g. attempts to take event noisiness; the numbers of those events, and the temporal distributions of those events in relation to other background noise sources present, into account) and also adjusted for influences on the noise experienced by individuals through, for example, life-style factors (use of garden, internal sound sources, propensity to open windows), work patterns and location.

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Wright, B. Peters, E. Ettinger, U. Kuipers, E. Kumari, V. (2014) Understanding noise stress-induced cognitive impairment in healthy adults and its implications for schizophrenia, *Noise and Health*, 16, pp.166–176

Yousefzadeh, A. Nassiri, P. Foroushani, A.R. (2016) The relationship between air traffic noise and its induced annoyance in the southwest area in Tehran – Iran, *Journal of Health and Safety at Work*, 6(3)

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7 ANNEXES

7.1 Approach to Research

The following sub-sections provide an overview of the literature searches undertaken by theme. Each sub-section relates to an individual substantive health impact which was discussed earlier in Section 3.

7.1.1 Section 3: Substantive Health Impacts

In order to comprise scientific findings on cardiovascular effects of aircraft noise exposure we implemented a systematic literature review. Because WHO has published in 2018 an extensive literature review on cardiovascular effects of environmental noise exposure, covering the review of studies published until August 2015, we restricted our search to publications published after this date (van Kempen et al., 2018).

In our review we have followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses Guidelines (PRISMA) (Moher et al., 2009).

We were interested in the studies, published since September 2015, which have investigated the association between cardiovascular diseases and aircraft noise exposure. We performed an electronic study search in the databases MEDLINE (PubMed), Scopus, Science Direct and Web of Science on 23th of April 2018. All search string combinations carried out are listed. We did not use any language restrictions.

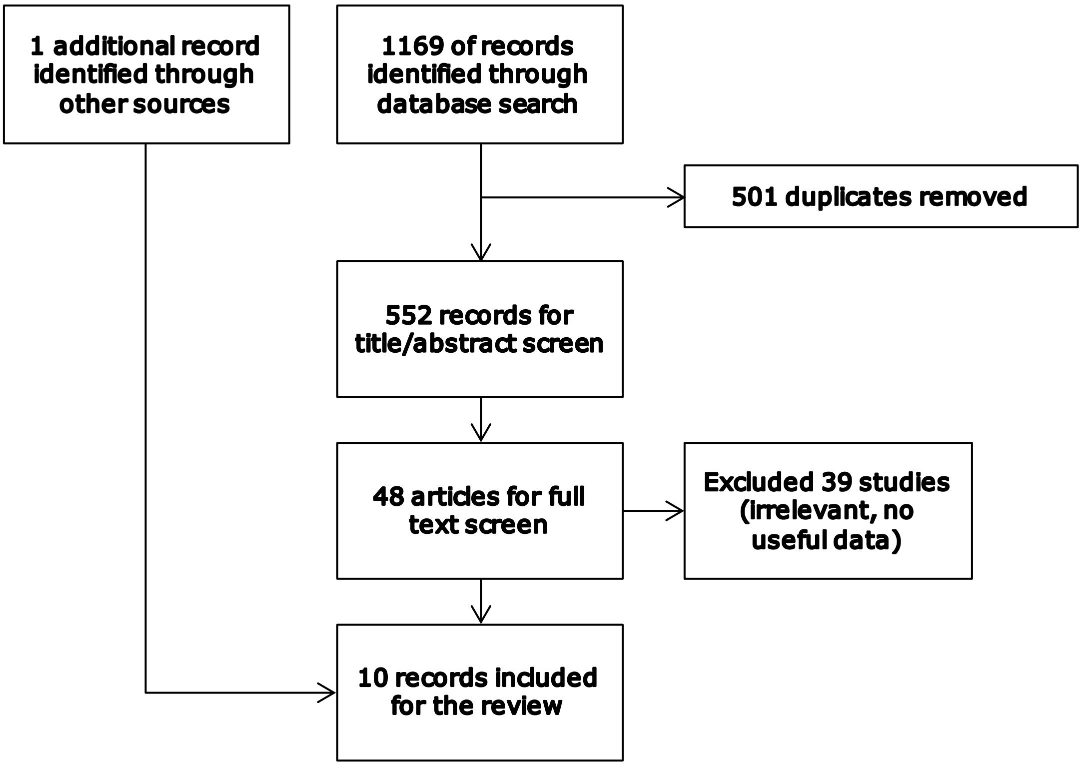
From the identified studies, we have removed all of the duplicates. The identified studies were screened regarding their suitability, considering the title, abstract and the full text.

In the first screen, we identified studies, which had air traffic noise exposure and cardiovascular diseases in their title and/or abstract.

The second screen was based on a full-text review. Studies were considered eligible if they met the following criteria:

- **Study type**: Original observational studies of cross-sectional, cohort, case control or ecological study design.
- **Participants**: Members of the general population exposed to aircraft noise.
- **Exposure type**: Long-term outside noise levels which are either expressed in $L_{Aeq,24h}$, L_{dn}, L_{den} or its components (L_{day}, $L_{evening}$, L_{night} and the duration in hours), exposure is either measured or modelled and the level is based on a reliable calculation procedure, using the actual traffic volume, composition, and speed per 24 h per airport as input, or the type.
- **Outcome measure**: Our outcome of interest were cardiovascular diseases, which were defined as:
    - Diagnosis by a physician;
    - Being under treatment with a specific drug;
    - Evidence from physical examination of the subject or other diagnostic or
    - Laboratory measurements;
    - Through self-report;
    - Death records in mortality registers; or
    - Insurance billing registers.
- **Risk assessment**: Assessed risks (odds ratios, risk ratios, hazard ratios) with corresponding 95% confidence intervals (CI) were reported for the groups exposed versus the groups not exposed to aircraft noise. Editorials, case reports and reviews were not considered eligible.
- **Confounders**: Preferably adjusted at least for age and/or gender.

Figure 1: Flowchart of Study Selection



Data extraction

We extracted the following data by means of a structured data extraction form.

1. Data regarding study characteristics:
    - Year of publication;
    - Period and location of the study;
    - Study design;
    - Population characteristics;
    - Outcome and classification;
    - Noise exposure assessment and noise indicators used;
    - Description of the exposure-response relationship;
    - Statistical analysis;
    - Adjustments for potential confounders;
    - Implementation of the follow-up; and
    - Noise level range.
2. Data regarding the assessed exposure-response risks for cardiovascular

As the search period was relatively short and we expected a small number of studies published after 2015, we did not implement a meta-analysis.

In studies with quantitative assessments of aircraft noise risk estimate on cardiovascular diseases, we gathered, in addition to the assessed risk estimates, information about corresponding epidemiology (incidence, prevalence, mortality), ratio of controls and cases, noise indicator, measurement of risk (RR, OR, HR).

A list of articles included in our systematic review is presented in Table 1 and Table 2.

Table 1: Included articles after full paper review

	Included articles
1.	Dimakopoulou, K. Koutentakis, K. Papageorgiou, I. Kasdagli, M.I. Haralabidis, A.S. Sourtzi, P. Samoli, E. Houthuijs, D. Swart, W. Hansell, A.L. and Katsouyanni, K. (2017) 'Is aircraft noise exposure associated with cardiovascular disease and hypertension? Results from a cohort study in Athens, Greece.' Occupational and Environmental Medicine, 74(11) pp.830–837
2.	Evrard, A.S. Bouaoun, L. Champelovier, P. (2015) Lambert Jacques and Laumon Bernard 'Does exposure to aircraft noise increase the mortality from cardiovascular disease in the population living in the vicinity of airports? Results of an ecological study in France.' Noise and Health pp. 328–336
3.	Evrard, A.S. Lefèvre, M. Champelovier, P. Lambert, J. and Laumon, B. (2017) 'Does aircraft noise exposure increase the risk of hypertension in the population living near airports in France?' *Occupational and Environmental Medicine*, 74(2) pp.123–129
4.	Hériticr, H. Vienneau, D. Foraster, M. Eze, I.C. Schaffner, E. Thiesse, L. Rudzik, F. Habermacher, M. Köpfli, M. Pieren, R. Brink, M. Cajochen, C. Wunderli, J. M. Probst-Hensch, N. M. Röösli, M. Ruzdik, F. and Schmidt-Trucksäss, A. (2017) 'Transportation noise exposure and cardiovascular mortality: a nationwide cohort study from Switzerland.' European Journal of Epidemiology, 32(4), pp.307–315
5.	Seidler, A. Wagner, M. Schubert, M. Droge, P. Pons-Kuhnemann, J. Swart, E. Zeeb, H. and Hegewald, J. (2016a) 'Myocardial Infarction Risk Due to Aircraft, Road, and Rail Traffic Noise' *Deutsches Arzteblatt international*, Germany, 113(24), pp.407–414
6.	Seidler, A. Wagner, M. Schubert, M. Dröge, P. Römer, K. Pons-Kühnemann, J. Swart, E. Zeeb, H. and Hegewald, J. (2016b) 'Aircraft, road and railway traffic noise as risk factors for heart failure and hypertensive heart disease—A case-control study based on secondary data' *International Journal of Hygiene and Environmental Health*, 219(8), pp.749–758
7.	Seidler, A.L. Hegewald, J. Schubert, M. Weihofen, V.M. Wagner, M. Dröge, S.E. Zeeb, H. Seidlers, A. (2018) The effects of aircraft, road, and railway traffic noise on stroke – results of a case-control study based on secondary data, *Noise and Health*, 20(95), pp.152-161
8.	Zeeb, H. Hegewald, J. Schubert, M. Wagner, M. Dröge, P. Swart, E. and Seidler, A. (2017) 'Traffic noise and hypertension – results from a large case-control study' *Environmental Research*, 157 pp.110–117
9.	Zur Nieden, A. Ziedorn, D. Römer, K. Spilski, J. Möhler, U. Harpel, S. Schreckenberg, D. Eikmann, T. (2016a) 'NORAH-field study: The effects of chronic exposure to traffic noise (aircraft, railway and road traffic) on hypertension' *Proceedings of Internoise*, New York, pp.21-24

