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FAA studies on the effects of aircraft noise on sleep

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ABSTRACT

Aircraft noise is disturbing to some people living near airports and can also affect sleep. Past field studies on the effects on aircraft noise on sleep often either lacked sufficient sample size or adequate physiological or behavioral endpoints. In order to inform future considerations, it is important to obtain exposure-response relationships between aircraft noise exposure and objective sleep disturbance data in ecologically valid field conditions. Recent advances in ease of use and miniaturization of physiological measurement technology, along with data analysis techniques allow for the investigation of large subject samples at low methodological expenses in field settings. The Federal Aviation Administration (FAA) is actively conducting research to advance scientific knowledge in this area. This paper will discuss objectives, long term goals, and current work sponsored by FAA.

BACKGROUND

Aircraft noise is disturbing to some people living near airports and can also affect sleep. Due to the increasing stresses of daily life, adequate sleep is necessary for sustaining a busy lifestyle. The effect of aviation noise on sleep is a long-recognized concern of those interested in addressing the impacts of noise on people’s wellbeing [1].

Different approaches are used for analyzing sleep disturbance attributed to environmental noise. These can be categorized as either laboratory studies or field studies.

There have been several studies of sleep disturbance conducted mainly in laboratories, using various indicators of response. Although laboratory studies play an important role in elucidating sleep mechanisms, these types of studies will not be able to determine the extent to which nocturnal aircraft noise exposure affects sleep in familiar environment and how it affects individuals who have lived in noise-exposed areas for years.

Field studies have been conducted in a number of locations, in which subjects were exposed to noise in their own homes. However, previous United States (U.S.) studies had an outcome of behavioral awakenings, which measured only when individuals were conscious and alert and therefore has low sensitivity.

In addition to awakenings, aircraft noise can result in difficulties falling asleep, changes in the structure of sleep - including time spent in various sleep stages and possible decreases in the restorative qualities of sleep, or difficulty reinitiating sleep after awakening [2].

There are European studies that show sleep disturbance and sleep-related health outcomes, specifically to cardiovascular disease (CVD) outcomes, are attributed to aviation exposure [3].

Transportation noise can affect cardiovascular health directly via noise induced stress, and another via sleep deprivation. Therefore, there was considerable interest in investigating the association between aircraft noise and cardiovascular outcomes, in both cross-section and over time, and in estimating the population attributable risk associated with aircraft noise.

