Project 086 Study on the Use of Broadband Sounds to Mitigate Sleep Disruption Due to Aircraft Noise

University of Pennsylvania

Project Lead Investigator

Mathias Basner, MD, PhD, MSc
Professor of Psychiatry
Department of Psychiatry
University of Pennsylvania
1019 Blockley Hall, 423 Guardian Dr.
Philadelphia, PA 19104-6021
215-573-5866
basner@pennmedicine.upenn.edu

University Participants

University of Pennsylvania (UPenn)

- P.I.: Prof. Mathias Basner
- FAA Award Number: 13-C-AJFE-UPENN, Amendment No. 015
- Period of Performance: October 1, 2024, to September 30, 2025
- Task:
  1. Complete data analysis

Project Funding Level

Project funding support from the Federal Aviation Administration (FAA) for the Year 2 award (January 1, 2024, to December 31, 2024) for this 2-year project totals $520,700. The cost-sharing requirement for this project is met by our international collaborators at the German Aerospace Center (DLR) and at St. George's University of London. Since January 1, 2025, the project has been in a no-cost extension that was extended once until September 30, 2026.

Investigation Team

University of Pennsylvania

Mathias Basner, MD, PhD, MSc (P.I.), All Tasks
Christopher Jones, PhD (co-investigator), All Tasks
Matthew Kayser, MD, PhD (co-investigator), Task 1
Haochang Shou, PhD (statistician), Task 2
Quy Cao, MS (statistician), Task 2
Michel Carlin (other professional), All Tasks
Adrian Ecker (other professional), All Tasks
Sierra Park-Chavar (other professional), All Tasks
Victoria Schneller (research assistant), All Tasks
Sinead Walsh (research assistant), All Tasks

Civil Aerospace Medical Institute (CAMI)

Hilary Uyhelji, PhD, PMP (co-investigator), All Tasks

Project Overview

Sound insulation of bedrooms is expensive and is typically provided only to residents living near an airport. The goal of this project is to investigate the effects of different types of aviation noise (AN) on sleep under controlled laboratory conditions, and to determine whether some of the sleep-disturbing effects can be mitigated by introduction of pink noise

(PN) into the bedroom or by wearing earplugs (EP). The study will be performed in the Chronobiology Isolation Laboratory at the Hospital of the University of Pennsylvania. This newly constructed facility includes four acoustically isolated bedrooms and a high-fidelity sound system.

Objectives

- Investigate the following hypotheses on the whole night level:
  - AN disturbs sleep and reduces time spent in slow wave sleep + rapid eye movement sleep.
    AN vs. control
  - PN mitigates the negative effects of AN in a dose-dependent manner.
    AN + 50-dBA PN (PN50) vs. AN + 40-dBA PN (PN40) vs. AN
  - EPs mitigate the negative effects of AN.
    AN + EPs vs. AN
  - PN promotes sleep.
    PN50 vs. control
- Investigate the following hypotheses on the event-related level:
  - Various types of AN differ in their awakening potential.
  - The masking effects of PN differ by AN type.
  - PN masks meaningful sounds (e.g., fire alarm or baby crying).

Research Approach

Study Design

The sleep of 24 participants will be monitored through polysomnography (PSG) over seven consecutive nights in groups of four participants. After an adaptation night, participants will be exposed to the following conditions:

1. Control night without noise and without EPs (control)
2. AN only
3. PN50
4. AN + EPs
5. AN + PN40
6. AN + PN50

Our team will investigate participants in six groups of four participants each. Each participant in a given group will be exposed to the same condition in each study night. Each group will receive the six exposure conditions in a randomized and balanced fashion, according to the randomization table below (see Table 1). Of note, in this randomization paradigm, each exposure appears in each position exactly once and is preceded by each other exposure exactly once (letters A–F will be randomly assigned to exposure conditions 1–6 listed above):

Table 1. Randomization of exposure conditions for the sleep research study using PSG.