Table 2: Excluded articles after full paper review

	Excluded articles	**Reason for exclusion**
1.	Akinseye, O.A. Williams, S.K. Seixas, A. Pandi-Perumal, S.R. Vallon, J. Zizi, F. Jean-Louis, G. (2015) Sleep as a mediator in the pathway linking environmental factors to hypertension: A review of literature, *International Journal of Hypertension,* 926414	*Relationship:* No direct relationship between aircraft noise exposure and cardiovascular health outcome (Sleep as a mediator)
2.	Azuma, K. Uchiyama, I. (2017) Association between environmental noise and subjective symptoms related to cardiovascular diseases among elderly individuals in Japan, *Public Library of Science ONE*, 12(11)	*Outcome:* No cardiovascular disease was observed

3.	Banerjee, D. (2014) Association between transportation noise and cardiovascular disease: A meta-analysis of cross-sectional studies among adult populations from 1980 to 2010, *Indian Journal of Public Health*, 58(2), pp.84-91	*Study design:* Review, not original study
4.	Barceló, M.A. Varga, D. Tobias, A. Diaz, J. Linares, C. Saez, M. (2016) Long term effects of traffic noise on mortality in the city of Barcelona 2004–2007, *Journal of Environmental Research*, 147, pp.193-206	*Noise source:* No aircraft noise
5.	Basner, M. Babisch, W. Davis, A. Brink, M. Clark, C. Janssen, S. Stansfeld, S. (2014) Auditory and non-auditory effects of noise on health, *Lancet*, 383(9925), pp.1325–1332	*Study design:* Review, not original study
6.	Basner, M. Clark, C. Hansell, A. Hileman, J.I. Janssen, S. Shepherd, K. Sparrow, V. (2017) Aviation Noise Impacts: State of the Science, *Noise and Health*, 19(87), pp.41-50	*Study design:* Review, not original study
7.	Brown, A.L. and van Kamp, I. (2017) WHO Environmental Noise Guidelines for the European Region: A Systematic Review of Transport Noise Interventions and Their Impacts on Health, *International Journal of Environmental Research and Public Health*, 14, p.873	*Study design:* Review, not original study *Noise source:* No new information for aircraft noise
8.	Bruno, R.M. Faraguna, U. Di Pilla, M. Di Galante, M. Banfi, T. Gemignani, A. (2016) Increased central pressure augmentation is associated with Reduced sleep duration in individuals exposed to aircraft Noise pollution: the SERA-CV study	*Relationship:* No direct relationship between aircraft noise exposure and cardiovascular health outcome (Sleep as a mediator)
9.	Bruno, R.M. Faraguna, U. Di Pilla, M. Di Galante, M. Banfi, T. Gemignani, A. (2017) Increased wave reflection is associated with reduced sleep duration in individuals exposed to aircraft noise pollution, *Nutrition, Metabolism and Cardiovascular Diseases,* 27(1), p.10	*Relationship:* No direct relationship between aircraft noise exposure and cardiovascular health outcome (Sleep as a mediator)
10.	Cairns, B.J. and Baigent, C. (2014) Air pollution and traffic noise: do they cause atherosclerosis? *European Heart Journal*, 35, pp.826–828	An editorial, no new information for aircraft noise
11.	Dzhambov, A.M. Dimitrova, D.D. (2016) Exposure-response relationship between traffic noise and stroke: a systematic review with meta-analysis, *Arh Hig Rada Toksikol*, 67, pp.136-151	*Study design:* Review, not original study
12.	Fernández-Ruiz, I. (2017) Aircraft noise impairs vascular function, *Nature Reviews Cardiology*, doi:10.1038/nrcardio.2017.32	*Relationship:* No new information on the relationship between aircraft noise and cardiovascular effects
13.	Foraster, M. Eze, I.C. Schaffner, E. (2017) Expousure to Road, Railway and Aircraft Noise and Arterial Stiffeness in the SAPALDIA Study: Annual Average Noise Levels and Temporal Noise Characteristics, *Environmental Health Perspective*	*Outcome:* No cardiovascular disease was observed
14.	Fu, W. Wang, C. Zou, L. Liu, Q. Gan, Y. Yan, S. (2017) Association between exposure to noise and risk of hypertension: a meta-analysis of observational epidemiological studies, *Journal of Hypertension, 35*	*Noise source:* No aircraft noise
15.	Fuks, K. B. Weinmayr, G. Basagaña, X. Gruzieva, O. Hampel, R. Oftedal, B. (2017) Long-term exposure to ambient air pollution and traffic noise and incident hypertension in seven cohorts of the European study of cohorts for air pollution effects (ESCAPE), *European Heart Journal*, 38, pp.983–990	*Noise source:* No aircraft noise

16.	Guski, R. Klatte, M. Moehler, U. Müller, U. zur Nieden, A. Schreckenberg, D. (2016) NORAH (Noise Related Annoyance, Cognition, and Health): Questions, designs, and main results. Noise Assessment and Control: Paper ICA2016-157, PROCEEDINGS of the 22nd International Congress on Acoustics, Buenos	*Relevance:* Only brief overview of the project
17.	Guski, R. NORAH Overview, Inter-Noise 2016.	*Relevance:* Only brief overview of the project
18.	Hänninen, O. Knol, A.B. Jantunen, M. Lim, T.A. Conrad, A. Rappolder, M. Carrer, P. Fanetti, A.C. Kim, R. Buekers, J. Torfs, R. Iavarone, I. Classen, T. Hornberg, C. Mekel, O.C. EBoDE Working Group, (2014) Environmental burden of disease in Europe: assessing nine risk factors in six countries, *Environmental Health Perspective*, 122, pp.439–446	*Relevance:* Burden of disease
19.	Hansell, A.L. Blangiardo, M. fortunate, L. Floud, S. de Hoogh, K. Fecht, D. (2014) Daytime and night-time aircraft noise and cardiovascular disease near Heathrow airport in London, Inter-Noise, Melbourne Australia, pp.16-19	Proceeding paper from a study that has been published in 2013
20.	Héritier, H. Vienneau, D. Foraster, M. Eze, I.C. Schaffner, E. Thiesse, L. (2018) for the SNC study group: Diurnal variability of transportation noise exposure and cardiovascular mortality: A nationwide cohort study from Switzerland, *International Journal of Hygiene and Environmental Health*, 221(3), pp.556-563	*Noise source:* Combined noise exposure, not aircraft noise specific
21.	Huang, D. Song, X. Cui, Q. Tian, J. Wang, Q. Yang, K. (2015) Is there an association between aircraft noise exposure and the incidence of hypertension? A meta-analysis of 16784 participants, *Noise and Health*, 17(75), pp.93-97	*Study design:* Review, not original study
22.	Lefevre, M. Carlier, M.C. Champelovier, P. Lambert, J. Laumon, B. Evrard, A.S. (2016) Effects of aircraft noise exposure on saliva cortisol near airports in France, *Occupational and Environmental Medicine*, pp.1-8	*Outcome:* Did not observe cardiovascular disease
23.	Liu, C. Fuertes, E. Tiesler, C.M.T. Birk, M. Babisch, W. Bauer, C.P. (2014) GINIplus and LISAplus Study Groups, The associations between traffic-related air pollution and noise with blood pressure in children: Results from the GINIplus and LISAplus studies, *International Journal of Hygiene and Environmental Health*, 217, pp.499–505	*Noise source:* No aircraft noise exposure
24.	Meline, J. Van Hulst, A. Thomas, F. Chaix, B. (2015) Road, rail and air transportation noise in residential and workplace neighbourhoods and blood pressure (RECORD Study), *Noise and Health*, 17(78), pp.308-19	*Relevance:* No new information
25.	Münzel, T. Schmidt, F.P. Steven, S. Herzog, J. Daiber, A. Sørensen, M. (2018a) Environmental Noise and the Cardiovascular System, *Journal of the American College of Cardiology*, 71(6), pp.688-97	*Study design:* Review, not original study
26.	Münzel, T. and Daiber, A. (2018) Environmental stressors and their impact on Health and disease with focus on Oxidative stress, *Antioxidants and Redox Signalling*, 28(9)	*Study design:* Review, not original study
27.	Münzel, T. Sørensen, M. Gori, T. Schmidt, F.P. Rao, X. Brook, J. Chen, L.C. Brook, R.D. Rajagopalan, S. (2017) Environmental stressors and cardio-metabolic disease: part I-epidemiologic evidence supporting a role for noise and air pollution and effects of mitigation strategies, *European Heart Journal*, 38, pp.550-555	*Study design:* Review, not original study
28.	Münzel, T. Gori, T. Babisch, W. Basner, M. (2014) Cardiovascular effects of environmental noise exposure, *European Heart Journal*, 35, pp.829-836	*Study design:* Review, not original study
29.	Münzel, T. Sørensen, M. Schmidt, F.P. Schmidt, E. Steven, S. Kröller-Schön, S. Daiber, A. (2018b) The Adverse Effects of Environmental Noise Exposure and Oxidative Stress and Cardiovascular risk,	*Study design:* Review, not original study

