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Evaluation and refinement of a methodology for examining the effects of aircraft noise on sleep in communities in the US

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ABSTRACT

The last U.S. field studies which examined the impact of aircraft noise on sleep were conducted over 15 years ago, and since then there have been substantial changes in air-traffic. In addition, these studies used an insensitive method to measure sleep disturbance. New field studies need to be conducted in the U.S. to acquire current data relative to varying degrees of noise exposure to develop exposure-response relationships and to inform policy. As studies may need to investigate samples around multiple airports it will not be possible to use polysomnography to monitor sleep, as it has a high methodological cost. Instead the use of actigraphy and electrocardiography (ECG), which is cost-effective and will allow a methodologically sound investigation of large subject cohorts, is being investigated. This methodology was implemented in a pilot study conducted around Philadelphia International Airport. Eighty participants were recruited for the study, with three nights of unattended measurements per participant. The primary purpose of this study was to evaluate the feasibility of the methodology. An overview of the study, lessons learned, and a discussion on how the methodology can be further simplified for future studies will be provided.

Keywords: Sleep, Aircraft Noise, Heart Rate I-INCE Classification of Subjects Numbers: 62.5, 66.1

1. INTRODUCTION

The gold standard for measuring sleep is polysomnography which is the simultaneous measurement of the electroencephalogram (EEG), electrooculogram (EOG), and electromyogram (EMG). This method has been implemented in a few field studies on the effects of road, rail, or aircraft noise on sleep (1-4). However, this approach is expensive to implement as trained staff are needed to apply and remove the electrodes. Trained staff is also needed to visually score sleep stages which has both high intra- and inter-rater variability (5). The number of participants in these studies has ranged from 18 to 64 with 2 to 9 nights per participant. A limitation of these studies is therefore the generalizability of the results due to the small sample sizes.

When awakened an individual's heart rate typically increases. Basner et al. (6) previously developed an algorithm for automatically identifying cortical arousals of 3 seconds or longer in duration based on increases in heart rate alone. This algorithm was refined in order to only identify cortical arousals that are 15 seconds or longer in duration (7), which is the indicator of noise induced sleep disturbance most commonly used (8). Agreement between cortical arousals identified visually based on polysomnography data and arousals identified using the refined ECG-based algorithm was evaluated by calculating Cohen's Kappa. An agreement between the two approaches of greater than 0.80 was found which is considered "near perfect" agreement according to conventional standards (9). An advantage of using ECG and actigraphy only for monitoring sleep is that participants can apply the equipment themselves therefore reducing the methodological cost of a study as staff is not needed in the field each night and morning. In addition, the device requires 2 chest electrodes only, compared to the multiple electrodes and wires that are required for polysomnographic sleep measurements which may have an effect on an individual's sleep quality. Also the algorithm that was developed allows arousals to be identified automatically and consistently across studies.

The methodology of using ECG and actigraphy to monitor sleep was implemented in a pilot study that was conducted around Philadelphia International Airport. Eighty participants were enrolled in the

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study, with each participant completing three nights of unattended sleep measurements. The primary objective of this study was to evaluate the feasibility of the study methodology, in particular the quality of data that could be obtained when participants use physiological and noise measurement equipment unattended. Based on the results, the study design is being refined and simplified even further. The goal is to develop an inexpensive yet sound study methodology which can be used to acquire data for developing exposure-response relationships that are representative of noise exposed communities around multiple airports.

2. METHODS

2.1 Study Methodology

The protocol of the pilot study was approved by the Institutional Review Board of the University of Pennsylvania. The measurements took place between July 2014 and July 2015. The study for each participant lasted for three nights and either took place on Monday thru Wednesday night or Tuesday thru Thursday night, depending on the participant's availability. Two staff members went to the participant's home on the first night of the study to explain the study protocol, obtain written informed consent, and setup equipment for monitoring the noise. The study measurements were then completed unattended for the next three nights, with staff members returning after the third night to collect the equipment. Staff members were available throughout the study via cell phones to address any questions or concerns that participants had.