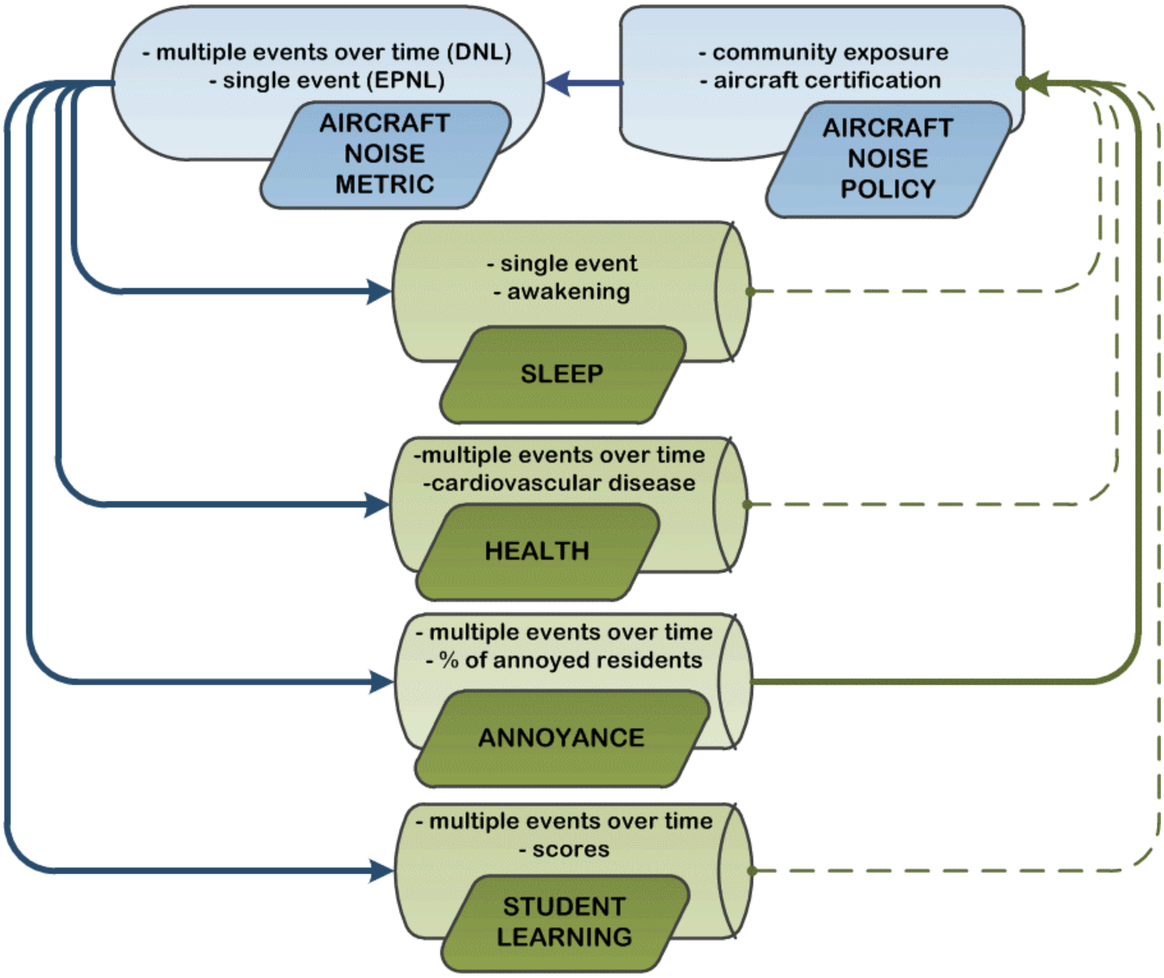

Figure 1: Relationship between noise impacts and policy

In order to inform future considerations regarding aviation noise and sleep, it is important to obtain dose-response relationships between aircraft noise exposure and objective sleep disturbance data in ecologically valid field conditions (Figure 1). Figure 1 demonstrates the current scope of noise-impact research sponsored by the United States Federal Aviation Administration (FAA). The research includes investigation in areas of sleep, health, student learning, and annoyance. Presently, the policy is based exclusively on knowledge resulting from studies of relationship between individual annoyance and aircraft noise (DNL metric) and regulating aircraft noise through noise certification (EPNLdB metric). FAA is conducting research to broaden the understanding between aviation noise and its impacts. The three dotted lines in Figure 1 represent this ongoing research. The graphic illustrates the current policy (blue boxes) and the on-going research (green). This paper discusses impacts of sleep disturbance and health.

Nighttime Noise Assessment in the United States

The FAA is promoting actions to reduce the impact of noise on people living around airports. The current criterion of Day-Night Average Sound Level (DNL) identifies 65 decibels (dBs) as the threshold for significant noise impact, and was established in 1980. Since that time, there have been large reductions in individual aircraft noise due to the introduction of new aircraft that incorporate advances in engine and airframe technology, but there has also been a substantial increase in the number of operations. The FAA is conducting research on the impacts of aircraft noise on sleep as part of a broader effort to understand whether or not changes in the metric and level are warranted.

The FAA uses DNL as the primary metric for quantifying individuals' cumulative noise effects on people due to aviation activities. It is based on outdoor A-weighted sound exposure levels of noise. The DNL metric accounts for the noise level of all individual aircraft events, the number of times those events occur, and the time of day, day or night, in which they occur. This metric represents logarithmically averaged aircraft sound levels at a location over a 24-hour period, with a 10 dB penalty added to those noise events occurring between from 10:00 p.m. and 7:00 a.m. local time. The 10 dB penalty adjustment has been added to account for the increased sensitivity to noise during normal nighttime hours and the fact that ambient (without aircraft) sound levels during nighttime are typically about 10 dB lower than during daytime hours. Given the logarithmic nature of decibels, this 10 dB penalty means that one nighttime sound event is equivalent to 10 daytime events of the same level.

The American National Standards Institute (ANSI) Standard S12.9/6 (2008) [4] methodology quantifies sleep disturbance in terms of the probability of awakening at least once due to single noise event levels expressed in terms of indoor A-weighted sound exposure level. The Standard was developed from field studies of behavioral awakening primarily in communities near airports in the U.S. and Europe. Behavioral awakening is a method where an individual is instructed to press a button when he/she is awoken by noise. It requires that individuals regain full consciousness and be motivated to press the button; therefore awakenings of this type occur infrequently during the night.