	Antioxidants and Redox Signalling, 28(9), pp.873-908	
30.	Pearson, T. Campbell, M.J. Maheswaran, R. (2016) Acute effects of aircraft noise on cardiovascular admissions –an interrupted time-series analysis of a six-day closure of London Heathrow Airport caused by volcanic ash, *Spatiotemporal Epidemiology*, 18, pp.38-43	*Outcome:* Acute effects
31.	Penzel, T. Glos, M. Renelt, M. Zimmermann, S. (2017) Auswirkungen von Fluglärm auf Schlaf und andere Schutzgüter, *Eine Übersicht unter Berücksichtigung der NORAH-Studie*, Somnologie, 21, pp.128–133	*Study design:* Review, not original study
32.	Schmidt, F. Kolle, K. Kreuder, K. Schnorbus, B. Wild, P. Hechtner, M. Binder, H. Gori, T. Münzel, T. (2015) Night time aircraft noise impairs endothelial function and increase blood pressure in patients with or at higher risk for coronary artery disease, *Clinical Research of Cardiology*, 104, pp.23-30	*Outcome:* Did not observe cardiovascular disease
33.	Schmidt, F.P. Kreuder, K. Kolle, K. Gori, T. Münzel, T. (2014) Severe adverse effects of nocturnal aircraft noise on endothelial function in patients with or being at risk for cardiovascular disease, *European Heart Journal*, (Abstract Supplement), 35, pp.561	*Outcome:* Did not observe cardiovascular disease
34.	Sørensen, M. (2017) Aircraft noise exposure and Hypertension, *Occupational Environmental Medicine*, 74, pp.85–86	*Study design:* Commentary
35.	Stansfeld, S. and Clark, C. (2015) Health effects of Noise Exposure in Children, *Current Environmental Health Report*, (2015) 2, pp.171-178	*Study design:* Review
36.	Tobias, A. Recio, A.M. Diaz, J. Linares, C. (2015) Noise levels and cardiovascular mortality: A case-crossover analysis, *European Journal of Preventive Cardiology*, 22(4), pp.496–502	*Noise source:* No aircraft nose exposure
37.	Van Kempen, E. Casas, M. Pershagen, G. Foraster, M. (2016) Noise levels and cardiovascular mortality: A case-crossover analysis, Internoise 2016, Hamburg	*Study design:* Review
38.	Vienneau, D. Perez, L. Schindler, C. Lieb, C. Sommer, H. Probst-Hensch, N. Künzli, N. Röösli, M. (2015a) Years of life lost and morbidity cases attributable to transportation noise and air pollution: A comparative health risk assessment for Switzerland in 2010, *International Journal of Hygiene and Environmental Health*, 218(6), pp.514-21	*Outcome:* Did not observe cardiovascular disease And *Noise source:* No aircraft noise exposure
39.	Vienneau, D. Schindler, C. Perez, L. Probst-Hensch, N. Röösli, M. (2015b) The relationship between transportation noise exposure and ischemic heart disease: A meta-analysis, *Environmental Research*, 138, pp.372-80	*Study design:* Review

7.1.2 Section 3.1: Cardiovascular Diseases

Table 3: Search profiles for aircraft noise and cardiovascular disease

Database	**Search no.**	**Search profile**	**Filters**	**Date of search**	**No. of results**
Science Direct	01	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (cardiovascular*)	Publication date >2013	24.04.2018	418
	02	((airport* OR aircraft* OR air traffic*) AND noise) AND (hypertension* OR blood-pressure* OR ischaemic heart disease* OR coronary heart disease* OR heart disease*)			658
Web of Science	01	((aircraft* OR air traffic* OR airport*) AND (noise*) AND (cardiovascular*))	Publication date >2013	24.04.2018	137
	02	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (hypertension*)			106
	03	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (blood-pressure*)			104
	04	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (ischaemic-heart-disease*)			4
	05	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (coronary-heart-disease*)			19
	06	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (heart-disease*)			59
PubMed	01	((airport*[ti] OR aircraft*[ti] OR air traffic*[ti]) AND noise*[ti])	Publication date >21.10.2014	20.04.2018	43
	02	((airport*[ti] OR aircraft*[ti] OR air traffic*[ti]) AND noise*[ti]) AND (hypertension*[ti] OR blood-pressure*[ti] OR ischaemic heart disease*[ti] OR coronary heart disease*[ti] OR heart disease*[ti] OR cardiovascular*[ti])			8
Scopus	01	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (cardiovascular*)	Publication date >2013	20.04.2018	118
	02	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (hypertension*)			65
	03	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (blood-pressure*)			46
	04	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (ischaemic-heart-disease*)			5
	05	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (coronary-heart-disease*)			5
	06	(aircraft* OR air traffic* OR airport*) AND (noise*) AND (heart-disease*)			41

7.1.2.1 Search results and screening

Table 4: Search Results and Screening

Database	No. Search Results	Without duplicates within database	Without duplicates	Included based on title and/or abstract
PubMed	51	43	992	50
Scopus	280	154		
ScienceDirect	1076	756		
WebofScience	429	216		

Table 5: A list of studies

Number	Publication	Number	Publication
1	Akinseye et al., 2015	27	Huang et al., 2015
2	Azuma and Uchiyama, 2017	28	Lefevre et al., 2017
3	Benerjee et al., 2014	29	Liu et al., 2014
4	Barcelo et al., 2016	30	Meline et al., 2015
5	Basner et al., 2014	31	Münzel et al., 2018a
6	Basner et al., 2017	32	Münzel and Daiber, 2018
7	Brown et al., 2017	33	Münzel et al., 2017
8	Bruno et al., 2016	34	Münzel et al., 2014
9	Bruno et al., 2017	35	Münzel et al., 2018b
10	Cairns and Baigent, 2014	36	Pearson et al., 2016
11	DeRose-Wilson et al., 2015	37	Penzel et al., 2017
12	Dimakopoulou et al., 2017	38	Schmidt et al., 2015
13	Dzhambov and Dimitrova, 2016	39	Schmidt et al., 2014
14	Eggermont and Jos, 2014	40	Seidler et al., 2016a
15	Evrard et al., 2015	41	Seidler et al., 2016b
16	Evrard et al., 2017	42	Sorensen, 2017
17	Fernandez-Ruiz, 2017	43	Stansfeld and Clark, 2015
18	Foraster et al., 2017	44	Tobias et al., 2015
19	Fu et al., 2017	45	Van Kempen et al., 2016
20	Fuks et al., 2017	46	Van Kempen et al., 2018
21	Guski, 2016	47	Vienneau et al., 2015a
22	Guski et al., 2016	48	Vienneau et al., 2015b
23	Hänninen et al., 2014	49	Zeeb et al., 2017
24	Hansell et al., 2014	50	Zur Nieden et al., 2016a
25	Heritier et al., 2017	51	Zur Nieden et al., 2016b
26	Heritier et al., 2018		

Table 6: A list of studies

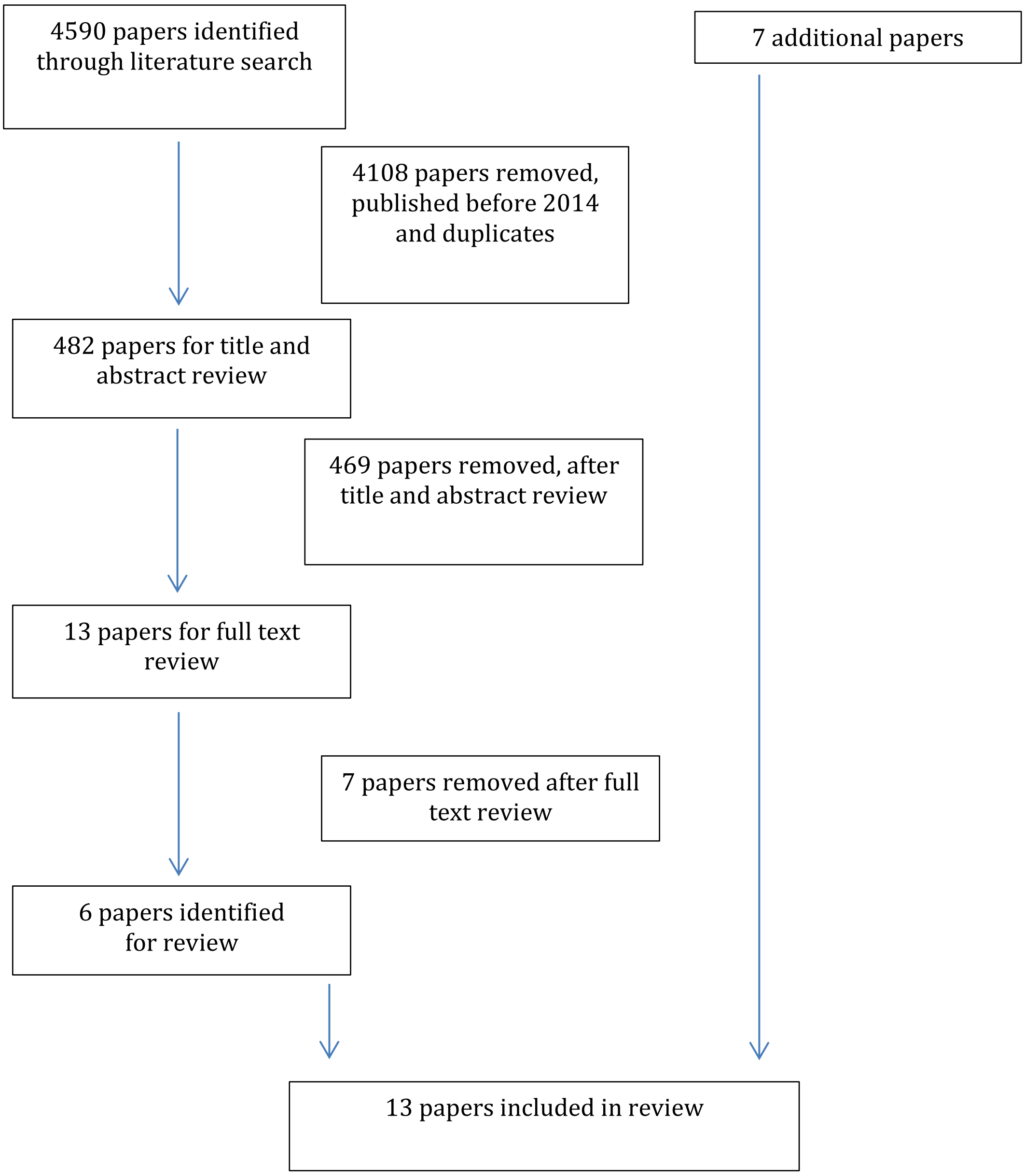
Records excluded after abstract screen	**Records of epidemiological studies of risk of CVD association with AN**	**Records of epidemiology studies of risk of CVD risk factors associated with AN**	**Reviews and meta-analysis**	**Mediation analysis**	**Irrelevant /not useful data – excluded after full text read**
10, 11, 17, 23, 24, 42	12, 15, 16, 25, 40, 41, 49, 50, 51	18, 28, 38, 39	3, 5, 6, 7, 13, 27, 43, 46, 48	1	2, 4, 8, 9, 14, 19, 20, 21, 22, 26, 29, 30, 36, 37, 44, 45, 47

AN – aircraft noise

7.1.3 Section 3.2: Sleep Disturbance

To gather the relevant research literature regarding the association of aircraft noise and sleep, a literature search was conducted at the end of June 2018 in the databases PubMed, ScienceDirect and PsycINFO using the search terms “aircraft noise” OR “aviation noise” AND “sleep” OR “sleep disturbance”. Figure 1 displays the steps taken to identify relevant papers and studies. Papers published in or after the year 2014 were included in the review. Studies had to have included a measured or predicted noise level for aircraft noise as well as an assessment of participants’ sleep either subjective via self-reports or physiological, e.g., using polysomnography. Laboratory studies were excluded, as they tend to have low generalizability, i.e. low external validity. Reviews as well as meta-analyses were excluded as they either have been covered in the WHO review or cover articles that are included as primary literature in this review.

