Pilot study examining the effects of aircraft noise on sleep in communities near Philadelphia International Airport

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ABSTRACT

Aircraft noise can disturb sleep and impair recuperation. Representative field studies are needed for health impact assessments and to inform noise policy. To evaluate feasibility of a new unobtrusive methodology that objectively monitors sleep and identifies awakenings based on heart rate and actigraphy, an unattended pilot field study was conducted in the vicinity of Philadelphia International Airport. Seventy-nine participants (39 exposed to aircraft noise, 40 controls) were monitored for 3 consecutive nights with concurrent sound recordings in the bedroom. Blood pressure measurements and brief questionnaires were completed each morning. Based on linear mixed models controlling for age, gender, and BMI, individuals living near the airport reported poorer sleep quality on the PSQI (p=0.0180) and worse health on the SF-36 (p=0.0074) surveys. No statistically significant differences were found for morning sleep assessments, diastolic (p=0.7108) and systolic (p=0.3255) blood pressure, or the sleep fragmentation index (p=0.6986) (calculated based on the ECG and actigraphy data). This study demonstrates feasibility of unattended physiological and noise measurements.

INTRODUCTION

To inform policy, representative field studies in the U.S. are needed on the effects of aircraft noise on sleep. For these studies the use of a non-invasive approach of using ECG and actigraphy to measure sleep fragmentation is being examined. Awakenings identified based on heart rate and body movements have been found to have high agreement with awakenings identified using EEG-based polysomnography which is the gold standard for monitoring sleep [1, 2]. Unlike polysomnography though, participants can use the equipment unattended which reduces or eliminates the need for staff in the field resulting in lower methodological costs per subject.

A pilot study was conducted around Philadelphia International airport to evaluate the feasibility of having participants complete unattended acoustic and physiological (ECG and actigraphy) measurements. This airport was selected due to its proximity to the University of Pennsylvania, relevant amount of night operations (> 100 flights between 23:00-7:00), and sufficient population for participant accrual. Half of the participants were recruited from communities near the airport. To examine how aircraft noise may disturb sleep above levels experienced due to other noise common in urban areas (e.g. trains, road traffic, neighborhood noise [3-6]) the other half of the participants were recruited from an area in Philadelphia that had similar socio-demographic characteristics, and road and train noise but was not exposed to relevant amounts of aircraft noise. Objective and subjective sleep and health measures were compared between participants living near the airport and those living in the control area.

METHODOLOGY

Study Protocol

This study was approved by the Institutional Review Board of the University of Pennsylvania. The duration for each participant was 4 days and 3 consecutive nights, taking place Monday thru Thursday or Tuesday thru Friday, depending on the participant's availability. The study was restricted to weeknights for consistency, as bedtime, sleep duration, and flight schedules may vary between weekday and weekends. Two staff members went to each participant's home on the first night of the study. They explained the study protocol, obtained written informed consent, and then instructed participants on equipment use. The staff also setup environmental monitoring equipment. Measurements were completed unattended for the three nights, with staff members returning after the third night to collect the equipment. Staff was available throughout the study to address any questions or concerns that participants had. The measurements took place over a period of 1 year from July 2014 thru July 2015.

Environmental Measurements

To measure noise levels in the bedroom, one microphone was setup near the head of the bed, at approximately the height of the pillow. L_{Aeq} levels and unweighted one-third octave band levels were recorded 24 hours a day throughout the study using a class-1 sound level meter (Larson and Davis Sound Level Meter 831). At night before going to bed, participants turned on a sound recorder in the bedroom which saved calibrated audio recordings. An additional sound recorder was placed outside near the participant's bedroom window. The purpose of the outdoor recordings was only for identification of sound sources. In addition to the noise measurements, temperature, light, and humidity were recorded in the bedroom every minute (T&D Illuminance UV Recorder TR-74UI), as these environmental factors can additionally affect sleep.

Physiological Measurements

During the night while sleeping, a single device (eMotion Faros 90) was worn which recorded a 1-channel electrocardiogram (ECG) and body movement. The ECG was sampled at 1 kHz and the peak of each R-wave was detected and recorded. Body Movement was measured using a 3-axis accelerometer at a sample rate of 10 Hz, 14 bit resolution. To examine potential consequences of noise-induced sleep disturbance, each morning participants completed blood pressure measurements using a home monitor with pre-formed arm cuff (Omron BP791IT). Three consecutive measurements were completed automatically with one minute intervals between measurements. Participants were instructed not to drink caffeine, smoke, or exercise, and to be sitting in a state of rest for 5-10 minutes before completing the measurements.