Currently the FAA is conducting research to reevaluate the knowledge on sleep disturbance patterns of residents living around U.S. airports. The projected average annual rate of increase of enplanements on U.S. mainline and regional carriers from the national forecast is expected to be 2.2 percent over the period between now and 2036 [5]. To help ensure the system is capable of handling the additional flights and that the growth is done in an environmentally responsible way, FAA is implementing NextGen. A key component of NextGen is Performance Based Navigation (PBN), which is a navigation based on specified system performance requirements for aircraft operating on an air traffic route, instrument approach procedure, or in a designated airspace. PBN uses Area Navigation (RNAV) and Required Navigation Performance (RNP) to improve access and flexibility in airspace system while also providing more efficient aircraft routes from departure runway to arrival runway. PBN defines the performance requirements for routes and procedures that enable aircraft to navigate with greater precision and accuracy, which can concentrate flights over a smaller area in the sky than traditional flight procedures.

Past field studies on the effects of aircraft noise on sleep often either lacked sufficient sample size or adequate physiological or behavioral endpoints. There is evidence that chronic sleep restriction leads to poor health outcomes [6]. Since the studies were not design to address aviation impacts, the existing U.S. national health cohort data typically have very coarse resolution (state or county level) which is not sufficient for drawing conclusion.

In order to inform future considerations regarding aviation noise in the U.S., it is important to obtain dose-response relationships between aircraft noise exposure and objective measurements of sleep data in ecologically valid field conditions which are representative of the exposed population. It can be achieved by addressing the following knowledge gaps: 1) quantify potential aircraft noise impacts on sleep, 2) define the levels of exposure at which awakenings begin to occur, 3) measure the level of awakenings at varied noise levels, and 4) provide a context for decision-making purposes.

THE FAA STUDIES ON AIRCRAFT NOISE EFFECTS ON SLEEP

For over a decade, the FAA has been actively engaged in research investigating how aviation noise affects the sleep pattern of U.S. residents. Significant progress was made within the FAA's Center of Excellence Partnership for Air Transportation Noise and Emission Reduction (PARTNER) [7] and Aviation Sustainability Center (ASCENT) [8], and within the National Academy of Sciences Airport Cooperative Research Program (ACRP) [9]. The studies are two-fold and conducted in parallel and include: physiological studies, and epidemiological analysis. The studies are conducted collaboratively with other U.S. government agencies, and with international scientists and organizations.

Physiological studies

To achieve the long-term goal of creating a dose-response curve, a representative data sample is essential. Conducting larger studies requires an inexpensive yet sound study methodology for obtaining objective measures of sleep and noise. The FAA has been conducting research on developing a methodology for conducting a nationwide sleep study.

U.S. studies on physiological responses to aviation noise and sleep is progressing in several stages. The first stage was to identify a scientifically sound and economically reasonable approach to a large sleep study, and the second will be to collect nation-wide sleep data.

The first FAA sponsored sleep studies began in 2007. At that time, work was focused on evaluating the existing physiological sleep models and modifying them to account for sleep fragmentation due to noise events [7]. These studies revealed that the models were suitable for predicting sleep disturbance and changes in sleep structure for different noise levels. Increase in awakenings and decrease in time spent in slow wave sleep was observed with rising noise levels.

The original models were developed using available data from European laboratories and field studies. However, in order to make these models generally applicable, data was required from communities around U.S. airports.

Recent advances in ease of use and miniaturization of physiological sleep measurement technology, along with new data analysis techniques, allow for the investigation of large subject samples at a low methodological expense.

By 2010, in collaboration with colleagues from the German Aerospace Center (DLR), a noninvasive methodology for monitoring physiological changes under field conditions was developed [10]. A combination of electrocardiography (ECG) and actigraphy was proposed as an inexpensive technique in which the equipment can be used unattended by study participants. To identify awakenings based on the measurements, an automatic algorithm for identifying awakenings was developed and validated.

Potentially these techniques can be used to collect data to relate noise characteristics of single aircraft events and physiological changes in exposed group defined based on ECG and actigraphy versus the physiological changes of the control group. The preliminary U.S. field study protocol was designed to acquire data on sleep disturbance relative to varying degrees of noise exposure [7].