Figure 2: Flowchart of Study Selection



Overall, 13 articles were selected for the full paper review. After examining each one of them, seven were excluded, as they did not meet the inclusion criteria. An overview of these excluded articles as well as the reasons for their exclusion can be found in Table 7.

Table 7: Excluded Articles after Full Paper Review

Excluded articles	Reason for exclusion
Héritier, H. Vienneau, D. Foraster, M. Eze, I.C. Schaffner, E. Thiesse, L. Röösli, M. (2018) Diurnal variability of transportation noise exposure and cardiovascular mortality: A nationwide cohort study from Switzerland, *International Journal of Hygiene and Environmental Health*, *221*(3), pp.556–563	Only noise metric for noise sources combined (road, rail, and aircraft)
Foraster, M. Eze, I.C. Vienneau, D. Brink, M. Cajochen, C. Caviezel, S. Probst-Hensch, N. (2016) Long-term transportation noise annoyance is associated with subsequent lower levels of physical activity, *Environment International*, *91*, pp.341–349	No noise metric for aircraft noise
Eze, I.C. Foraster, M. Schaffner, E. Vienneau, D. Heritier, H. Rudzik, F. Probst-Hensch, N. (2017) Long-term exposure to transportation noise and air pollution in relation to incident diabetes in the SAPALDIA study, *International Journal of Epidemiology*, *46*(4), pp.1115–1125	No results regarding aircraft noise and sleep
Eriksson, C. Hilding, A. Pyko, A. Bluhm, G. Pershagen, G. and Ostenson, C.G. (2014) Long-term aircraft noise exposure and body mass index, waist circumference, and type 2 diabetes: a prospective study, *Environmental Health Perspectives*, *122*(7), pp.687–694	Sleep as modifier
Dzhambov, A.M. Dimitrova, D.D. and Mihaylova-Alakidi, V. K. (2015) Burden of Sleep Disturbance Due to Traffic Noise in Bulgaria, *Folia Medica*, *57*(3-4), pp.264–269	Sleep disturbance was calculated
Colrain, I.M. and Willoughby, A.R. (2014) If a tree doesn't fall in a forest? *Clinical Neurophysiology*, *125*(8), pp.1507–1508 ht	Summary of other studies and findings
Perron, S. Plante, C. Ragettli, M.S. Kaiser, D.J. Goudreau, S. and Smargiassi, A. (2016) Sleep Disturbance from Road Traffic, Railways, Airplanes and from Total Environmental Noise Levels in Montreal, *International journal of environmental research and public health,* 13(8)	Noise exposure indicated by proximity to airport

In addition to the papers identified in the literature search, another search was conducted in the databases of the two conferences ICBEN (International Commission on Biological Effects of Noise) and Inter-Noise using the same search terms and inclusion criteria as mentioned above. In this way, seven additional papers were identified and included in this review.

7.1.4 Section 3.3: Cognitive Impairment

We aimed to implement a review covering the effect of exposure to aircraft noise on cognitive impairment, on cognitive domains such as reading, memory and attention. As WHO has in 2018 published an extensive systematic review on the association between cognitive impairment outcomes in school children and environmental noise exposure up to June 2015, we implemented our review to cover studies published after that period.

We sought to identify and summarize the latest research papers on the effects of air traffic noise exposure on cognition, with the primary focus on children and in elderly.

7.1.4.1 Methods

Types of cognition search:/domain

The types of cognition used in our search were adapted from WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cognition and are the following:

- Tests of reading and oral comprehension,
- Tests of memory, including both tests of short-term and long-term memory,
- Standardized assessment tests

Search strings

We used the following search strings for noise exposure:

(Environmental noise OR traffic noise OR aircraft noise OR airport noise OR transportation noise OR noise exposure OR combined exposure to noise and air pollution)

We used the following search strings for study design/publication type:

(Prospective OR retrospective OR cohort studies OR case-control OR observational

OR experimental OR cross-sectional)

We used the following search strings for cognitive impairment outcomes:

(Learning impairment OR reading and oral comprehension OR short-term memory

OR long-term memory OR attention OR impairment assessed through standardized assessments OR hyperactivity

OR concentration OR speech intelligibility OR executive function deficit OR working memory OR memory capacity OR reasoning OR task flexibility OR problem solving)

Publication date:

Studies published after June 2015.

Language restrictions:

No language restrictions.

Database search:

- PubMed/Medline;
- Web of Science;

- Science Direct

Research papers were included in our review if they corresponded to the following criteria:

1. Noise exposure was assessed objectively, either by measurements or modelled values.
2. The source of noise was environmental noise from air traffic.
3. The study investigated the following cognitive domain:
    - Learning impairment
    - Reading and oral comprehension
    - Short-term memory
    - Long-term memory
    - Attention
    - Impairment assessed through standardized assessments
    - Hyperactivity
    - Concentration
    - Speech intelligibility
    - Executive function deficit
    - Working memory
    - Memory capacity
    - Reasoning
    - Task flexibility
    - Problem solving
4. Research paper examined a direct relationship between the above health outcomes and noise exposure.

7.1.4.2 Search Results

Table 8: Study Selection

Database	**Filters**	**Search results**
PubMed/Medline	Publication date from July 2015	199
Google Scholar	Publication date from July 2015	7,960
Web of Science	Publication date from July 2015	1,250

Table 9: Inclusion and Exclusion Explanations

Articles	**Exclusion or inclusion reason**
Basner, M. (2015) ICBEN review of research on the biological effects of noise 2011-2014, Noise and Health, 17(75), pp.57-85	Excluded: Not relevant for the association between aircraft noise and cognition.
Bent, T. and Atagi, E. (2015) Children's perception of	Excluded:

nonnative-accented sentences in noise and quiet, *Journal of The Acoustical Society of America*, 138(6), pp.3985-3993	*Noise source (Combined noise exposure)*
Bhang, S. Yoon, J. Sung, J. Yoo, C. Sim, C. Lee, C. Lee, J. (2018) Comparing Attention and Cognitive Function in School Children across Noise Conditions: A Quasi-Experimental Study, *Psychiatry Investigation*, 15(6), pp.620-627	Excluded: *Noise source (Combined noise exposure)*
Bitar, M.L. Calaco, S.L.F. Simoes-Zenari, M. (2018) Noise in early childhood education institutions, *Ciencia and Saude Coletiva*, 23(1), pp.315-324	Excluded: *Does not investigate the interested topic*
Brännström, K.J. Johansson, E. Vigertsson, Morris, D.J. Sahlen, B. Lyberg-Åhlander, V. (2017) How Children Perceive the Acoustic Environment of Their School, 19(87), pp.84-94	Excluded: *Perception of the school environment, not assessing the relationship between aircraft noise exposure and cognition*
Brännström, K.J. Kastberg, T. von Lochow, H. Haake, M. Sahlen, B. Lyberg-Åhlander, V. (2018) The influence of voice quality on sentence processing and recall performance in school-age children with normal hearing, *Journal of Speech Language and Hearing*, 21(1), pp.1-9	Excluded: *No evaluation of the relationship of noise exposure on cognitive performance*
Chetoni, M. Ascari, E. Bianco, F. Fredianelli, L. Licitra, G. Cori, L. (2015) Global noise score indicator for classroom evaluation of acoustic performances in LIFE GIOCONDA project	Excluded: Topic (*noise characterization of classrooms)*
Clark, C. (2016) Systematic review of the evidence on the effect of environmental noise on cognition, Internoise	Excluded: *No text available*
Diaz, J.J. Linares, G.C. (2015) Health effects of noise traffic: Beyond 'discomfort', *Revista De Salud Ambiental*, 15(2), pp.121-131	Excluded: *General description*
Dreger, S. Meyer, N. Fromme, H. Bolte, G. (2015) Environmental noise and incident mental health problems: A prospective cohort study among school children in Germany, *Journal of Environmental Research*, 143, pp.49-54	Excluded: *Outcome (mental health)*
Forns, J. Dadvand, P. Foraster, M. Alvarez-Pedrerol, M. Rivas, R. Lopez-Vicente, M. Suades-Gonzalez, E. Garcia-Esteban, R. Esnaola, M. Cirach, M. Grellier, J. Basagana, X. Guxens, M. Querol,X. Nieuwenhuijsen, M.J. Sunyer, J. (2016) Traffic-Related Air Pollution, Noise at School, and Behavioral Problems in Barcelona Schoolchildren: A Cross-Sectional Study, *Environmental Health Perspectives*, 124(4), pp.529-535	Excluded: *Noise source (Not aircraft noise)*
Gilavand, A. (2018) Investigating the Impact of Environmental Factors on Learning and Academic Achievement of Elementary Students: Review, *International Journal of Medical Research and Health Sciences*, 5(7S), pp.360-369	Excluded: *Exposure (environmental factors, no noise exposure)*
Gupta, A. Jain, K. Jain, S. (2018) Noise Pollution and Impact on Children Health, *The Indian Journal of Paediatrics,* 85(4), pp.300–306	Excluded: *Nothing new for aircraft noise exposure on cognition*
Hernandez, E. Tristan, G. Ignacio, P. Navarro, J.M. Lopez, K.M. Eleazar, S. (2016) Evaluation of noise environments during daily activities of university students, *International Journal of Occupational Safety and Ergonomics*, 22(2), pp.274-278	Excluded: *No evaluation of the relationship of noise exposure on cognitive performance*
Irgens-Hansen, K. Gundersen, H. Sunde, E. Baste, V. Harris, A. Bratveit, M. Moen, B.E. (2016) Noise exposure and cognitive performance: A study on personnel on board Royal Norwegian	Excluded: *Noise source (Occupational noise exposure)*

