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February 24, 2017

EA-18G Growler EIS Project Manager
Naval Facilities Engineering Command Atlantic
6506 Hampton Boulevard
Norfolk, VA 23508
Attn: Code EV21/SS

Subject: Comments on the Environmental Impact Statement for EA-18G Growler Airfield
Operations at Naval Air Station Whidbey Island

Thank you for the opportunity to comment on the draft environmental impact statement (DEIS) for the proposed expansion of EA-18G Growler airfield operations at the Naval Air Station Whidbey Island complex. As the state health department, we are interested in the impact this project will have on the health and well-being of people in Washington State.

As noted in the DEIS, this project may result in negative impacts to the public's health from changes in noise, air quality, use of hazardous materials, and increasing greenhouse gases. This project may also impact social determinants of health such as employment, education, and transportation. Though these potential impacts are all important to the overall health of the public, our comments will focus on the potential for non-auditory community health impacts from noise associated with the aircraft. We have chosen this focus for our comments because we have received multiple inquiries, complaints, and requests for assistance from local community groups concerned about potential health impacts from aircraft noise. Current scientific literature suggests that noise at levels similar to those reported on Whidbey Island is associated with annoyance, sleep disturbance, cognitive impairment, and adverse cardiovascular outcomes (see Appendix A). We have provided recommendations for better understanding the potential impact of the planned activities on the health of this community. They are summarized here and explained in more detail below. Please contact us if you have any questions or if you would like to collaborate on solutions.

Summary of Recommendations

- 1. Provide evidence to assure NOISEMAP model estimates are applicable for use at Naval Air Station Whidbey.** Although the NOISEMAP model has been previously validated based on information obtained from other locations, evidence was not provided to indicate that the model accurately predicts actual exposure to noise under conditions at Naval Air Station Whidbey. It is also not clear how NOISEMAP has been updated to reflect recent research findings.

2. **Improve description of current state of science around noise and public health; specifically non-auditory health effects.**
 - a. **Describe and conduct a comprehensive review of the literature.** At the request of the Washington State Board of Health and Island County Public Health Department, we prepared a summary of recently published epidemiological literature about the health effects of noise exposure. We have attached this review (Appendix A), which references a significant number of directly relevant articles that were not included in the DEIS.
 - b. **Do not require a “definitive causal and significant relationship” between aircraft noise and health prior to including the health outcome in the model.** This standard is unreasonably high and resulted in non-auditory health effects being excluded from the model.
 - c. **Expand review to include studies examining the health effects of noise from sources other than aircraft.** It is unclear why literature from other noise sources which can result in similar effects were not considered, especially since there are limited data on effects from noise originating with non-commercial aircraft.
3. **Conduct a Health Impact Assessment.** Current scientific literature suggests that noise at levels similar to those reported on Whidbey Island is associated with annoyance, sleep disturbance, cognitive impairment, and adverse cardiovascular outcomes. However, whether people on Whidbey Island are *actually experiencing* these outcomes as a result of their exposure to aircraft noise is a question beyond the scope of a literature review. Therefore, we recommend that the Navy conducts a Health Impact Assessment to better understand the potential impact of the planned activities on the health of the community.

Recommendation One: Provide evidence to assure NOISEMAP model estimates are applicable for use at Naval Air Station Whidbey.

Estimates of noise exposure, from noise associated with aircraft operations, to the residents within the surrounding communities were derived from Department of Defense computer modeling software entitled NOISEMAP. The major metric for estimating noise exposure was the Day-Night Average Sound Level (DNL), but depending on outcome being investigated other metrics were used. For example, to investigate noise effects on recreation, a metric which estimates the number of noise events per daytime hour above a maximum A-weighted sound level of 65 dB was used (NA65 L_{max}). For sleep disturbance, the metric was a sound exposure level (SEL) that combines the intensity of a sound with its duration. The SEL was estimated for an outdoor environment and converted to an indoor level. A third example is the use of an L_{max} for indoor speech interference as this metric used within the model identifies the estimated number of events per daytime hour that exceed an instantaneous maximum sound level of 50 dB (50 dB L_{max}). There are several additional metrics used to evaluate various effects from noise (e.g., annoyance, classroom/learning interference, etc.).