Subjective Assessments

Each morning participants completed a brief questionnaire on their previous night's sleep quality and their level of fatigue in the morning. Subjects also completed four surveys on the first day of the study, which included a socio-demographic questionnaire, the Health Survey (SF-36) [7], the Pittsburgh Sleep Quality Index (PSQI) [8], and the Horne-Ostberg Morningness-Eveningness Questionnaire [9].

Subject Recruitment

The majority of participants were recruited through flyers mailed to residences. Addresses were purchased from a commercial vendor. For the control region, addresses were randomly selected. For communities near the airport, addresses with the highest predicted nighttime noise levels were selected. A total of 3700 flyers were mailed. Individuals interested in taking part in the study were screened over the phone to determine their eligibility. Participants had to be 21 years or older and not be morbidly obese (BMI over 35). Also the participants could not have a history of cardiac arrhythmia or history of a sleep disorder (including obstructive or central sleep apnea, narcolepsy, restless legs syndrome). In addition participants had to have normal hearing, not consume sleep medication on a chronic basis, not work night shifts, or have children under five years old. More than one person per household could take part in the study.

Analysis

Acoustic Analysis

Aircraft events were identified in the recordings based on flight schedules and flight paths. All identified aircraft events were also verified by listening to the sound recordings. The maximum noise level of each aircraft event was calculated (L_{ASmax}) as well as the average noise level (L_{Aeq}) during the 1 minute prior to each aircraft event to determine the background noise level.

Awakening Analysis

Awakenings were identified automatically based on the heart rate and actigraphy data. The program used for the detection is based on the algorithm of Basner et al. [1] which was refined and validated to identify EEG awakenings (≥15 seconds) based on both heart rate and actigraphy [2]. Artifacts in the heart rate signals were visually identified, and these periods were removed from analysis. During periods in which the heart rate signal was invalid (6% of nights), awakenings were identified based on actigraphically determined movement only and included in the analysis.

Statistical Methods

Statistical analysis was performed using SAS (version 9.3, SAS Institute, Carey, NC). For all outcomes linear mixed models were calculated using Proc Mixed. For sleep fragmentation and blood pressure measurements the model had a random subject intercept, to account for the correlation of the repeated observations for each subject.

RESULTS

Eighty participants were enrolled in the study, 39 in the airport region and 40 in the control region completed measurements. The participants were from 56 different households. Data for 3 participants were removed from analysis due to potential health conditions identified after examining the ECG and actigraphy data. This resulted in n=38 for the control region (22-68 years, mean 31, 45% male) and n=38 for the airport region (22-77 years, mean 46, 39.5% male).

Acoustical Analysis

The median value of maximum sound pressure levels (L_{ASmax}) for all aircraft events in the study was 45.5 dBA, and the median value of average noise level (LAeq) during the 1 minute prior to each aircraft event was 35.4 dBA. The median number of aircraft events per subject across the 3 nights was 69.

Sleep Fragmentation Index

Participants in the study were allowed to go to sleep and wake up at their normal times. The majority of participants were asleep between 23:00 and 7:00, with a median sleep period time of 7.5 hours. The sleep fragmentation index was calculated for each night. This index is defined as the number of awakenings divided by the sleep period time in hours. Two linear mixed models with a random subject intercept were calculated, Model 1 was adjusted for age, gender, BMI, and study region, and Model 2 contained the average noise level during the sleep period (L_{Aeq}) instead of the region. In both models the only variable that was significant was age, which was negatively associated with the sleep fragmentation index. We also added a term for age^2 to determine whether there was a non-linear trend, but no significant effect was observed (p = 0.8037 in Model 1 and p = 0.8912 in Model 2 for age^2).

Table 1: Mixed model results for the Sleep Fragmentation Index

	Model 1			Model 2		
	Estimate	**Standard Error**	**p-value**	**Estimate**	**Standard Error**	**p-value**
Age	-0.0363	0.0160	0.0260	-0.0358	0.0160	0.0285
Male	0.5205	0.4234	0.2230	0.6816	0.4280	0.1160
BMI	-0.0057	0.0537	0.9158	0.0153	0.0543	0.7791
Airport	0.1850	0.4760	0.6986			
L_{Aeq} [dB]				0.0036	0.0242	0.8809

Blood Pressure Measurement Analysis

The systolic and diastolic blood pressure levels were averaged across the 3 measurements completed each morning. Linear Mixed models with a random subject intercept were calculated and adjusted for age, gender, BMI, and study region. Systolic blood pressure increased significantly with age (p<0.0001), BMI (p=0.0159) and was higher in male participants (p<0.0001). No statistically significant association was found for region (p=0.3255). For diastolic blood pressure, there was a statistically significant association with BMI (p=0.0011) and age (p=0.0009), but not gender (p=0.0896). No statistically significant association was found for the region (p=0.7108).