Navy vessels, *Noise and Health*, 17(78), pp.320-327	
Klatte, M. Spilski, J. Mayerl, J. Möhler, U. Lachmann, T. Bergström, K. (2016) Effects of Aircraft Noise on Reading and Quality of Life in Primary School Children in Germany: Results From the NORAH Study, *Journal of Environment and Behaviour*, 49(4), pp.390-424	*Included*
Kristiansen, J. Lund, S.P. Persson, R. Challi, R. Lindskov, J.M. Nielsen, P.M. Larsen, P.K. Toftum, J. (2016) The effects of acoustical refurbishment of classrooms on teachers' perceived noise exposure and noise-related health symptoms, *International Archives of Occupational and Environmental Health*, 89(2), pp.341-350	Excluded: *Noise source (Combined noise exposure)*
Lewis, L., Patel, H. Cobb, S. Mirabelle. D'. Bues, M. Stefani, O. Tredeaux, G. (2016) Distracting people from sources of discomfort in a simulated aircraft environment. Work, *Journal of Prevention Assessment & Rehabilitation*, 54(4), pp.963-979	Excluded: *Does not investigate the relationship between aircraft noise exposure and cognition*
Lilian, T. Martha, D. Winkler, A. Hennig, F. Fuks, K. Sugiri, D. Schikowski, T. Jakobs, H. Erbel, R. Jöckel, K.H. Moebus, S. Hoffmann, B. and Weimaron, C. on behalf of the Heinz Nixdorf Recall Study Investigative Group (2016) Long-term air pollution and traffic noise exposures and cognitive function: A cross-sectional analysis of the Heinz Nixdorf Recall study, *Journal of Toxicology and Environmental Health*, Part A, 79(22-23), pp.1057-1069	Excluded: *Noise source (Combined noise exposure)*
Minichilli, F. Gorini, F. Ascari, E. Bianchi, F. Coi, A. Fredianelli, L. Licitra, G. Manzoli, F. Mezzasalma, L. Cori, L. (2018) Annoyance Judgment and Measurements of Environmental Noise: A Focus on Italian Secondary Schools, *International Journal of Environmental Research and Public Health*, 15, p.208	Excluded: *Mediation analysis (through noise annoyance)*
Pakulski, L.A. Glassman, J. Anderson, K. Squires, E. (2016) Noise Pollution (Noise-Scape) Among School Children, *Journal of Educational, Paediatric and Rehabilitative Audiology*, 22	Excluded: Topic (noise scape)
Prodi, N. Visentin, C. (2015) Listening efficiency during lessons under various types of noise, *Journal of The Acoustical Society of America*, 138(4), pp.2438-2448	Excluded: *Noise source (no aircraft noise exposure)*
Valderrama, J.T, Beach, E.F. Yeend, I. Sharma, M. Van Dun, B. Dillon, H (2018) Effects of lifetime noise exposure on the middle-age human auditory brainstem response, tinnitus and speech-in-noise intelligibility, 365, pp.36-48	Excluded: *Noise source (Combined noise exposure)*
Warner-Czyz, A.D and Cain, S. (2016) Age and gender differences in children and adolescents' attitudes toward noise, *International Journal of Audiology*, 55(2), PP.83-92	Excluded: *Noise source (Not environmental noise specific)*
Yousefzadeh, A. Nassiri, A. Foroushani, A.R. (2016) The relationship between air traffic noise and its induced annoyance in the southwest area in Tehran – Iran, *Journal of Health and Safety at Work*, 6(3)	Excluded: *Outcome (Noise annoyance no cognitive domains)*
Schäffer, B. Pieren, R. Mendolia, F. Basner, M. Brink, M. (2015) Noise exposure-response relationships established from repeated binary observations: Modelling approaches and applications, *Journal of The Acoustical Society of America*, 141(5), pp.3175-3185	Excluded: *No relationship between aircraft noise exposure and cognition (Methodological approach for modelling measurements)*
Tobias, A. Recio, A. Diaz, A. Linares, C. (2015) Health impact	Excluded:

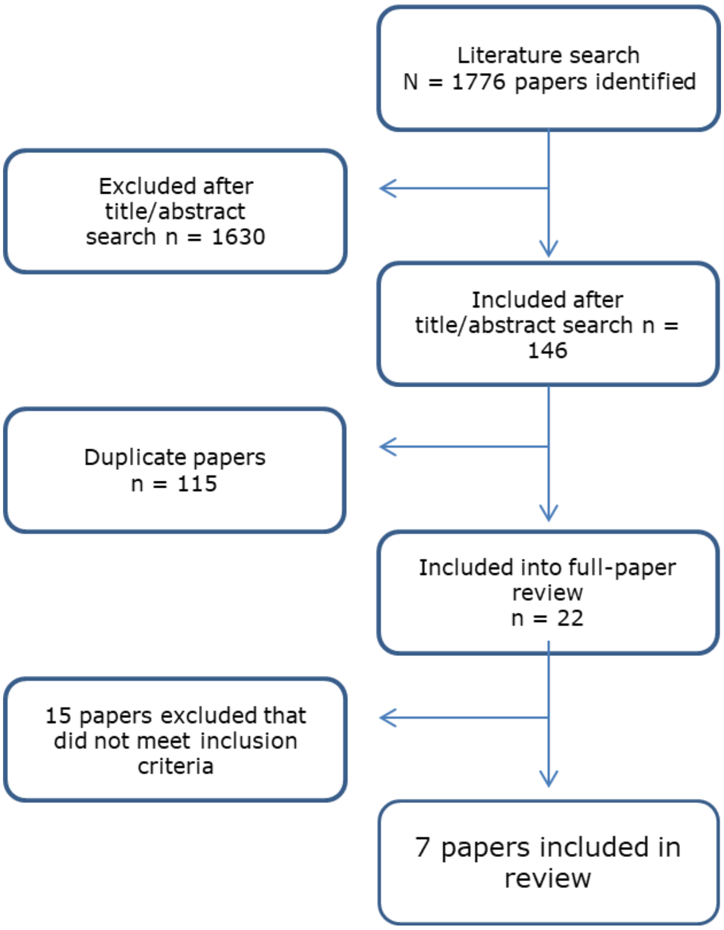
assessment of traffic noise in Madrid (Spain), 137, pp.136-140	*Noise source (road traffic noise exposure) and outcome (no cognition)*
Tzivian L, Winkler A, Dlugaj M, Schikowski T, Vossoughi M, Fuks K, Weinmayr G, Hoffmann B. (201) Effect of long-term outdoor air pollution and noise on cognitive and psychological functions in adults, *International Journal of Hygiene and Environmental Health*, 218, pp.1–11	Excluded: *Noise source (Combined noise exposure)*
Tzivian, L. Dlugaj, M. Winkler, A. Weinmayr, G. Hennig, K. Fuks, K.B. Sugiri, D. Schikowski, T. Jakob, H. Erbel, H. Joeckel, K.H. Moebus, S.Hoffmann, B. Heinz, N. Weima, C. (2016) Recall Study Group. Long-term air pollution and traffic noise exposures and cognitive function: A cross-sectional analysis of the Heinz Nixdorf Recall study, *Journal of Toxicology and Environmental Health-Part A-Current Issues*, 79 (22-23), pp.1057-1069	Excluded: *Noise source (Combined noise exposure)*
Tzivian, L. Dlugaj, M. Winkler, A. Weinmayr, G. Hennig, K. Fuks, K.B. Vossough, M. Schikowski, T. Weimar, C. Erbel, R. Joeckel, K.H. Moebus, S.Hoffmann, B. Heinz, N. (2016) Recall Study Group. Long-Term Air Pollution and Traffic Noise Exposures and Mild Cognitive Impairment in Older Adults: A Cross-Sectional Analysis of the Heinz Nixdorf Recall Study, *Environmental Health Perspectives*, 124(9), pp.1361-1368	Excluded: *Noise source (Combined noise exposure)*
Zijlema, W.L. Smidt, N. Klijs, B. Morley, D.W. Gulliver, J. de Hoogh, K. Scholtens, S. Rosmalen, J.G.M, Stolk, R.P. (2016) The Life Lines Cohort Study: a resource providing new opportunities for environmental epidemiology, *Archives of Public Health*, 74	Excluded: *No relationship between aircraft noise exposure and cognition*

7.1.5 Section 3.4: Mental Health and Well-Being

To build on the latest state of the art, a literature search for published studies on the association between aircraft noise and quality of life, wellbeing and mental health was conducted in June 2018. For this purpose, the systematic approach of Clark and Paunovic was adapted to give an overview of the recent progress since 2014. Search terms used are "aircraft noise" in combination with "mental health", "depression", "anxiety", "quality of life", "wellbeing" or "well-being", respectively. Data bases searched are PubMed/MEDLINE, ScienceDirect (Elsevier), Scopus (including Embase), Web of Science, EBSCO (including PsycINFO, PsyndexPlus and PsycArticles as well as other databases from social sciences). Moreover, conference proceedings from ICBEN (2017 and 2014) and Internoise (annually) were examined.

Exclusion criteria are missing noise measurements/assessments and/or outcome measures referring to mental health, animal studies, experimental studies and laboratory studies as well as review papers.

Figure 3: Flowchart Illustrating Literature Search Process



The flow chart in figure 3 illustrates the whole review process of identifying eligible literature examining effects of aircraft noise on mental health. In total, 1.776 studies were identified during the literature search resulting in seven papers that meet the inclusion criteria. 22 papers were included in the full paper review, with 14 papers excluded after full paper review that did not meet the inclusion criteria (see Table 10 for a list of the excluded studies along with the reason for exclusion).