Group	Night 1	Night 2	Night 3	Night 4	Night 5	Night 6	Night 7
1	Adaptation	A	B	C	D	E	F
2	Adaptation	B	D	A	F	C	E
3	Adaptation	C	A	E	B	F	D
4	Adaptation	D	F	B	E	A	C
5	Adaptation	E	C	F	A	D	B
6	Adaptation	F	E	D	C	B	A

Measurements During Sleep

Participants' sleep will be measured polysomnographically with the Prodigy® system, which includes electroencephalography with frontal electrodes only, electrooculography, and electromyography. Data will be transmitted wirelessly to a bedside tablet. The tablet will also record sound pressure levels to help synchronize the polysomnographic

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and acoustic data. Participants will also wear a Bittium Faros™ device that measures the electrocardiogram (1 kHz) and body movements (25 Hz).

Noise Exposure

The AN night will consist of 93 noise events with maximum sound pressure levels (i.e., $L_{AS,\,max}$ of 45, 55, or 65 dB), including noise from jet engine aircraft, helicopters, drones, low sonic booms, rail, and road traffic. The jet engine, and road and rail noise events will be identical to events used in a prior study at the DLR and another study on broadband sounds on sleep performed by collaborator Dr. Michael Smith in Sweden, thus enabling direct comparison with those studies. Our team will choose several events within each noise level category and repeatedly play those events back. Each aircraft noise event is played back three times at three different maximum sound pressure levels (45, 55, and 65 dBA) for a total of nine times. Because of the limited sample size, playing every event back only once would not provide sufficient data for averaging. An alarm sound and the sound of a baby crying will also be included because a potential caveat of using EPs/PN is that meaningful sounds may be missed. The sequence and spacing of noise events will be identical within a study group but different across study groups. Noise scenarios will be preprogrammed and will start 15 min after the lights are turned off (PN playback will start immediately after lights out). The lights are planned to be turned off at 11:00 p.m. and turned on at 7:00 a.m. for an 8-hour sleep opportunity.

Evening and Morning Procedures

Participants will arrive at the laboratory at approximately 7:00 p.m. and will be able to leave the laboratory at approximately 9:00 a.m. Because our noise exposures can affect sleep and impair recuperation to some degree, participants will be informed in the consent form that they should not operate heavy machinery during the study. A taxi will also be offered for participants who would otherwise use a car to travel to the Chronobiology Isolation Laboratory. Snacks will be provided in the evening and a light breakfast in the morning. Participants will be able to shower in the morning (after all tests) if they wish.

In the evening (before bed) and in the morning (after waking up), the following will be conducted:

1. Blood draw (for untargeted messenger ribonucleic acid [mRNA] analyses expected to be performed by the FAA CAMI, morning only)
2. Completion of a survey asking participants about the previous day (evening survey) or the previous night (morning survey)
3. Cognition test battery (10 cognitive tests)
4. Driving simulator task
5. Hearing test (up to 16 kHz)
6. Blood pressure and heart rate variability measurements

The four participants of a group will be rotated through the six tasks. Each participant will perform the different tasks always in the same order.

Participant Recruitment

Participants will be screened on two occasions. The first screening will include blood draws with drug screening, electrocardiography, and a hearing test. Participants will receive a pulse oximeter, which they will return at the second screening. At the second screening, participants will be familiarized with the cognitive tests and the driving simulator. They will also receive an actigraph that they will wear in the week before the start of their study run. They will be asked to adhere to a sleep schedule of 11:00 p.m. to 7:00 a.m. to the extent possible in the week before participation. We plan to conduct a seventh backup study run if participants drop out during the first six study runs.

Study inclusion criteria:

- Age between 21 and 50 years
- Absence of psychological/psychiatric conditions precluding participation
- Body mass index < 35 kg/m^2
- Self-reported regular sleep schedule; ability to maintain sleep schedule during the course of the study

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- Self-reported sleep duration of 6–8.5 hours per night (verified by six workdays of ambulatory sleep monitoring with wrist actigraphy and daily logs)
- Ability to read and write in English
- Full vaccination against, or recovery from, COVID-19

Study exclusion criteria:

- Hearing loss > 25 dB in any frequency band up to 8 kHz
- History of neurological, psychiatric, or other medical conditions precluding participation
- Current mania or psychosis
- Current depression, according to the Beck Depression Inventory (Beck et al., 1996)
- Excessive alcohol or drug use in the past year, on the basis of history and urine toxicology screening
- Excessive alcohol intake (≥ 21 drinks per week) or binge alcohol consumption (more than five drinks per day)
- Excessive caffeine consumption (> 650 mg/day from all caffeinated drinks regularly absorbed during the day)
- Current use of cigarettes/tobacco, or nicotine replacement therapy (those nicotine-free for 30 days will be included)
- Body mass index ≥ 35 kg/m^2
- Acute, chronic, or debilitating medical conditions, major axis I psychiatric illness, according to history, physical examination, blood and urine chemistry, and complete blood count
- Self-reported history of recurrent seizures or epilepsy or a history of medical conditions that could increase the chance of seizure (e.g., stroke, aneurysm, brain surgery, or structural brain lesion)
- Cardiovascular, neurological, gastrointestinal, or musculoskeletal problems that preclude participation
- Major controlled or uncontrolled medical conditions, such as congestive heart failure, neuromuscular disease, renal failure, cancer, chronic obstructive pulmonary disease, respiratory failure or insufficiency, cardiac arrhythmia, or a need for oxygen therapy (as determined by self-report)
- Current night, swing, split, or rotating shift work
- Current use, or use of within the prior month, of a prescription or over-the-counter sleep medication or stimulant; use of psychoactive medication (based on self-report and review by a study clinician)
- Pregnancy or current breastfeeding
- Prior history or diagnosis of any sleep disorder including obstructive sleep apnea (Apnea-Hypopnea Index ≥15 events/hour) from ambulatory or in-laboratory PSG; restless legs syndrome or periodic limb movement disorder; insomnia; parasomnia; high risk of obstructive sleep apnea, according to the STOP-BANG Questionnaire ("yes" on at least four of eight questions); high risk of restless legs syndrome, according to the Cambridge-Hopkins Screening questionnaire; or high risk of insomnia, according to the Insomnia Severity Index (score of 22 or higher)
- Self-reported severe contact dermatitis, or allergy to silicone, nickel, or silver
- Planned travel across more than one time zone up to one month before and/or during the anticipated study period
- Intentional naps during the week
- Habitual use of broadband noise to facilitate sleep

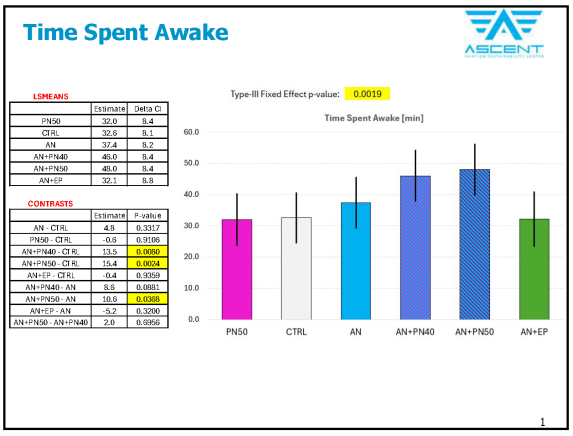
Endpoints and Power Considerations

The primary outcome of the study is time spent in slow wave sleep plus rapid eye movement sleep during an 8-hour sleep opportunity (11:00 p.m. to 7:00 a.m.). Our team will investigate several other outcomes related to the entire night (e.g., sleep efficiency or wake after sleep onset); to outcomes before and after sleep (e.g., cognitive performance and driving); or to individual noise events (e.g., event-related analysis).

All power calculations were conducted in the Power Analysis & Sample Size (PASS) (Version 21; NCSS, 2021), by assuming a 5% type I error rate and using two-sided hypothesis tests. The data collected in the AIRORA study (Study on the effects of Air, Road, and Rail traffic noise on sleep), performed at DLR, was used to inform power calculations. With a proposed sample size of 24 participants, our team expects to have at least 80% power to detect a medium effect size of 0.60 for the mitigation effect of PN on our primary outcome due to aviation noise.