Using the newly developed methodology, a field study was conducted around Philadelphia International Airport (PHL) [11] in 2014-2015 with the goal to validate the study design and to determine its applicability to a larger study. Eighty participants were recruited in the Philadelphia area. The participants fell into two categories, one which was exposed to aviation noise, and the other, a control group, with similar socio-demographic and road traffic characteristics. The control group provided a background level of sleep fragmentation in a field setting. The house selection was based on noise modeling. During the study, noise exposure levels were recorded inside and outside of the bedroom. Unlike previous studies using electroencephalography, which requires staff to go to participants homes each day, 3 days of noise and physiological measurements were performed unattended with staff going to participants' homes only to setup and collect the equipment on the first and last day of the study.

The PHL study demonstrated the feasibility of unattended physiological and noise measurements with about a 10% data loss. Although the noise levels in residential housing were not very high with median indoor single event sound levels of 45.5 dB, there were some conclusions made in terms of a dose-response relationship. There was a statistically significant probability of awakening with an increase in noise level. A fact that residents living near airport reported a poor sleep quality reflected in questionnaires can be attributed to additional confounding factors. Although generally successful, the pilot study methodology revealed several limitations including: low response rates and high recruiting and subject training expenses [12].

A follow-up pilot study is being planned at an additional airport. To overcome limitations of the first pilot study, the protocols for the next pilot study have been refined. The new protocols will not require research personnel to enter participants' home, and all testing equipment will be mailed to participants.

Data collection for a second sleep study at a different U.S. airport began in the fall of 2016 and is expected to be completed by the end of 2017. One additional year will be needed for data analysis. The targeted maximum number of subjects is 200 for in-home noise and physiological sleep measurements.

In preparation for a nationwide, multi-airport U.S. study, the data from PHL and from the second airport will be combined and analyzed jointly with the data available from studies conducted in Germany to examine the variance between airports when estimating probability of awakening due to aircraft noise exposure.

Using the information gained from the U.S. airport specific studies and the studies conducted in Germany, a multi-airport nationwide study will be undertaken and it is anticipated it will take four years to complete. The first year will concentrate on planning, determining statistical samples, identifying airports whose communities can be studied, and modeling the necessary noise metrics for those airports. The accuracy of dose-response curves for different numbers of participants per airport and different numbers of events per participant will be calculated. This analysis will be used to determine the sample size for the objective measurements for the nationwide sleep study.

Epidemiological studies

In parallel, the FAA is sponsoring epidemiological studies investigating sleep disturbance and other health outcomes of aviation noise. This is currently being done by leveraging data from existing U.S. epidemiological health cohorts and studying them retrospectively in relationship to predicted exposures.

The first study investigated the relationship between aviation noise and sleep in the Behavioral Risk Factor Surveillance System (BRFSS) survey, one of the largest databased of health risk behaviors in the U.S. The BRFSS survey is conducted by sampling adult participants from every territory of the U.S., including all 50 states, the District of Columbia, Guam, Puerto Rico, and the US Virgin Islands. The best available geographical data resolution is available on the Zone Improvement Plan (ZIP) code level and was for data collected in 2008 and 2009. The main question on sleep included in the BRFSS questionnaire was, "During the past 30 days, for about how many days have you felt you did not get enough rest or sleep?" Airport noise exposure was modeled for corresponding years, and linked to residential responses [13]. Three DNL noise exposure zones were constructed for each airport: 65 dB or more, 60 dB to less than 65 dB, and 55 dB to less than 60 dB. After controlling for individual socio-demographic and socioeconomic status, no significant difference in sleep insufficiency was found between three aircraft noise exposure zones and the zones without aircraft noise exposure. This study had several limitations, one of which was that the ZIP code centroid noise levels represented individual exposure. The ZIP code land area size is irregular, depends on population density and averaging to around 90 square miles. However, it was the first of its kind U.S. national-scale investigation, and confirmed the possibility of retrospective analyses using U.S. health cohort data.

The BRFSS analysis was completed between 2011 and 2014, and generated methodologies and noise data sets which have been used in follow up work. These studies continue to investigate the relationship between aircraft noise exposure and cardiovascular health by linking noise exposure data to existing national health cohorts.

Since these are longitudinal studies, one of the key barriers is historical noise modeling that requires spatially and temporally interpolating noise exposure. Historical noise exposure was modeled for ninety U.S. airports using the U.S.'s environmental consequence tool, the Aviation Environmental Design Tool (AEDT), for 5 year intervals starting from 1995 to 2015, and at noise levels as low as DNL 45 dB.