The NOISEMAP model has been previously validated based on information obtained from other locations but has not been validated for this naval air station. Due to the complexities involved in validating this model along with the cost and time requirements, there is no expectation of efforts to validate this model at the locations addressed in this DEIS. However, there is an expectation that evidence be provided to determine if the model is predictive by comparing the modeled estimates to observed measurements at locations of concern. While the authors of the DEIS dismissed the very limited sound pressure data that have been provided by outside sources for select locations within the area to be impacted, no effort was made to indicate that their modeling efforts are predictive of estimates provided. It is unclear why efforts were not made to test the multiple estimates provided for the various metrics.

Each metric for exposure used for an outcome should be measured under appropriate conditions (scenarios) and the model estimates need to be compared against these actual values to identify the model's predictive nature. If there are shortcomings, these need to be identified and addressed. With many models, such as those attempting to identify pollutant dissemination characteristics within ground water, surface water, or air, this can be a difficult, costly, and frequently impossible task. However, in this case, there are ongoing operations so these metrics can be measured in a timely manner that is not cost-prohibitive. Without such data there is no means by which to suggest that the model is reflective of actual exposures and accordingly brings the predicted outcomes into question.

In addition, the DEIS should provide greater detail on how this modeling software has been updated to address ongoing findings, such as within the health outcomes arena, as the text indicates the most recent citation for this frequently updated model to be 1992. Also, in 1980 it was determined that 87 percent of the population was not annoyed by sound pressure levels (A weighted) below 65dB. Detail needs to be provided to indicate that no information has been identified in the last 35 years to support or question the use of 65dB within the model as the lowest range when investigating impacts from noise. A discussion also needs to be included pertaining to the remaining (not insignificant) 13 percent of the population that do find these levels annoying and how this portion of the population was addressed within the model.

Recommendation Two: Improve description of current state of science around noise and public health; specifically non-auditory health effects.

In addressing the effects from noise on those impacted, the document divided effects into the categories: annoyance, speech interference, sleep disturbance, noise-induced hearing impairment, non-auditory health effects, performance effects, and noise effects on children. The model attempts to address these endpoints directly (annoyance, speech interference, sleep disturbance, noise-induced hearing impairment) through the DNL or other exposure metrics, indirectly (performance effects and noise effects on children) by using a metric for classroom/learning interference, or excludes them from the model (non-auditory health effects) based on the reasoning that no studies have shown a definitive causal and significant relationship between aircraft noise and health.

Requiring that "definitive causal and significant relationship" between aircraft noise and health is demonstrated prior to including health outcomes within the model is an unreasonably high standard that resulted in non-auditory health effects being excluded from the model.

In our summary of the literature (attached), we found evidence of multiple non-auditory effects that may be attributed to noise exposure, including: annoyance, sleep disturbance, cognitive impairment, and adverse cardiovascular outcomes. Biological mechanisms of the non-auditory effects of noise exposure require further study. Research to date indicates that adverse health effects are initiated by chronic stress and/or sleep disturbance. Recent studies also suggest that noise-induced annoyance is associated with a stress response, which can affect cardiovascular health.

In the review of the literature provided in the DEIS, odds ratio values are provided without confidence intervals, which are critical to understanding the precision of the estimate and whether the null is overlapped. To provide context of the odds ratios (OR), the DEIS indicates (through citation) that an OR of 9.0 is needed for a strong relationship to exist between an exposure and outcome. As such, an OR of 3.5 provides for a moderate relationship and the OR values of 1.5 are weak. If an odds ratio is shown to be statistically significant, it needs to be considered further. Once determined that an odds ratio is statistically significant, the strength of association can be discussed in terms of the percentage of the

population that could be affected. In addition, even if the effect size is small, a statistically significant odds ratio from a well-defined study that has adjusted for possible confounding may indicate that a sensitive population is being affected and this would need to be evaluated and discussed. A multitude of examples exist within the literature in which an odds ratio has a small effect size but is found to be statistically significant, and because of the size of the at-risk population this represents an exposure of considerable public health consequence.

Another issue of note is that this short review was confined to effects from noise originating with aircraft. There is increasing evidence that noise exposure, as defined from multiple sources including commercial aircraft, is associated with numerous adverse health effects. There are likely nuances associated with noise exposures specific to military aircraft that are not thoroughly understood. However, noise levels similar to those reported from NAS Whidbey Island Complex described in all recent reports pose a threat to public health. It would seem prudent to include the effects from other noise sources as there are limited data on effects from noise originating with non-commercial aircraft.

Recommendation Three: Conduct a Health Impact Assessment.