Key Findings

Key findings of the first study are shown in Figure 1. In a dose-dependent fashion, time spent awake was longer and time spent in rapid eye movement (REM) sleep was shorter in nights with aircraft noise and pink noise, while time spent in deep



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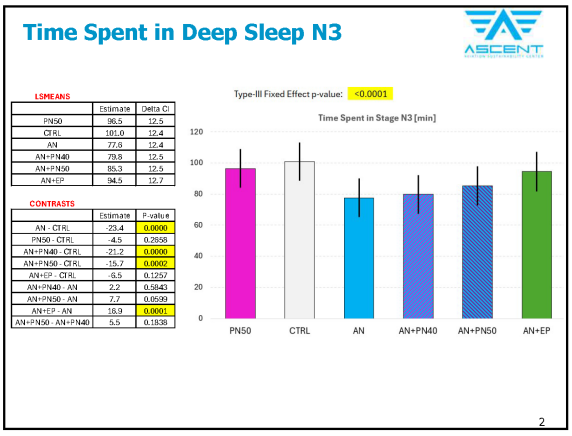

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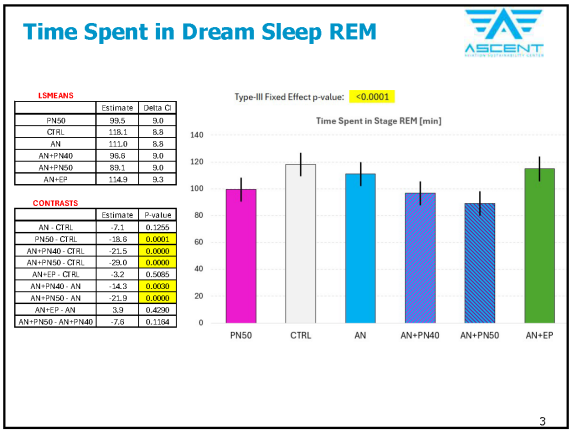

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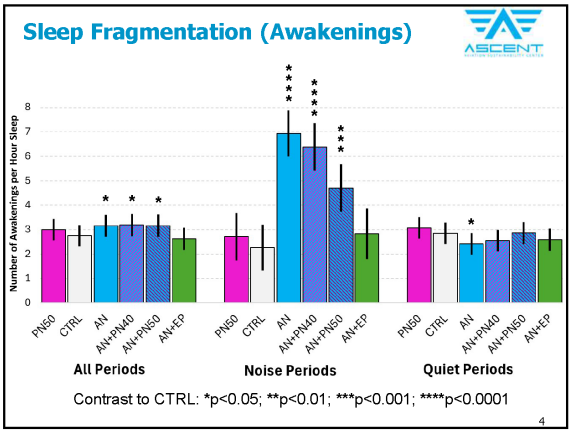

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Figure 1. Polysomnography findings of the first study. (1) Time spent awake was significantly higher in aircraft noise plus pink noise at 40 dBA (AN+PN40) nights and aircraft noise plus pink noise at 50 dBA (AN+PN50) nights compared to noise-free control nights (CTRL). Time spent awake was not significantly different for the aircraft noise only night (AN), the pink noise at 50 dBA night (PN50), or the aircraft noise plus earplugs (AN+EP) night relative to CTRL. (2) Time spent in deep sleep stage N3 was significantly lower in AN, AN+PN40, and AN+PN50 nights relative to CTRL. It was slightly longer in AN+PN40 and AN+PN50 nights relative to AN, albeit not statistically significantly. (3) Time spent in rapid eye movement (REM) sleep was significantly lower in all nights containing pink noise relative to CTRL. It was also significantly lower in AN+PN40 and AN+PN50 relative to AN. (4) Pink noise at 40 dBA and 50 dBA were able to mitigate some of the effects of aircraft noise on sleep fragmentation measured by awakenings (Noise Periods).

The different aircraft noise events and alarm sounds differentially affected sleep, and that they were also differentially mitigated by pink noise (see Figure 2).