2.1.1 Physiological Measurements

At night the participant's sleep was monitored using one device (eMotion Faros 90) which measured both heart rate and body movement. The device was battery operated and attached with two electrodes to the chest. The ECG was sampled at 1 kHz and the peak of each R-wave was detected and recorded. Movement was also measured using a 3-axis accelerometer at a sample rate of 10 Hz, 14 bit resolution. As movement was recorded with a high resolution, breathing could be detected based on the movement of the chest and it could be determined whether participants had chest movements that would be suggestive of sleep apnea during the night. To examine potential consequences of noise-induced sleep disturbance, each morning participants completed blood pressure measurements using a home monitor with arm cuff. Three consecutive measurements were taken automatically with one minute between measurements.

2.1.2 Environmental Measurements

To monitor the noise in the participant's bedroom, one microphone was setup near the head of the bed. One second 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 an additional sound recorder which saved .wav files of the sounds. Sound recordings during the night were made so that the source of noise events could be determined. A less expensive audio recorder was placed outside near the participant's bedroom window, which also recorded sounds. The purpose of the outdoor recordings was for identification of the noise source. In addition to the noise measurements, temperature, light, and humidity in the bedroom were recorded every one minute throughout the study (T&D Illuminance UV Recorder TR-74UI), as these environmental factors can also affect sleep.

2.1.3 Subjective Assessments

Each morning participants completed a brief questionnaire on their previous night's sleep quality, noise during the night, and their level of fatigue in the morning. Participants also completed four surveys on the first day of the study, three of which were on their sleep and health which included the Health Survey (SF-36) (10), the Pittsburgh Sleep Quality Index (PSQI) (11), and the Horne-Ostberg Morningness-Eveningness Questionnaire (12). The participants also completed a questionnaire with socio-demographic questions. All questionnaires were implemented as web-based surveys and completed using computer tablets.

2.2 Measurement Site Selection

As staff members needed to go to participants' homes as part of the study protocol, airports within proximity of the University of Pennsylvania were considered for this pilot study. Philadelphia International Airport (PHL) was selected due to its proximity and as it had relevant amounts of nighttime flight operations. Predictions of nighttime noise levels were made for PHL using flight operations data for the time period of June 2012 to September 2012. The dataset included radar flight tracks, time of each operation, runway use, and aircraft type. Noise predictions were made for Monday thru Thursday nights during this 4 month time frame, for a total of 68 nights, using the FAA's Integrated Noise Model (INM 7.0d). The total population within each contour was calculated using block level population data from the 2010 US Census. The number of people predicted to be exposed to nighttime noise levels above L_{night} >= 55 dB(A) was estimated to be low (less than 350 for both east and west flow of the airport). On average there was estimated to be approximately 85,000 people living within the 40-45 dB, 44,000 within the 45-50 dB, and 8,000 within the 50-55 dB L_{night} contours. PHL had a sufficient number of nighttime flight operations (on average 130 events between 11:00 pm and 7:00 am) to merit the study being completed, with cargo departure flights between 3 and 4 am.

The target enrollment for the study was 80 participants. Half of the participants were recruited from two areas near the airport. The other half of the participants was recruited from communities without relevant amounts of aircraft noise (control region) in Philadelphia. The control region was selected so that it had similar socio-demographic characteristics as the noise exposed region which was determined based on data from the 2012 American Community Survey as well as similar road traffic levels determined based on yearly traffic counts.

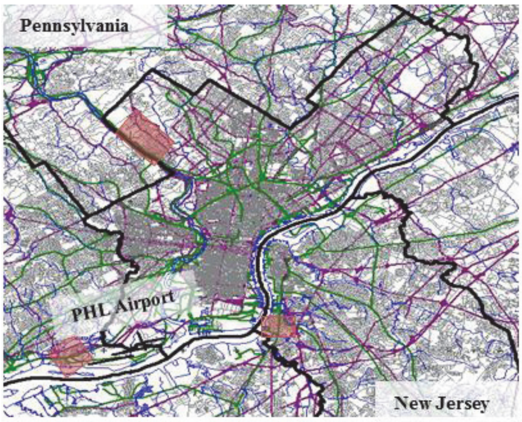

Figure 1-Measurement regions for the pilot sleep study conducted near Philadelphia International Airport. Measurement areas are highlighted in red.