Current scientific literature suggests that noise at levels similar to those reported on Whidbey Island is associated with annoyance, sleep disturbance, cognitive impairment, and adverse cardiovascular outcomes. However, whether people on Whidbey Island are *actually experiencing* these outcomes as a result of their exposure to aircraft noise is a question beyond the scope of a literature review. Therefore, we recommend that the Navy conduct a Health Impact Assessment to better understand the potential impact of the planned activities on the health of the community. Groups that have been described as potentially susceptible to the effects of noise include smokers, children, the elderly, shift-workers, and individuals with sleep disorders, mental disorders, and physical illnesses.

In our summary of the literature, we see increasing evidence that noise exposure, as defined from multiple sources including commercial aircraft, is associated with numerous adverse health effects. There are likely nuances associated with noise exposures specific to military aircraft that are not thoroughly understood. However, noise levels similar to those reported from NAS Whidbey Island Complex pose the following threats to public health:

- **Annoyance:** The scientific literature provides evidence that noise exposure leads to annoyance, which causes a decrease in quality of life. While definitively quantifying annoyance and its effect on the population is challenging, there is strong evidence that feeling annoyed has negative impacts on mental health and cardiovascular endpoints.
- **Sleep Disturbance:** A variety of measurement techniques have been used to study sleep disturbance. There is general agreement that noise is associated with sleep disturbance and if the disturbance is severe and frequent, it can lead to negative health consequences.
- **Cognitive Impairment:** Studies of noise effects on children's cognition reveal an increasing trend that noise exposure results in impaired reading skills. One of the largest studies to date found that reading comprehension falls below average when children are exposed to aircraft noise that is above 55 dB L_{Aeq16} at school.
- **Cardiovascular Disease:** The extent and underlying mechanisms for the relationship between noise exposure and cardiovascular health are still poorly understood. However, the scientific literature has provided increasing evidence of a positive association.

Health Impact Assessment is a rapidly emerging practice among local, state, and federal jurisdictions that helps assess how a proposed decision will affect the health of a population and whether vulnerable populations are more likely to be impacted. The goal of a Health Impact Assessment is to provide

recommendations during the decision-making process that will protect health and reduce health inequities. A Health Impact Assessment brings potential positive and negative public health impacts and considerations to the decision-making process for plans, projects, and policies that fall outside traditional public health arenas, such as military aircraft use and associated noise. A Health Impact Assessment can engage community members and stakeholders to provide practical recommendations to increase positive health effects while minimizing negative ones.

If you have any questions, please contact Lauren Jenks at (360) 236-3325 or lauren.jenks@doh.wa.gov.

Sincerely,



Clark Halvorson
Assistant Secretary

Attachment

Attachment A

A Summary of the Association Between Noise and Health

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EXECUTIVE SUMMARY

The objective of this document is to summarize recent literature exploring the health effects of noise exposure, and compare our findings to reported noise levels originating from the Naval Air Station (NAS) Whidbey Island Complex. The relationship between noise exposure and health has been studied extensively, and the body of knowledge on this topic is rapidly increasing. We described noise measurements taken on Whidbey Island and summarized literature on five of the most studied health outcomes associated with noise: noise induced hearing loss and tinnitus, annoyance, sleep disturbance, cognitive impairment, and cardiovascular disease, in addition to a discussion of susceptible populations. While we found that noise-induced hearing loss is typically not associated with aircraft noise, there is increasing evidence that noise exposure is associated with annoyance, sleep disturbance, cognitive impairment, and adverse cardiovascular outcomes. Groups that have been described as particularly susceptible to the effects of noise include: smokers, children, the elderly, shift-workers, and individuals with sleep disorders, mental disorders, and physical illnesses. There were limitations associated with this summary including gaps of knowledge related to exact exposure-response relationships and underlying pathways for some health endpoints. In addition, there have been minimal studies specific to health effects associated with military aircraft noise exposure. More research is needed to understand differences in risk attributed to susceptible groups compared to the general population. Despite these limitations, the current body of scientific literature suggests that noise levels similar to those reported from the NAS Whidbey Island Complex pose a threat to public health.

INTRODUCTION

This report was written by the Washington State Department of Health at the request of the Washington State Board of Health and Island County Public Health Department to summarize recently published epidemiological literature about the health effects of noise exposure. Noise is being evaluated in response to community concerns on Whidbey Island and the surrounding area over air traffic noise levels originating from the NAS Whidbey Island Complex. These concerns are related to historical and current noise in addition to proposed increases in naval air traffic. Our specific objectives were to summarize recent literature on the most pertinent health effects of noise exposure and relate our findings to noise exposure on Whidbey Island.