Table 10: Excluded articles after full paper review with reason for exclusion

Excluded articles	**Reason for exclusion**
Baudin, C. Lefèvre, M. Laumon, B. and Evrard, A.S. (2017) Self-reported health and aircraft noise exposure: the results of the DEBATS study in France. Proceedings of the 12th ICBEN Congress on Noise as a Public Health Problem, Zurich, Switzerland	Not specified to mental health outcomes, just general health
Bartels, S. Márki, F. and Müller, U. (2015) The influence of acoustical and non-acoustical factors on short-term annoyance due to aircraft noise in the field – the COSMA study, *Science of the Total Environment*, 538, pp.834-843	No health outcome
Beutel, M.E. Jünger, C. Klein, E.M. Wild, P. Lackner, K. Blettner, M. Binder, H. Michal, M. Wiltink, J. Brähler, E. and Münzel, T. (2016) Noise Annoyance Is Associated with Depression and Anxiety in the General Population- The	No noise exposure measurement

Contribution of Aircraft Noise, *Public Library of Science One*, 11(5)	
Dirks, K.N. Shepherd, D. Welch, D. and McBride, D. (2014) Aviation-related noise-induced annoyance and health-related quality of life, Proceedings of Internoise 2014, Melbourne, Australia	No noise measurement
Dreger, S. Meyer, N. Fromme, H. and Bolte, G. Study Group of the GME cohort, (2015) Environmental noise and incident mental health problems: A prospective cohort study among school children in Germany, *Journal of Environmental Research*, 143(Part A), pp.49-54	No noise exposure measurement
Forns, J. Dadvand, P. Foraster, M. Alvarez-Pedrerol, M.I. Lopez-Vicente, M. Suades-Gonzalez, E. Garcia-Esteban, R. Esnaola, M. Cirach, M. Grellier, J. Basagana, X. Querol, X. Guxens, M. Nieuwenhuijsen, M.J. and Sunyer, J. (2016) Traffic-Related Air Pollution, Noise at School, and Behavioural Problems in Barcelona Schoolchildren: A Cross-Sectional Study, *Environmental Health Perspectives*, 124(4), pp.529-535	No specification of noise source
Guski, R. (2016) NORAH Overview. Proceedings of Internoise 2016, Hamburg, Germany	Just a description of used methods in the study, no results included
Hammersen, F. Niemann, H. and Hoebel, J. (2016) Environmental Noise Annoyance and Mental Health in Adults: Findings from the Cross-Sectional German Health Update (GEDA) Study 2012, *International Journal of Environmental Research and Public Health*, 13, 954	No noise measurement
Kim, H.S. Park, J.S. Son, J.W. and Park, S.K. (2017) A study on the evaluation of aircraft noise using the stress index. Proceedings of the 12th ICBEN Congress on Noise as a Public Health Problem, Zurich, Switzerland	Noise source road traffic
Lefèvre, M. Carlier, M. Champelovier, P. Lambert, J. Laumon, B. and Evrard, A.S. (2017) Effects of aircraft noise exposure on saliva cortisol near airports in France, *Journal of Occupational and Environmental Medicine*, 74(8), pp.612-618	Investigated health outcome linked to mental health but not specifically a mental health outcome
Smith, A.P. (2017) Prior and current perceptions of noise exposure: effects on university students' wellbeing and attainment. Proceedings of the 12th ICBEN Congress on Noise as a Public Health Problem. Zurich, Switzerland	No noise measurement
Stansfeld, S.A. and Clark, C. (2015) Health Effects of Noise Exposure in Children, *Current Environmental Health Reports*, 2(2), pp.171-178	Review
Stansfeld, S.A. and Shipley, M. (2015) Noise sensitivity and future risk of illness and mortality, *Science of the Total Environment*, 520, pp.114-119	No noise exposure measurement
Tamini, B.K. and Pak, M.M. (2016) Comparative Study of the Effect of Aircraft Noise on Emotional States Between Airport Neighbouring and City Residents, *Shiraz E-Medical Journal*, 17(12)	No noise measurement
Turunen, A.W. Yli-Tuomi, T. Tiittanen, P. Halonen, J. Männistö, S. and Lanki, T. (2014) Traffic noise in relation to self-reported mental health, Proceedings of Internoise 2014, Melbourne, Australia	No specification of noise source
van den Berg, F. Verhagen, C. and Uitenbroek, D. (2015) The Relation between Self-Reported Worry and Annoyance from Air and Road Traffic, *International Journal of Environmental Research and Public Health*, 12, 2486-2500	No link between noise metrics and risk for depression as mental health outcome examined
Welch, D. Dirks, K.N. Shepherd, D. and McBride, D. (2016) Health-related quality of life is impacted by proximity to an airport in noise sensitive people, Proceedings of Internoise 2016, Hamburg, Germany	No noise measurement

7.1.6 Section 3.5: Hearing Impairment

7.1.6.1 Methods

We aimed to implement a review covering the effect of exposure to aircraft noise on permanent hearing impairment outcomes, such as permanent hearing loss and permanent tinnitus. As WHO has in 2017 published an extensive systematic review on the association between hearing impairment outcomes and environmental noise exposure up to June 2015, we implemented our review to cover studies published after that period.

We searched the following databases for scientific publications on hearing impairment in relation to environmental noise exposure – aircraft noise exposure:

- PubMed/Medline;
- Scopus (with Embase);
- Web of Science;
- Science Direct

The search consisted of the following search strings:

Noise exposure: (environmental noise OR traffic noise OR aircraft noise OR airport noise OR transportation noise OR noise exposure OR combined exposure to noise and air pollution)

Publication type: (prospective OR retrospective OR cohort studies OR case-control OR observational OR experimental OR cross-sectional)

Types of hearing impairment: (noise induced hearing loss OR hearing impairment OR permanent hearing impairment OR acoustic trauma OR tinnitus OR permanent tinnitus)

We limited our search for studies published after June 2015, as previous knowledge was summarized in WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Permanent Hearing Loss and Tinnitus published in 2017. We did not use any language restrictions.

Research papers were included in our review if they corresponded to the following criteria:

1. Noise exposure was assessed objectively, either by measurements or modelled.
2. The source of noise was environmental noise from air traffic
3. The study investigated the following hearing impairment outcomes:
    - Noise induced hearing loss;

  - Hearing impairment;
  - Permanent hearing impairment;
  - Acoustic trauma;
  - Tinnitus;
  - Permanent tinnitus

4. Research paper examined a direct relationship between the above health outcomes and noise exposure.

7.1.6.2 Search Results

Table 11: Study Selection

Database	**Filters**	**Search results**	**First screen**
PubMed/Medline	After 30 June 2015	399	15
Web of Science	After 30 June 2015	193	18

Table 12: Inclusion and exclusion explanations

Articles	**Exclusion or inclusion reason**
Jones, H.G. Greene, N.T. Chen, M.R. Azcona, C.M. Archer, B.J. Reeves, E.R. (2018) The Danger Zone for Noise Hazards Around the Black Hawk Helicopter, *Aerospace, Medicine and Human Performance*, 89(6), pp.547-551	Excluded: *No applicable for general population*
Jarosińska, D. Héroux ,M.È. Wilkhu, P. Creswick, J. Verbeek, J. Wothge, J. Paunović, E. (2015) Development of the WHO Environmental Noise Guidelines for the European Region: An Introduction, *International Journal of Environmental Research and Public Health*, 15(4)	Excluded: *Does not give any additional information on the researched topic*
Greenwell, B.M. Tvaryanas, A.P. Maupin, G.M. (2018) Risk Factors for Hearing Decrement Among U.S. Air Force Aviation-Related Personnel, *Aerospace, Medicine and Human Performance,* 89(2), pp.80-86	Excluded: *Occupational noise exposure*
Gupta, A. Jain, K. Gupta, S. (2018) Noise Pollution and Impact on Children Health, *Indian Journal of Paediatrics*, 85(4), pp.300-306	Excluded: *Does not cover the topic of observation*
Hansen, M.C.T. Schmidt, J.H. Brøchner, A.C. Johansen, J.K. Zwisler, S. Mikkelsen, S. (2017) Noise exposure during pre-hospital emergency physicians work on Mobile Emergency Care Units and Helicopter Emergency Medical Services, *Scandinavian Journal of Trauma Resuscitation and Emergency Medicine*, 25(1), p.119	Excluded: *Occupational noise exposure*
Kampel-Furman, L. Joachims, Z. Bar-Cohen, H. Grossman, A. Frenkel-Nir, Y. Shapira, Y. Alon, E. Carmon, E. Gordon, B. (2018) Hearing threshold shifts among military pilots of the Israeli Air Force, *Journal Royal Army Medicine Corps*, 164(1), pp.46-51	Excluded: *Occupational noise exposure*
Müller, R. Schneider, J. (2017) Noise exposure and auditory thresholds of German airline pilots: a cross-sectional study, British Medical Journal, 7(5)	Excluded: *Occupational noise exposure*

Yankaskas, K. Fischer, R. Spence, J. Komrower, J. (2017) Engineering out the noise, *Hearing Research*, 349, pp.37-41	Excluded: *Occupational noise exposure*
Gordon, B. Joachims, Z. Cohen, H.B. Grossman, A. Derazne, E. Carmon, E. Zilberberg, M. Levy, Y. (2016) Hearing Loss in Israeli Air Force Aviators: Natural History and Risk Factors, *Military Medicine*, 181(7), pp.687-92	Excluded: *Occupational noise exposure*
Pankova, V.B. Skryabina, L.Y. Barkhatova, O.A. (2016) The algorithm for the medical maintenance of the aircraft personnel suffering from chronic sensory-neural impairment of hearing, *Vestnik Otorinolaringologii*, 81(2), pp.34-38	**Russian** Excluded: *Occupational noise exposure*
Pankova, V.B. Skryabina, L.Y. Kas'kov, Y.N. (2016) The prevalence of hearing impairment in transport workers and peculiarities of management of occupational loss of hearing (as exemplified by the situation in the air and railway transport, *Vestnik Otorinolaringologii*, 81(1), pp.13-18	**Russian** Excluded: *Occupational noise exposure*
Park, W.J. Moon, J.D. (2016) Changes in the mean hearing threshold levels in military aircraft maintenance conscripts, *Archives of Environmental and Occupational Health*, 71(6), pp.347-352	Excluded: *Occupational noise exposure*
Atalay, H. Babakurban, S.T. Aydın, E. (2015) Evaluation of Hearing Loss in Pilots, urk Archives of Otorhinolaryngol, 53(4), pp.155-162	Excluded: *Occupational noise exposure*
Lahtinen, T.M. Leino, T.K. (2015) Molded Communication Earplugs in Military Aviation, *Journal of Aerospace, Medicine and Human Performance*, 86(9), pp.808-14	Excluded: *Occupational noise exposure*
Rizk, S.A. Sharaf, N.E. Mahdy-Abdallah, H. ElGelil, K.S. (2016) Some health effects of aircraft noise with special reference to shift work, *Toxicology and Industrial Health*, 32(6), pp.961-967	Excluded: *Occupational noise exposure*
Koukouian, V.N. Mechefske, C.K. (2018) Computational modelling and experimental verification of the vibro-acoustic behaviour of aircraft fuselage sections, *Journal of Applied Acoustics*, 132, pp.8-18	Excluded: *Occupational noise exposure*
Nserat, S. Al-Musa, A. Khader, Y.S. (2017) Blood Pressure of Jordanian Workers Chronically Exposed to Noise in Industrial Plants *International Journal Of Occupational And Environmental Medicine*, 8(4), pp.217-223	Excluded: *Occupational noise exposure, irrelevant health outcome*
Yousefzadeh, A. Nassiri, P. Foroushani, A.R. (2016) The relationship between air traffic noise and its induced annoyance in the southwest area in Tehran – Iran, *Journal Of Health And Safety At Work*, 6(3), p.15	Excluded: *Irrelevant health outcome*
Liu, J. Xu, M. Ding, L. (2016) Prevalence of hypertension and noise-induced hearing loss in Chinese coal miners, *Journal Of Thoracic Disease*, 8(3), pp.422-429	Excluded: *Occupational noise exposure*

7.1.7 Section 3.6: Adverse Birth Outcomes

We aimed to implement a review covering the effect of exposure to aircraft noise on adverse birth outcomes, such as low birth weight, preterm birth and congenital malformations. As WHO has in 2017 published an extensive systematic review on the association between birth outcomes and environmental noise exposure up to December 2016, we implemented our review to cover studies published after that period.

