Sleep Quality and Nightly Aircraft Noise: Methods and Preliminary Results of a Long-term Experimental Field Study

Mark Brink[1], Katja Wirth[1], Christoph Schierz[1],

[1] *ETH Zürich, Institut für Hygiene und Arbeitsphysiologie, NW-F83, CH-8092 Zürich, E-mail: brink@ethz.ch*

Introduction

Peoples annoyance reactions to traffic noise are, to a large extent, caused by noise-induced sleep disturbances. Among the different traffic noise sources, aircraft noise poses a specific problem to noise abatement since it can barely be deterred by acoustic barriers. Thus, in the case of air traffic, noise abatement must concentrate on reducing the number of noise events and on optimizing the local and timely distribution of noise such that as few people as possible are affected at times where the health-relevant impact of air traffic noise is as small as possible. To explore the influence of timely distribution in the night, maximum sound pressure level and number of aircraft noise events on sleep quality, an experimental field study among residents in the Zurich Airport area, who are already used to aircraft noise, is being carried out currently. The goals of the study are to assess the magnitude of the aircraft noise problem as referred to sleep disturbance. Special attention is being paid to the times at sleep onset in the evening and before wakeup in the morning.

For noise research in Switzerland, it is the first attempt to not only measure self-reported annoyance as the outcome variable, but to also employ physiological measurements as objective indicators of sleep quality.

Method

Experimental Design

In the current study, 64 subjects are exposed to different combinations of number of aircraft noise events, maximum noise levels and timely distribution of noise during the night. In order to assess long term habituation to nightly aircraft noise, experiments run a full 30 consecutive nights for each subject. This amounts to a total of 1920 nights and 18'944 noise events. To exactly control for the amount and timely distribution of aircraft noise a subject is exposed to each night, we used pre-recorded aircraft noise which was played back through a loudspeaker in the bedroom. Each subject is exposed to the same total amount of noise during the 30 night period and each subject constitutes a complete within-subject experiment using a 2 x 2 x 2 factorial design. The factors/levels are TIME (evening vs. morning), LEVEL (50 vs. 60 dB $_{LAS,\ max}$) and NUMBER (8 flights vs. 16 flights). Each factor combination is administered twice consecutively whereas the first half of the sample (32 subjects) start with noise being played back in the evening (block 1) and the second half start with noise being played back in the morning (block 2). Beside the "noise-nights" two consecutive "zero-nights" (without noise) are introduced in each block. To elucidate the effect of different noise sources, street traffic noise (matching the sound energy of 8 x 60 dB $L_{AS,\ max}$ aircraft noise events) has been added to the design and is played back at two evenings and two mornings. Thus, a total of 24 nights with different kinds of noise including baseline nights without noise are available for analysis. All experiments start with three habituation nights and end with one dishabituation night which are not analyzed. The main experimental plan is based on two Latin squares (30×30) so that (1) each subject is administered all possible treatments and (2) noise treatments are balanced evenly over each of the 30 nights in the whole sample. This setup allows not only for the analysis of individual reaction patterns to noise, but also to assess the general trend of (potential) habituation to noise over the 30-nights experimental period.

Subject recruitment and data acquisition

Subjects were recruited from a large pool of participants from two surveys on aircraft noise annoyance that have been carried out by our institute in the years 2001 and 2003. Originally it was intended to employ a case-controlled approach (balancing age, gender, attitude towards and experience with aircraft noise) to constitute the 64-subject sample based on the data previously gathered in the surveys. But lack of interest turned the recruitment of the subjects into a major problem of the ongoing study and we had to widen the criteria for participants.

Once the subjects agreed on the participation in the study they were subjected to a health screening and a hearing test. After obtaining consent, physiological data acquisition and noise simulation equipment (described in detail in the next chapters) was installed in the subject's bedrooms. Subjects were handed out a "sleep diary" and were instructed on how to fill it out every evening and morning. Physiological data was recorded using a specially designed non-contact method. Concurrently, indoor and outdoor sound pressure levels where recorded continuously as well as temperature, humidity and light intensity in the subject's bedroom. Different outcome variables are being analyzed, such as self reported sleep quality, number of awakenings during the night etc. on one hand and actimetry as well as changes in heart and respiration rate and their variability on the other hand.

Recording of physiological parameters

When it comes to physiology, investigations of the effects of aircraft noise on sleep usually employ either rather complex (polysomnography, PSG) or quite simple (actigraphy) measurement methods. The methods used for field research mostly fall in the latter category, while PSG recordings are usually confined to the lab. We set out to develop a completely new system from scratch meeting the particular needs for field researchers. It should be more sophisticated than actimetry but less complex than PSG, and it should be able to record not only actimetry, but also heart rate, heart rate variability and respiration parameters during sleep in a non-invasive, in other words – contactless manner. The principle of measurement that was found to meet this goal is based on seismic waves (vibrations) originating from the activity of the vital organs (heart and lung) and therefore – as opposed to polysomnography – we termed the method seismosomnography (SSG).