Noise and Health

Noise is generally defined as unwanted sound. This definition of noise recognizes the psychological role of the impact of noise. Auditory effects of noise exposure, specifically noise-induced hearing loss and tinnitus, have been well-established for decades.¹ Multiple non-auditory effects may be attributed to noise exposure, including: hypertension, cardiovascular disease and events, diabetes, obesity, reduced cognitive functioning, declines in performance, and birth defects.¹⁻⁵

Biological mechanisms of the non-auditory effects of noise exposure require further study. Research to date indicates that adverse health effects are initiated by chronic stress and/or sleep disturbance.^{1,6,7} Recent studies also suggest that noise-induced annoyance is associated with a stress response, which can affect cardiovascular health.^{6,8,9}

Noise Measurements

Sound is the fluctuation of pressure through a medium, such as air or water. Sound level is measured in decibels (dB) on a scale that is based on human hearing, where 0 dB is barely audible and a turbojet engine is approximately 160 dB.¹⁰ Because decibels are based on a logarithmic scale, when two sounds are combined the total sound level is much less than simply adding the two sound levels together. For example, if there are two sources that each produce 80 dB of noise at a single location, the resulting sound level is 83 dB (*not* 160 dB).

In addition to pressure differences that determine sound level, sound has varying frequencies measured in hertz (Hz) that are heard as pitch. The human ear is less sensitive to hearing extremely low and high frequencies. One way of adjusting sound levels to incorporate the varying sensitivity and perceived loudness across frequencies is to apply an A-, B-, or C-weighted scale. The A-weighted scale was derived from an equal-loudness contour for pure tones.¹¹ Studies indicate that the A-weighted scale provides a better estimate of human hearing threat than the other weightings and it is the most commonly used among human noise impact studies.¹⁰ However, there is some concern that the A-weighted scale underestimates the perceived loudness of low frequency noise.^{11,12}

While there are over 20 different metrics of sound, a few are typically used in studies of health effects. The highest sound level measured is often reported as an A-weighted Maximum Sound Level (L_{Amax}) or a Peak Sound Pressure Level (L_{pk}), both of which may occur in less than a second. The sound exposure level (SEL) is the total energy of noise measured over a specified time period, often one second or a single noise event. Longer term measurement of noise is often reported as the Equivalent Sound Level-A-Weighted (L_{Aeq}), which is the A-weighted average sound level based on the equivalent-continuous sound level over a specified time period. The Day-Night Average Sound Level (L_{dn} or DNL) is an average sound level over a 24-hour period that incorporates a 10-dB penalty for sound events at night. In studies that focus on sound only during the night, L_{night} is typically used, and similarly L_{day} is typically used for only daytime noise. Thus, the duration of sound exposure measurements can range from an instantaneous event to a year.

The selection of the sound metric used in studies depends on characteristics of the noise and the type of health effect being studied. Uncertainty remains in terms of understanding the measurement of noise, such as the number of events or the peak sound level, that is most relevant for health.¹³

Noise from Military and Commercial Aircraft

The majority of literature investigating the relationship between health effects and noise from aircraft is based on commercial aircraft rather than military aircraft.¹⁴⁻²¹ The main factors that affect ground-level noise from aircraft are: (1) the type of aircraft and engine including the thrust, flap, and airspeed

management procedures, and (2) factors that affect sound propagation, such as distance to the point of concern (e.g., the receptor), topography, and weather.²²

Noise from aircraft is predominately low frequency (approximately 10 to 250 Hz).^{11,23} High frequency is generally defined as up to 5,000 or 10,000 Hz.¹¹ People may perceive low frequency sounds either with their ears or by sensing vibrations.²⁴

Different types of aircraft have different acoustic signatures, which makes it possible to distinguish noise measured from military and commercial aircraft.²⁵ It is likely that different flight activities (e.g., takeoffs, field carrier landing practice, low-flying) and aircraft types alter noise in ways that are determinants of health outcomes. However, these distinctions are not evaluated in this summary because of the paucity of published research on military aircraft noise.