7.1.7.1 Search strategy

We searched the following databases for scientific publications on adverse birth outcomes in relation to environmental noise exposure – aircraft noise exposure:

- PubMed/Medline
- Web of Science

The search consisted of the following search strings:

- For noise exposure: (environmental noise OR traffic noise OR aircraft noise OR airport noise OR transportation noise OR noise exposure OR combined exposure to noise and air pollution)
- For publication type: (prospective OR retrospective OR cohort studies OR case-control OR observational OR experimental OR cross-sectional)
- For types of adverse birth outcomes: (prenatal OR perinatal OR labour OR birth OR malformation OR gestation OR preterm OR fetus OR pregnancy)

We limited our search for studies published after December 2016. We did not use any language restrictions.

7.1.7.2 Inclusion criteria

Studies were screened on two levels, title or abstract screen and full text screen. Research papers were included in our review if they corresponded to the following criteria:

1: Noise exposure was assessed objectively, either by measurements or modelled;

2: The source of noise was environmental noise from air traffic;

3: The study either of investigated reproductive outcomes:

- Birth weight;
- Gestation length;
- Preterm birth;
- Prematurity;
- Reproductive health;
- Congenital malformation;
- Foetal growth retardation;
- Small-for-gestation-age infant; or
- Spontaneous abortion

These health outcomes must have occurred during pregnancy or delivery up to 4 weeks after birth.

4: Research paper examined a direct relationship between the above health outcomes and noise exposure.

7.1.7.3 Search Results

Table 13: Study Selection

Database	Filters	Search results	First screen	Second screen
PubMed/Medline	Publication date after Dec 2016	129	4	0
Web of Science	Publication date after Dec 2016	37	7	0

Table 14: Inclusion and Exclusion Explanations

Articles	Exclusion or inclusion reason
Arroyo, V. Diaz, J. Ortiz, C. Carmona, R. Saez, M. Linares, C. (2016) Short term effect of air pollution, noise and heat waves on preterm births in Madrid (Spain), *Environmental Research*, 145, pp.162-168	Excluded: Noise source (not aircraft noise specific)
Auger, N. Duplaix, M. Bilodeau-Bertrand, M. Lo, E. Smargiassi, A. (2018) Environmental noise pollution and risk of preeclampsia, *Environmental Pollution*, 239, pp.599-606	Excluded: Noise source (not aircraft noise specific)
Barba-Vasseur, M. Bernard, P.S. Sagot, P. Riethmuller, D. Thiriez, G. Houot, H. Defrance, J. Mariet, A. Luu, V. Barbier, A. Benzenine, E. Quantin, C. Mauny, F. (2017) Does low to moderate environmental exposure to noise and air pollution influence preterm delivery in medium-sized cities? *International Journal of Epidemiology*, 0(0), pp.1–11	Excluded: Noise source (not aircraft noise specific)
Lech Cantuaria, M. Usemann, J. Proietti, E. Blanes-Vidal, V. Dick, B. Flück, C.E. Rüedi, S. Héritier, H. Wunderli, J. Latzin, P. Frey, U. Röösli, M. Vienneau, D. (2018) on behalf of the BILD study Group, Glucocorticoid metabolites in newborns: A marker for traffic noise related stress? *Environment International*, 117, pp.319–326	Excluded: Noise source (road traffic noise)
Gong, W. Liang, Q. Zheng, D. Zhong, R. Wen, Y. Wang, X. (2017) Congenital heart defects of fetus after maternal exposure to organic and inorganic environmental factors: a cohort study, *Oncotarget*, 8(59), pp.100717-100723	Excluded: Noise source (occupational noise)
Gupta, A. Gupta, A. Jain, K. Gupta, S. (2018) Noise Pollution and Impact on Children Health, *The Indian Journal of Paediatrics*,	Excluded: General review, that does not provide any new information in regard to the aircraft noise effects on birth outcomes.
Mendola, P. Sundaram, R. Buck Louis, G.M. Sun, L. Wallace, M.E. Smarr, M.M. Sherman, S. Zhu, Y. Ying, Q. Liu, D. (2017) Proximity to major roadways and prospectively-measured time-to-pregnancy and infertility, *Science of the Total Environment*, 576, pp.172–177	Excluded: Noise source (road traffic noise)
Min, K. and Min, J. (2017) Noise exposure during the first trimester and the risk of gestational diabetes mellitus, *Environmental Research Letters*, 12, p.074015	Excluded: Outcome (metabolic disease (type 2 diabetes mellitus) in pregnant women)

Min, K. and Min, J. (2017) Exposure to environmental noise and risk for male infertility: A 2population-based cohort study, *Environmental Pollution*, 226, pp. 118-124	Excluded: Outcome (male infertility, not aircraft noise specific)
Pedersen, M. Halldorsson, T.I. Olsen, S.F. Hjortebjerg, D. Ketzel, M. Grandström, C. Raaschou-Nielsen, O. Sørensen, M. (2017) Impact of Road Traffic Pollution on Pre-eclampsia and Pregnancy-induced Hypertensive Disorders, *International Journal of Epidemiology*, 28(1), pp.99-106	Excluded: Noise source (road traffic noise)

7.1.8 Section 3.7: Metabolic Diseases

We have implemented an updated review of scientific findings on adverse metabolic effects of aircraft noise exposure. Because WHO published an extensive overview earlier this year we implemented an updated review of studies that have not yet been included.

In our review we followed the Preferred Reporting Items for Systematic Reviews and Meta-analysis Guidelines (PRISMA). We performed an electronic study search in the databases MEDLINE (PubMed), Science Direct and Web of Science on the 31st of August 2018. No language restrictions were used.

From the identified studies, we have removed all of the duplicates. The identified studies were screened regarding their suitability, considering the title, abstract and the full text.

In the first screen we have identified studies based on title and/or abstract, the second screen was based on a full-text review. Studies were considered eligible if they met the following criteria:

1. **Study type**: Original observational studies of cross-sectional, cohort, case control or ecological study design.
2. **Participants**: Members of the general population exposed to aircraft noise.
3. **Exposure type**: Long-term outside noise levels which are either expressed in L_{Aeq24h}, L_{dn}, L_{den} or its components (L_{day}, $L_{evening}$, L_{night} and the duration in hours), exposure is either measured or modelled and the level is based on a reliable calculation procedure, using the actual traffic volume, composition, and speed per 24 h per airport as input, or the type.
4. **Outcome measure**: Our outcome of interest were metabolic system health outcomes, which were defined as:
    - Diagnosis by a physician;

- Being under treatment with a specific drug;
- Evidence from physical examination of the subject or other diagnostic or laboratory measurements;
- Through self-report;
- Insurance billing registers

5. **Risk assessment**: Assessed risks (odds ratios, risk ratios, hazard ratios) with corresponding 95% confidence intervals (CI) were reported for the groups exposed versus the groups not exposed to aircraft noise. Editorials, case reports and reviews were not considered eligible.
6. **Confounders**: Preferably adjusted at least for age and/or gender.

A flow-chart of study selection is presented in Figure 5. A list of excluded and included studies from our full text review is presented in the Table 10a and Table 10b.