A seismosomnographic measurement system records physiological parameters during sleep by sensing the tiny vibrancies of the body caused by the heartbeat, breathing and body movements. The basic principle of SSG is based on the fact that the human body, even if motionless, exerts vibration energy on an underlying surface (such as a mattress) by the activity of the heart (causing a small displacement of the body due to its rebound at each contraction ("cardioballistic effect")), and the lifting and lowering of the thorax while breathing. These vibrations propagate through the body and are in turn coupled to any surface or object with which the body is in contact. With the possible application of long term field studies of sleep disturbances in mind, we developed a method that is sensitive and reliable enough to detect these vibrations using very sensitive pressure sensors. These sensors are placed under each bed-post and pick up the tiny oscillations originating from the beating heart and the respiratory activity.

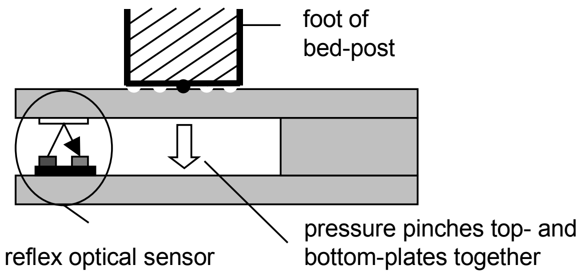

Fig 1: Schematic drawing of a sensor (side view)

Each sensor is composed of a top and bottom aluminum plate with a reflex light barrier in between (Fig. 1). If the plates are pinched together, the voltage output of the light barrier increases and a signal emerges from which a variety of physiological parameters can be derived. From the 4 signals stored for each sample point, a coordinate pair (transverse axis/longitudinal axis) of the current center of gravity of the bed can be calculated. The value of the longitudinal axis, for instance, changes according to the rhythmic pattern of the lifting and lowering of the thorax while breathing, whereas the pattern of the heartbeat is reflected on multiple axes. At each contraction of the left ventricle of the heart, the accelerated blood output into the arch of aorta causes the body to rebound – which in turn changes the center of gravity of the bed for a tiny fraction of time: This displacement is detected by the sensors and results in the signal to oscillate in accordance with the pace of the heart. Since all shifts of the center of gravity are recorded continuously, precise actimetry/actigraphy data can be obtained too.

Simulation of Aircraft Noise

As mentioned before, pre-recorded aircraft noise was played back through a loudspeaker in the bedrooms of the subjects. Outdoor aircraft noise in the vicinity of Zurich Airport has been previously taped on DAT. From these recordings 8 different wave-files (takeoffs and landings, different aircraft types) have been created and filtered to match the indoor-frequency spectrum. A powered (active) speaker with a linear frequency response was connected to the control device's internal audio module to play back the different noise events. For each 30-night session the control device (also recording seismosomnographic data) was programmed to play back the noise events according to the experimental plan either at the beginning or the end of the night, at certain times, with predefined sound pressure levels ($L_{AS,max}$ of 50 or 60 dB). Exact acoustic calibration after the experimental setup in a particular bedroom was accomplished to make sure that each subject was administered the accurate noise levels (at the ear). Then, for each individual installation, the most frequently occurring "switching off the lights" and wakeup-time was determined. According to these specifications obtained from the subjects, the control device was programmed when to start the noise simulations during the night.

Preliminary Results

The ongoing study is still only in its experimental phase and just about half of the 64 experiments have been completed so far. Thus, preliminary results cannot be reported reliably. Fig. 2 shows some sample data obtained from one experimental night with aircraft noise simulation in the morning. It shows a slight increase in heart rate variability and actimetry after the onset of the simulation period.

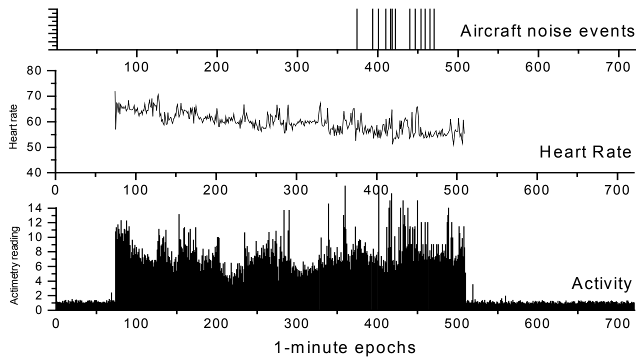

Fig 2: Sleep quality data plotted against time (scaled as 1-minute epochs) from one experimental night with aircraft noise simulation in the morning.

Another analysis of the available data comparing aircraft vs. street traffic noise showed that, contrary to our expectations, subjects judged aircraft noise in the evenings and mornings to be less annoying than street traffic noise.