METHODS

We described noise measurements from three publications to understand the noise levels on Whidbey Island. These data included recent measurements by JGL Acoustics Inc.^{26,27} and the National Park Service Natural Resource Stewardship and Science Office,²⁵ and modeled noise levels presented in the draft Environmental Impact Statement (EIS) prepared by the United States Department of the Navy.²⁸

There is an extensive body of scientific literature on noise-related health effects. We summarized literature about commercial aircraft noise, as well as noise from other sources, because of the limited peer-reviewed literature on noise from military aircraft. Due to time constraints we primarily focused on peer-reviewed literature reviews with an emphasis on articles published since 2012. This summary includes a detailed description of noise-induced hearing loss and tinnitus, annoyance, sleep disturbance, cognitive impairment, and cardiovascular disease. These effects impact welfare, social, mental and physical health, and have been the most thoroughly investigated to date.²

RESULTS AND DISCUSSION

Naval Air Station Whidbey Island Complex Noise

Noise levels originating from the NAS Whidbey Island Complex have recently been measured by JGL Acoustics Inc.^{26,27} and the National Park Service Natural Resource Stewardship and Science Office.²⁵ Modeled noise levels are presented in the draft Environmental Impact Statement (EIS) prepared by the United States Department of the Navy.²⁸ There are discrepancies in reported noise levels across these three reports due, at least in part, to differences in measurement methods and sample locations. There are limitations to each approach and challenges to directly comparing the reported measurements that will not be addressed in this summary. The objective here is not to comprehensively evaluate the three existing reports, but to provide a useful reference for gauging possible noise exposure levels under various conditions on Whidbey Island.

JGL Acoustics Inc. measured noise originating from military aircraft operations on May 7, 2013, at five locations in close proximity to one of two landing strips at NAS Whidbey Island Complex.^{26,27} Among

other measures, they reported 24-hr L_{Aeq} noise measurements ranging from 64.1 dBA to 75.0 dBA, and Max L_{Aeq} ranging from 81.1 dBA to 119.2 dBA across the sampled sites.

The National Park Service took noise measurements at Ebey's Landing National Historical Reserve, which is located five miles south of NAS Whidbey Island Complex.²⁵ They took multiple measurements for ~735 continuous hours from two locations. For example, they reported L_{dn} levels of 73.6 dBA and 54.7 dBA at the two locations with L_{Amax} levels of ~114 dBA and ~85 dBA. They also found that levels of L_{Amax} 70 dBA were exceeded by 281 and 125 military aircraft events at the two locations over 31 days.

The EIS estimated noise levels for the area surrounding NAS Whidbey Island Complex using NOISEMAP modeling software.²⁸ Their models were based on multiple scenarios of predicted flight activity in the year 2021, which accounts for the proposed increases in flight activity and estimated changes in population. They estimated that in an average year 3,875 people across 7,299 acres will live within a 65 to <70 dBA L_{dn} noise contour, 3,165 people across 6,211 acres will live within a 70 to <75 dBA L_{dn} noise contour, and 3,993 people across 6,423 acres will live within a >75 dBA L_{dn} noise contour. In addition, they estimated L_{Amax} levels at multiple points of interest. The highest L_{Amax} at a residential point of interest was 114 dBA with 267 annual events. The highest L_{Amax} at a school point of interest was 94 dBA with 178 annual events. The highest L_{Amax} at a park point of interest was 106 dBA with 267 annual events.

Noise Induced Hearing Loss & Tinnitus

Noise-Induced hearing loss is defined as an increase in hearing threshold level sufficient to affect daily living.⁴ Hearing loss has more specifically been defined as a 10 dB shift from baseline hearing involving multiple frequencies in the same ear.²⁹ Noise-induced hearing loss can be caused by long-term exposure to steady state sound, or one-time exposure to an intense impulse sound.² Long-term exposures cause ongoing degeneration of sensory cells in the inner ear, which are irreversible and progressive.^{2,30} The progression of hearing loss is also affected by the frequency, intensity, and duration of the noise exposure.³¹

There is some debate about the sound pressure range that can cause hearing loss. The permissible exposure limit set by the United States Occupational Safety and Health Administration (OSHA) is 90 dBA over 8 hours as a time-weighted average. The National Institute of Occupational Safety and Health (NIOSH) recommends an exposure limit of 85 dBA for 8 hours^{31,32} as a time-weighted average. Research suggests that an exposure limit of >70 dBA L_{Aeq} over a 24 hour period from environmental and leisure noise could pose a risk of hearing impairment.⁴ Instantaneous peak sound pressure levels of 140 dBA can cause mechanical damage to the middle and inner ear, and this level of exposure is likely applicable to occupational and environmental exposures.⁴