2.3 Participant Recruitment

Three methods were used to recruit participants for this study. The first approach was to go door-to-door. Staff members knocked on the door of every house on a block in the evening hours between 5:00 and 8:30 pm for a total of 35 blocks that had the required L_{night} levels. If household members were not home, a flyer on the study was left hanging on the door. Flyers on the study were also placed throughout the community on public bulletin boards at locations including the post-office, library, and community centers. A total of ten participants near the airport were recruited using these two approaches. Due to the low response, the remaining 70 participants were recruited by mailing flyers to residences. All addresses within eight census tracts were purchased from a commercial vendor. For the control region, addresses were randomly selected from the list of addresses that were obtained. For the communities near the airport, the residents with the highest predicted nighttime noise levels were selected. While the target enrollment of 80 participants was met using this approach the response rate was still low with 3700 flyers mailed to obtain this enrollment.

Individuals interested in taking part in the study were screened over the phone to determine their eligibility. As few selection criteria as possible was used in order to increase response rates and the generalizability of results: participants had to be 21 year or older, not be morbidly obese, have no history of cardiac arrhythmia or history of a sleep disorder including obstructive or central sleep apnea, narcolepsy, restless legs syndrome or periodic limb movement 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.

3. RESULTS

Of the eighty participants that were enrolled in the study, 79 completed measurements. The participants were from 56 different households. Demographic characteristics for the 79 participants are in Table 1. While the mean age of participants near the airport was higher than for the control region, participants from both areas were of a wide age range. The majority of participants in both regions had at least some college education, and the percentage of participants who considered themselves noise sensitive was low in both areas.

Table 1 – Socio-demographic characteristics of participants in the pilot study

	Aircraft Noise Exposed (n=39)	Control Region (n=40)
Age (mean, range)	46, 22-77	32, 22-68
Gender (% Male)	41%	48%
Education Level (% that had at least some college)	67%	90%
Duration of Residence (mean)	11 years	6 years
% Noise Sensitive	13%	10%

The primary objective of this study was to evaluate the quality of data that could be obtained by performing an unattended sleep study. Overall it was found that participants were able to follow the study protocol well. For 93% of the nights there were no missing periods of ECG data due to participants not wearing the device or due to improper use of the device, electrodes, or cables. For 6% of the nights partial ECG recordings were obtained and for only 1% of nights no valid ECG data was recorded. For 94% of the mornings, participants completed all three blood pressure measurements and for 5% of the mornings at least one blood pressure reading was recorded. For 91% of the nights, full sound recordings were obtained with 6% data loss due to either equipment problems or participants failing to turn on the second sound recorder at night. All questionnaires for the study were completed. The surveys were web-based which allowed staff members to verify completion of the surveys in real time and contact participants if the study protocol was not being followed.

4. DISCUSSION

With this pilot study it was verified that participants could complete the physiological and noise measurements unattended. However, the response rate was still low which could limit the generalizability of the results. One contributing factor to the low response rate may be that, while the measurements took place unattended, staff members still had to enter participant's homes to setup and take down the equipment. A website was created with information on the study which allowed individuals to verify both the study and study team. The link for the website was provided on the recruitment flyers. However, despite the website and provided information, potential participants may still have been reluctant to allow unknown individuals into their home.

Another limitation of the study design was the methodological expense. This study required staff to be in the field from 2 to 4 days per week. The need for staff in the field also restricted the airport that could be studied. In addition, the sound recording equipment used for this study can cost several thousand dollars, which restricts the number of devices that can be purchased or available for use, restricts the number of sites that can be studied concurrently, and the total enrollment for the study. The use of portable sound recorders, mobile devices, and microphones developed for these devices should be examined to determine whether there are less expensive options that can provide an accurate measure of the noise, and are easy for participants to use on their own.

Based on the lessons learned, the study methodology is being refined further. A second pilot study will be conducted in which less expensive sound recording equipment will be used and all equipment will be mailed to participants' homes. This study design will eliminate the need for staff in the field, reduce the cost for conducting in-home sleep and noise studies, and hopefully increase response rates and generalizability of the findings.

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