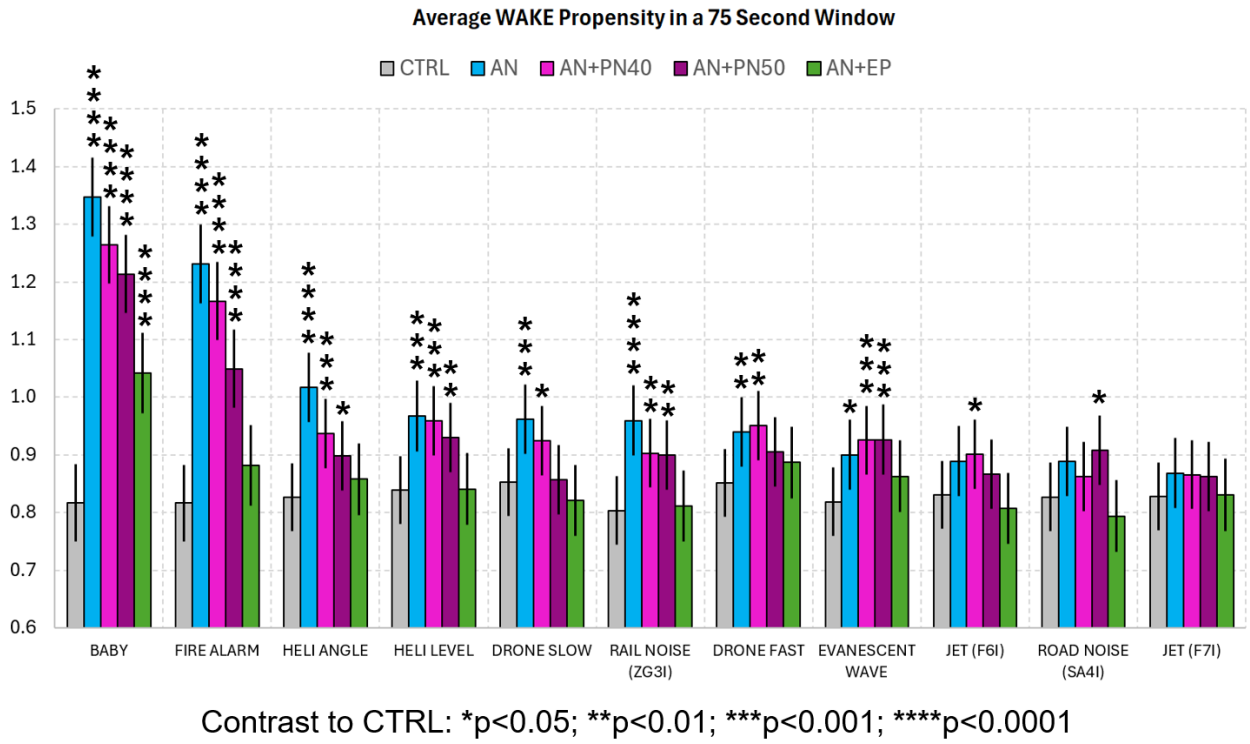

Figure 2. Effects of different noise sources on wake propensity adjusting for maximum sound pressure level. Wake propensity decreased in the following order: crying baby, fire alarm, helicopter noise, drone noise, low boom noise (evanescent wave), and jet noise. CTRL: control night (sham events); AN: aircraft noise only night; AN+PN40: aircraft noise plus pink noise at 40 dBA; AN+PN50: aircraft noise plus pink noise at 50 dBA; AN+EP: aircraft noise plus earplugs

Milestones

- Finalized data analysis in July 2025 (except for mRNA analysis, which is still ongoing).
- Submitted first scientific manuscript.

Major Accomplishments

- Enrolled a total of 27 subjects in the study, three of whom withdrew early from the study. Partial data of one subject withdrawing early can still be used for analysis. Thus, complete data of n=24 participants and partial data of n=1 participant will be used for data analysis (planned total was n=24).
- Analyzed all study data. mRNA data were initially analyzed by CAMI. We are currently performing an in-depth analysis of the mRNA data with UPenn collaborators. These analyses are still ongoing.

Publications

One manuscript was submitted to the journal *Sleep*. Two more manuscripts are in preparation.

Outreach Efforts

A press release for the first manuscript is in preparation and was shared with the FAA project manager.

Awards

None.

Student Involvement

Six temporary undergraduate or post-baccalaureate student workers have supported participant screening and data acquisition in the sleep laboratory.

Plans for Next Period

- Finalize mRNA analysis.
- Generate report.

References

Beck, A.T., Steer, R.A., Ball, R., & Ranieri, W.F. (1996). Comparison of Beck Depression Inventories-IA and -II in psychiatric outpatients. *Journal of Personality Assessment*, 67(3):588-597.

NCSS. (2021). *Power Analysis & Sample Size* (Version 21) [Computer software]. https://www.ncss.com/download/pass/updates/pass-2021/