Noise-induced hearing loss is generally from exposures to higher noise frequencies ranging from 3,000 to 6,000 Hz,^{4,33} which are above frequencies normally associated with aircraft. However, there is potentially a risk of adverse auditory effects from exposure to low flying aircraft noise characterized by rapid noise level increases at noise levels exceeding 115 dBA.³⁴ Hearing loss can affect cognitive performance, attention, and social interactions, and has been associated with accidents and falls.²

Tinnitus has broadly been defined as the inability to perceive silence,³⁵ its expression, etiology, and effect on patients is highly variable.³⁶ Tinnitus can be caused by excessive noise exposure and is sometimes associated with noise-induced hearing loss, but it may also be experienced in the absence of measurable hearing loss.³⁵ An observed adverse effect level for noise-induced tinnitus has not been established in the literature, but protective levels for noise-induced hearing loss have been applied to tinnitus.³⁵ Tinnitus can have a significant impact on quality of life and can cause sleep disturbance, cognitive effects, anxiety, hearing problems, irritability, and an inability to work.²

Annoyance

Exposure to environmental noise causes subjective discomfort, which is referred to as noise annoyance.^{8,37} The relationship between noise exposure and annoyance is generally quantified by linking the results of noise annoyance surveys, summarized by the percentage of the population highly annoyed, and L_{dn} noise exposure estimates. Measuring a subjective outcome is complex and individual annoyance reactions to the same noise exposure can be highly variable.³⁸ The specific wording in a questionnaire and how the study is administered can influence how participants rate annoyance.^{39,40} Documented non-acoustic factors that affect how individuals report noise annoyance include demographics, personal, social, and situational conditions.^{39,41} For example, attitudes towards the noise source or perceived malfeasance related to the noise source can strongly influence survey results.⁴² Despite these complexities, exposure response curves have increasingly found that the degree of annoyance rises with increasing noise levels from transportation noise.^{35,43}

Noise annoyance is one of the most prevalent effects of environmental noise and can cause feelings of anger, exhaustion, and displeasure.^{35,37,44} There is also evidence of a link between noise annoyance and neurologic symptoms such as headaches and difficulties concentrating.²⁴ Multiple studies have recently analyzed the association between noise annoyance and depression. While the statistical significance of the associations reported in these studies have been inconsistent,⁴⁵ there is growing evidence that noise annoyance could increase the risk of depression.⁴⁵⁻⁴⁸ There is also evidence that individuals with higher noise sensitivity are at greater risk of noise-related psychological disorders.³⁷ Noise annoyance, and specifically the associated stress response, is frequently cited as a modifier in the association between noise and cardiovascular health.^{6,8,9}

Sleep Disturbance

Sleep disturbance is a deviation, either measured or perceived, from an individual's habitual or desired sleep behavior.⁴⁹ It is characterized in several different ways including: awakenings, sleep quality, medication to control sleep, total sleep time, time spent in slow wave sleep, sleep stage changes, and arousals.⁴⁹ Sleep disturbance measurement techniques include: polysomnography (the gold standard that measures brain, eye, and muscle activity), seismosomnography or actigraphy (both measure body movement), questionnaires, and push button responses.⁵⁰ The effects of noise on sleep are commonly measured using field studies where participants sleep in their homes with natural noise exposures, and laboratory studies where noise is controlled and participant noise exposures are consistent.^{51,52} In field studies, another layer of complexity is added by the need to distinguish indoor noises from outdoor noises.⁵¹ On the other hand, typical habituation to noise may not be reflected in studies where

participants sleep in a laboratory^{51–53} or where sleep disturbance is predicted from exposure-response models.⁵⁴ A limitation that affects both field and laboratory studies is the difficulty of distinguishing sleep disturbances that would have occurred without the noise event, referred to as spontaneous awakenings.⁵⁰

Sleep is generally thought to play a role in recuperation and restoration of the body.^{50,55,56} There is increasing evidence that chronic sleep loss is associated with obesity, hypertension, diabetes, psychological changes, and increased mortality, as well as impairment in immune, endocrine, and cardiovascular function.^{49,55,57} Low levels of noise lead to minor sleep fragmentation, such as shifts to lighter sleep and movement.⁵⁸ There is broad agreement that noise exposure, and specifically noise from aircraft, is related to sleep disturbance and can lead to serious impacts on physical and mental health if the disturbance is severe and frequent enough.^{50,58} All nine moderate to high quality studies considered in a recent review found that sleep disturbance was linked to aircraft noise events.⁴⁹ The estimated degree of sleep disturbance that occurs with different levels of sound is not certain.⁵⁴ For example, the indoor sound exposure level—at which 5 percent of the population is estimated to awaken—ranged between approximately 55 and 85 dB across four different studies that estimated exposure-response curves.⁵⁰ One study estimated the effect level well above 85 dB.⁵⁰