Figure 4: Flowchart Illustrating Study Selection

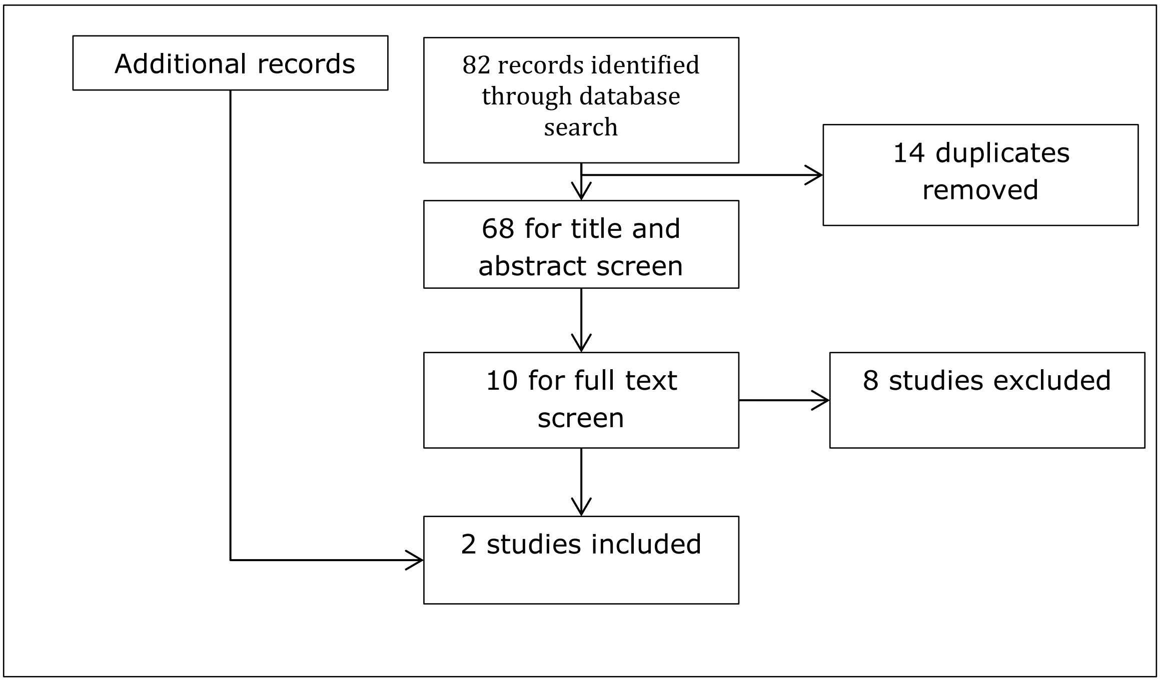


Table 15: Included articles after full paper review

Included articles
Eze, I.C. Foraster, M. Schaffner, E. Vienneau, D. Héritier, H. Rudzik, F. Thiesse, L. Pieren, R. (2017) Long-term exposure to transportation noise and air pollution in relation to incident diabetes in the SAPALDIA study, *International Journal of Epidemiology*, 46(4), pp.1115-1125
Pyko, A. Eriksson, C. Lind, T. Mitkovskaya, N. Wallas, A. Ögren, M. Östenson, C.G. Pershagen, G. (2017) Long-Term Exposure to Transportation Noise in Relation to Development of Obesity—a Cohort Study, *Environmental Health Perspective*, 125(11), p.117005

Table 16: Excluded articles after full paper review

Excluded articles	**Reasons for exclusion**
Kempen, E.V. Casas, M. Pershagen, G. Foraster, M. (2018) WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cardiovascular and Metabolic Effects: A Summary, *International Journal of Environmental Research and Public Health*, 15(2)	Study design: Review
Jarosińska, D. Héroux, M.È. Wilkhu, P. Creswick, J. Verbeek, J. Wothge, J. Paunović, E. (2018) Development of the WHO Environmental Noise Guidelines for the European Region: An Introduction, *International Journal of Environmental Research and Public Health*, 15(4)	Study design: Review
Zare Sakhvidi, M.J. Zare Sakhvidi, F. Mehrparvar, A.H. Foraster, M. Dadvand, P. (2018) Association between noise exposure and diabetes: A systematic review and meta-analysis, *Journal of Environmental Research*, 166, pp.647-657	Study design: Review
Belojevic, G. Paunovic, K. (2016) Recent advances in research on non-auditory effects of community noise, SRPSKI ARHIV ZA CELOKUPNO LEKARSTVO, 144(1-2), pp.94-98	Study design: Review
Diaz Jimenez, J. Linares Gil, C. (2015) Health effects of noise traffic: Beyond 'discomfort', *Revista de Salud Ambiental*,15(2,) pp.121-131	Study design: Review
Eriksson, C. Hilding, A. Pyko, A. (2014) Long-Term Aircraft Noise Exposure and Body Mass Index, Waist Circumference, and Type 2 Diabetes: A Prospective Study, *Environmental Health Perspectives*, 122(7), pp.687-694	Included in WHO review on metabolic disease
Dzhambov, A.M. (2015) Long-term noise exposure and the risk for type 2 diabetes: A meta-analysis, *Journal of Noise and Health*, 17(74), pp.23-33	Included in WHO review on metabolic disease
Pyko, A. Eriksson, C. Oftedal, B. Hilding, A. Östenson, C.G. Krog, .H. Julin, B. Aasvang, G.M. Pershagen, G. (2015) Exposure to traffic noise and markers of obesity, *Occupation and Environmental Medicine*, 72(8), pp.594-601	Included in WHO review on metabolic disease

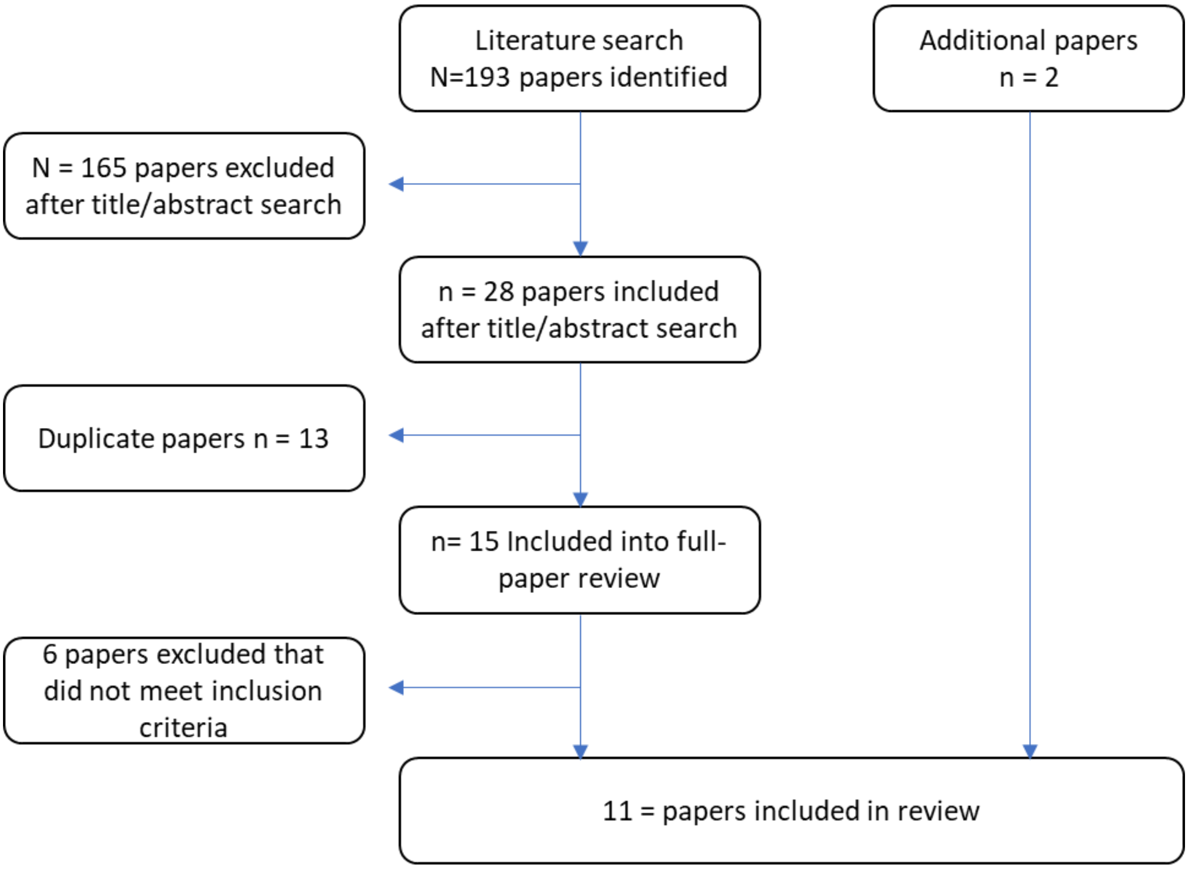
7.1.9 Section 3.8: Annoyance and Health

This review aimed at identifying relevant studies and research papers regarding the link between noise annoyance and diverse health outcomes, namely sleep parameters, mental health outcomes, and cardiovascular disease.

Literate search was conducted for literature published since 2000 in the following data bases: EBSCO (including PsycINFO, PsyndexPlus and PsycArticles), PubMed/MEDLINE and Scopus (including Embase).

The search strings are "aircraft noise AND annoyance AND sleep (respectively cardiovascular disease or mental health or health."

Figure 5: Flowchart Illustrating the Literature Search Process



Inclusion criteria are that papers have been published after (or in) 2000 and it provided results for a potential link between aircraft noise annoyance and included health outcomes (sleep parameters, mental health outcomes, and cardiovascular problems). Exclusion criteria are animal studies, experimental studies, and laboratory studies as well as review papers.

Figure 5 illustrates the review process of identifying literature considering the link between annoyance and health outcomes in studies on aircraft noise. Overall, 193 papers were identified of which 9 papers met the inclusion criteria. Two additional papers were added (Baudin et al., 2018; Schreckenberg et al., 2017) other researchers provided us with. All in all, 11 papers were reviewed. The six papers excluded after full paper review not satisfying the inclusion criteria are listed in table 6 along with individual reasons for exclusion.

Table 16: Excluded articles after full paper review with the reason for exclusion

	Excluded articles	**Reason for exclusion**
1.	Basner, M. Müller, U. and Elmenhorst, E.M. (2011) Single and Combined Effects of Air, Road, and Rail Traffic Noise on Sleep and Recuperation, *Journal of Sleep*, 34(1), pp.11–23	No annoyance measure
2.	Lefèvre, M. Carlier, M.C. Champelovier, P. Lambert, J. Laumon, B. and Evrard, A.S. (2017) Effects of aircraft noise exposure on saliva cortisol near airports in France, *Occupational and Environmental Medicine*, 74(8), pp.612-618	Saliva cortisol is linked to health outcomes, but not health outcome itself
3.	Niemann, H. Maschke, C. and Hecht, K. (2005) Lärmbedingte Belästigung und Erkrankungsrisiko Ergebnisse des paneuropäischen LARES-Survey [Noise induced annoyance and morbidity. Results from the pan European LARES-survey], *Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz*, 48(3), pp.315–328	Just overall noise annoyance not differentiated for sources.
4.	Samel, A. Basner, M. Maaß, H. Müller, U. Quehl, J. and Wenzel, J. (2005) Effects of nocturnal aircraft noise on sleep: Results from the "Quiet Air Traffic" project, *Umweltmedizin in Forschung und Praxis*, 10(2), pp.89-104	No link between annoyance and health outcomes assessed
5.	Schreckenberg, D. Griefahn, B. and Meis, M. (2010) The associations between noise sensitivity, reported physical and mental health, perceived environmental quality, and noise annoyance. *Noise and Health*, 12 (46), pp.7-16	Contrary description of results in tables and text…
6.	Stansfeld, S. and Crombie, R. (2011) Cardiovascular effects of environmental noise: research in the United Kingdom, Noise and Health, 13(52), pp.229-233	Review