Self-Report Results

SF-36 Health Survey

The SF-36 survey contains questions to evaluate an individual’s perceived health. Linear mixed models adjusted for age, gender, BMI, and study region were calculated. When participants were asked to rate their health from poor (1) to excellent (5), those living in the airport region tended to rate their health worse than those living in the control region, albeit statistically non-significantly (-0.4122, p=0.0538). The coefficient for the airport region for several questions in which participants were asked to rate how true or false the statements were can be found in Table 2. Participants living near the airport rated that they expected their health to get worse (+0.60, p=0.0308) and that their health was not excellent (-0.58, p=0.0074) compared to the control region.

Table 2: Coefficient for airport region for linear mixed models adjusted for age, gender, and BMI for the listed health questions. Response categories were (5) Definitely true, (4) Mostly true, (3) Don't know, (2) Mostly false, and (1) Definitely false.

	Estimate	Standard Error	p-value
I seem to get sick a little easier than other people.	0.1548	0.2635	0.5586
I am as healthy as anybody I know.	-0.1939	0.2486	0.4380
I expect my health to get worse.	0.6035	0.2739	0.0308
My health is excellent.	-0.6145	0.2228	0.0074

PROMIS Sleep Questions

In our sociodemographic questionnaire we asked several questions on sleep that were based on the PROMIS Sleep Questionnaire [10]. Each question had a 5 point response scale which ranged from never (1) to always (5). All questions referred to the past month. Linear mixed models adjusted for age, gender, BMI, and study region were calculated. The coefficients for airport region are in Table 3. Several results were statistically significant with participants near the airport reporting their sleep as less refreshing (p=0.0255), they had more difficulty falling asleep (p=0.0267), and did not get enough sleep (p=0.0235) compared to those living in the control region.

Table 3: Coefficient for airport region based on linear mixed models adjusted for age, gender, and BMI for the listed sleep questions. Response categories were always (5), often (4), sometimes (3), rarely (2), and never (1).

	Estimate	Standard Error	p-value
My sleep was restless	0.2056	0.2163	0.3450
I was satisfied with my sleep	-0.3522	0.2279	0.1266
My sleep was refreshing	-0.4698	0.2059	0.0255
I had difficulty falling asleep	0.5771	0.2551	0.0267
I had trouble staying asleep	0.3472	0.2736	0.2086
I had trouble sleeping	0.3200	0.2300	0.1684
I got enough sleep	-0.4612	0.1991	0.0235

Pittsburgh Sleep Quality Index (PSQI)

The Pittsburgh Sleep Quality Index retrospectively assesses sleep quality over a period of one month. Responses to individual questions on the PSQI survey were combined to obtain a global score, which ranges from 0 (indicating best sleep quality) to 21 (indicating worst sleep quality). Scores > 5 are typically used to distinguish poor quality sleep from high quality sleep. Linear mixed models adjusted for age, gender, BMI, and study region were calculated for the global score. Those living near the airport had a significantly higher global PSQI score indicating worse sleep quality compared to the control region (p=0.0180).

DISCUSSION

Overall it was found that participants were able to follow the study protocol well with minimal data loss (< 10%) across all measurements. This study therefore demonstrates the feasibility of conducting unattended physiological and noise measurements. For the physiological measurements no significant difference was found for diastolic or systolic blood pressure or the sleep fragmentation index between the two study regions. The finding for sleep fragmentation index is unexpected given a significant exposure-response relationship between aircraft noise L_{ASmax} and awakenings inferred from body movements and ECG arousals were found (results not shown here). It is possible however that airport residents were able to compensate for noise-induced awakenings during noise-free intervals. Basner et al. [11] have found that many noise induced awakenings simply replaced awakenings that would have otherwise occurred spontaneously. Furthermore, the ECG-based algorithm is somewhat less sensitive in older subjects, and even though we adjusted for age in our models, residual confounding may have masked a higher sleep fragmentation in airport residents. Finally, the study may have been underpowered to find the small difference in sleep fragmentation index statistically significant. For subjective responses it was found that those living near the airport reported poorer sleep quality reflected in responses to the PROMIS sleep questions and the PSQI, and they also reported poorer health as reflected in the SF-36. It is currently unclear though whether additional confounding variables may account for these differences.

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