Cognitive Impairment

Cognitive impairment is typically measured as the ability to perform a task that is assessed with neurobehavioral tests, written questionnaires, or interviews. Daytime studies of children and adults performing the same tasks have found that the relative impact of acute noise on performance is similar between adults and children.⁵⁹ In adults, there is evidence of chronic noise being associated with impaired attention and short-term memory.^{60,61} However, there is particular concern about impairment in children because of the importance of early learning and development, and the effects these have on subsequent adult health.^{13,62,63}

With respect to noise exposure, more information exists for cognitive impairment in children than for other health effects. Recent research focused on cognitive impairment from chronic noise exposures in children indicates that noise does not affect all aspects of cognitive function.¹³ An increasing trend has emerged for an association between noise exposure in children and impaired reading skills and memory, and a less consistent association with attention.^{13,61} It has been postulated that noise exposure leads to communication difficulties, impaired attention, increased arousal, learned helplessness, frustration, noise annoyance, sleep disturbance, and/or psychological stress, all of which can result in impaired cognition.⁴⁴

In the Road-traffic and Aircraft Noise Exposure and Children's Cognition and Health (RANCH) Study, the most comprehensive study of noise and cognitive impairment in children to date, a linear exposure-effect relationship was established between aircraft noise and decreased reading comprehension.⁶¹ Findings of the RANCH study, which incorporated adjustment for several confounding factors, indicate that reading comprehension falls below average with aircraft noise above 55 dB L_{Aeq16} .¹³ Further, an increase of 5 dB L_{Aeq16} noise exposure to aircraft at school was associated with a 2-month delay in reading age in the United Kingdom and a 1-month delay in reading age in the Netherlands.¹³

Cardiovascular Disease

There is a growing body of literature describing the association between cardiovascular disease and noise exposure. Environmental epidemiological studies are most commonly used to investigate the relationship between environmental noise and cardiovascular health effects, and include retrospective, cohort, cross sectional, case-control, and meta-analyses. The relationship between environmental noise and cardiovascular disease is complex. This complexity has contributed to epidemiological studies reaching inconsistent conclusions related to the strength and significance of associations. There are a number of variables that potentially influence study outcomes such as source of noise,⁴⁴ selection of noise metric,⁶⁴ time of day,^{35,65} characteristics of the study population,⁶⁶ and study design. The relationship between noise exposure and cardiovascular health is also often confounded by air pollution, and adjusting for this poses a challenge.^{67,68}

Despite these complexities, recent studies have presented increasing evidence of a positive association between noise exposure and cardiovascular health effects.^{35,44,65,69,70} Acute noise exposure is associated with increased systolic and diastolic blood pressure, changes in heart rate, and stress hormone release.⁴⁴ Long-term environmental noise exposure can affect the cardiovascular system and manifest diseases including hypertension, ischemic heart diseases, and stroke.^{44,64,65} For example, recent meta analyses assessing exposure-response relationships between transportation noise (road traffic and aircraft) and cardiovascular effects (hypertension and ischemic heart diseases) revealed a 6–8 percent increase in risk per increase L_{dn} , with effects starting at noise levels as low as 50 dB.^{69,71} The Hypertension and Exposure to Noise near Airports (HYENA) cohort study^{72–77} found a general positive association between aircraft noise and hypertension, but the significance of their findings varied by day versus night noise, country, and gender.⁶⁶ There is also increasing evidence that nighttime noise is more relevant to cardiovascular effects than daytime noise,⁶⁵ and men might be at greater risk than women from noise-related cardiovascular disease.⁶⁶

Susceptible Populations

Some population groups within the general public are likely at greater risk of developing health effects from noise exposure. However, there are few published studies designed to compare noise susceptibility of a particular subgroup to the general population.⁶³ More often, studies report effects of varying noise exposure within a population that is thought to be at greater risk without comparison to another population, or cite that a group is more susceptible based on plausibility. Susceptibility may be impacted by numerous traits including behavior, individual circumstances (e.g., location of residence), physical and mental characteristics, and developmental phase. For auditory effects, smokers may represent a more susceptible population.⁷⁸ Children, the elderly, shift-workers, and individuals with sleep disorders, mental disorders, and physical illnesses are often cited as being more susceptible to non-auditory effects of noise.^{55,56,63}