Several additional large national cohort studies have been identified and accessed for retrospective analysis.

The initial work analyzed a U.S. medical database, Medicare, and demonstrated that medical cohort could be used retroactively to examine health effects of noise. An association was found between aircraft noise and risk of hospitalization for cardiovascular diseases for older people residing near airport in the Medicare population [14]. Results suggest a positive link between certain levels of aircraft noise exposure and hospitalizations due to cardiovascular disease for persons over 65 years of age. The research shows a link between noise exposure and cardiovascular hospitalizations in ZIP codes with a noise exposure greater than 55 dB, with an estimated 3.5% increase in the cardiovascular hospitalization rate per 10 dB increase in airport-related noise.

The Medicare database has several limitations that influence the certainty of the research findings. Similar to the BRFSS database it relies on ZIP code resolution address information, and has limited data on individual risk factors. There was still a need for a national health cohort with detailed individual data and high geographical resolution.

Currently another large national epidemiological study is ongoing to evaluate the association between aircraft noise and cardiovascular outcomes or risk factors, both cross- sectionally and prospectively. This study leverages data from the Women's Health Initiative, which is one of the largest ongoing cohorts in the U.S., and includes individual data information on study participants. Initiated in 1993, it includes more than 65,000 participants living within ten kilometers of an airport. This study will assign noise exposure levels to geocoded participant addresses over time, interpolate noise estimates spatially and temporally, and investigate pathways by which aircraft noise can influence health.

Last year two other U.S. health cohorts were added to the analysis – the longitudinal Nurses' Health Studies and the companion Health Professional Follow-up Study cohorts [REF 14]. Both cohorts include individual data on traditional CVD risk factors and high geographical resolution over time. These studies began with the original U.S. cohort in 1976 and are currently recruiting the third generation with over 330,000 total participants, including the recently included residents of Canada. In this cohort, there is also a potential to develop future sub-studies within the currently on-going health data collections to introduce additional tests or questionnaires to estimate sleep deprivation.

At present, more studies are needed to determine the connection between exposure to aircraft noise, sleep, and cardiovascular health. Currently the FAA is mining existing U.S. cohorts;

however these ongoing studies were not specifically design to evaluate the effects of noise on health. They rely on self-identification of sleep deprivation, and therefore are limited in their ability to fully quantify the impact of noise on sleep.

Next Steps and Unanswered Questions

Research to collect data and develop dose-response relationships for aircraft noise-induced sleep disturbance representative by exposed U.S. population will continue.

This research is expected to leverage the developed methodology and lessons learned through PARTNER, ASCENT and ACRP research to conduct a multi-year nationwide study on the impact of aviation noise on sleep. A new, multi-year physiological study will address acute effects but is not expected to make any direct conclusions about long term effects on health or about the mechanism by which noise affects health.

There is also a potential to develop future sub-studies within the currently on-going health data collections to introduce additional tests or questionnaires to evaluate sleep quality.

Currently, the assumption is that the most suitable noise exposure metrics during physiological sleep studies is a maximum noise level of single aircraft event. This assumption is due to a limited number of aircraft operations at night and due to awakenings being driven by whether an event happened, not necessarily the duration of the event. This assumption will be further tested as this work progresses.

Studies of the impacts on vulnerable groups can provide a valuable contribution in the determination of substantial outcomes such as morbidity and mortality. Transportation noise exposure can potentially result in mental health outcomes and the excessive use of sleep promoting medications, but these outcomes have not been studied sufficiently in the past.

CONCLUSIONS

In order to inform future considerations regarding aviation noise and sleep, it is important to develop dose-response relationships between aircraft noise exposure and sleep disturbance based on data collected in ecologically valid field conditions which are representative for the exposed U.S. population.

This paper described the existing epidemiological and observational studies sponsored by the U.S. FAA on the effects of aircraft noise on sleep and health in the U.S.

The research has included study design, validating and optimizing methodology, and collection of objective noise and physiological sleep disturbance data. The research is progressing rapidly, with the next step being a nationwide sleep study using a combination of ECG and actigraphy.

Also in the future, it may be possible to integrate a sleep questionnaire or physiological measurements in one of the ongoing health cohort data collections.

In conducting sleep disturbance research, the FAA is looking to partner with other organizations and experts who have expertise on the subject matter or are interested in sleep and health research.

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