- There is evidence of an association between cigarette smoking and hearing loss.^{78,79} Co-exposures to cigarette smoke have been found to increase the risk of noise-induced hearing loss in occupational settings.¹

- Children are thought to be at greater risk from the effects of noise exposure because they are still developing both physically and mentally.^{13,63} There is substantial evidence that noise impairs children's cognitive function.¹³ There are inconsistent findings reported for an association between prenatal noise exposures and low birthweight in two systematic reviews,^{5,80} and there is some indication that children exposed in utero to elevated noise have elevated systolic blood pressure and stress hormone levels.⁸⁰
- The proposed vulnerability to noise in shift-workers, the elderly, and people with sleep disorders may occur through sleep disturbance.^{55,56} In shift-workers both daytime and nighttime noise pose a problem.⁵⁵ Sleep patterns also change with age, and the elderly are generally more prone to waking up.⁸¹
- There is evidence that mental health status and personality traits are determinants of noise perception, which is potentially linked to sleep disturbance and subsequent health effects. For example, neuroticism has been associated with increased noise sensitivity and annoyance.⁶⁰ More generally, attitude toward noise, sleep sensitivity, and personality traits seem to modify noise impacts on sleep disturbance.⁵²
- Individuals with physical illness have been cited as a population potentially more susceptible to noise exposure.^{41,59,63} For instance, people with a prevalent chronic disease could be at an increased risk of heart diseases associated with noise exposure.⁸² Pre-existing disease has also been described as a potential effect modifier in the association between noise annoyance and ischemic heart disease, as individuals with chronic illness were more likely to report higher annoyance levels.⁷⁰

More research is needed to compare particularly susceptible population groups to the general population, and the degree to which these groups are more at-risk to harmful effects of noise exposure.

CONCLUSION

The primary findings considered in this review are summarized below.

- **Noise-Induced Hearing Loss and Tinnitus:** There is a risk of hearing impairment from long-term exposure to steady state noise levels greater than 85 dBA for an 8-hour period, and greater than 70 dBA L_{Aeq} for a 24-hour period at frequencies ranging from 3,000 Hz to 6,000 Hz. This type of noise exposure is generally not associated with aircraft noise.
- **Annoyance:** The scientific literature provides evidence that noise exposure leads to annoyance, which causes a decrease in quality of life. While definitively quantifying annoyance and its effect on the population is challenging, there is strong evidence that feeling annoyed has negative impacts on mental health and cardiovascular endpoints.
- **Sleep Disturbance:** A variety of measurement techniques have been used to study sleep disturbance. There is general agreement that noise is associated with sleep disturbance and if the disturbance is severe and frequent, it can lead to negative health consequences.
- **Cognitive Impairment:** Studies of noise effects on children's cognition reveal an increasing trend that noise exposure results in impaired reading skills. One of the largest studies to date found that reading comprehension falls below average when children are exposed to aircraft noise that is above 55 dB L_{Aeq} .

- **Cardiovascular Disease:** The extent and underlying mechanisms for the relationship between noise exposure and cardiovascular health are still poorly understood. However, the scientific literature has provided increasing evidence of a positive association.
- **Susceptible Populations:** Groups that have been described as potentially more susceptible to the effects of noise include smokers, children, the elderly, shift-workers, and individuals with sleep disorders, mental disorders, and physical illnesses. However, more research is needed to understand differences in risk in these groups compared to the general population.

The relationship between noise exposure and health has been studied extensively, and the body of knowledge on this topic is rapidly increasing. However, there are gaps of knowledge to consider. For instance, additional research is needed to thoroughly understand the specific exposure-response relationship and underlying pathways for some health endpoints. There are also complexities related to selecting the most appropriate noise measurement for assessing health outcomes. For example, the L_{dn} metric is commonly used to quantify aircraft noise exposure levels, yet this metric does not account for infrequent loud events, which could have impacts on health effects such as sleep disturbance.²³ Different measurements might be more appropriate for specific noise sources or health outcomes, and future work parsing out these relationships will greatly enhance our understanding of the association between specific noise characteristics and health.

In general, there is increasing evidence that noise exposure, as defined from multiple sources including commercial aircraft, is associated with numerous adverse health effects. There are likely nuances associated with noise exposures specific to military aircraft that are not thoroughly understood. However, noise levels similar to those reported from NAS Whidbey Island Complex described in all recent reports^{25,26,28} pose a threat to public health.

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