



## The NORAH-sleep study: effects of the night flight ban at Frankfurt Airport

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### ABSTRACT

As part of the NORAH study the German Aerospace Center (DLR) examined during three measurement periods in 2011-2013 the "Effects of aircraft noise on sleep" around Frankfurt airport before and after the implementation of a night flight ban (11 p.m. - 5 a.m.) in October 2011.

A total of 202 healthy adult airport residents aged 18 to 78 years were investigated at their homes during these three study years. Polysomnograms of 49 subjects in 2011 and 83 subjects in 2012 were recorded for three nights each. In 2013, a total of 187 volunteers were examined for 3 nights with a less expensive method, measuring heart rate and body movements in order to assess vegetative-motoric reactions to noise. In each study year, the sound pressure level and the noise at night were continuously registered at the sleeper's ear.

Exposure-response curves representing the awakening/vegetative-motoric reaction probabilities for an overflight depending on the maximum sound pressure level were calculated for the different years as well as sleep quality parameters for 2011 and 2012. Sleep behavior of two bed time groups (one exposed to aircraft noise in the evening and in the morning, the other just in the morning) were compared.

Keywords: Aircraft Noise, Sleep, Polysomnography, Physiology, Fatigue, Drowsiness, Annoyance  
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### 1. INTRODUCTION

In October 2011 a new runway at Frankfurt Airport, Germany, was put into operation. At the same time, a nightly flight ban between 11 p.m. and 5 a.m. was implemented. Aim of the extensive NORAH (Noise-Related Annoyance, Cognition, and Health) study from 2011-2015 was to survey the impact (health, sleep disturbance, quality of life, mental development of children) of traffic noise on the population in the Rhine-Main area (1, 2). A special focus was on the effects of aircraft noise before and after the implementation of the night flight ban.

Increasing transportation noise during night time has become a major source of sleep disturbances. Therefore, sleep of residents is increasingly disrupted by this noise, because the auditory system

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perceives acoustic stimuli even while asleep and the brain is able to process the incoming stimuli and cause the organism to arouse. The implementation of a night flight ban at Frankfurt airport provided an opportunity to investigate the possible benefit of those noise-free hours at night for residents' sleep quality.

## 2. METHODS

In three measurement periods between 2011-2013 the German Aerospace Center (DLR) examined as part of the NORAH study the "Effects of aircraft noise on sleep" around Frankfurt airport before and after the opening of the new runway in October 2011 and the associated ban of night flights between 11 p.m. and 5 a.m. A total of 202 healthy adult airport residents aged 18 to 78 years were investigated at their homes in these three study years. 49 subjects in 2011 and 83 subjects in 2012 were investigated with polysomnography (PSG) for three nights each. Regarding the number of subjects the NORAH sleep study is to date the world's largest collection of field data measuring the acute effects of aircraft noise on local residents by PSG. In 2013, 187 volunteers were also investigated for 3 consecutive nights with a less expensive method for the detection of body movements and increases in heart rate (so-called vegetative-motoric reactions, VMR) during sleep. 39 volunteers participated in all three years, 36 took part in two years. In 2011, the volunteers went to bed around 10-10:30 p.m. and got up at 6-6:30 a.m. (bed time group 1). In 2012 and 2013, in addition, another group with a one hour later bed time (bed time group 2) was investigated. In all years, the sound pressure level and the the actual noise events were recorded continuously with class-1 sound level meters at the sleeper's ear.

## 3. RESULTS AND DISCUSSION

The results of the sleep study show that with the initiation of the night flight ban and the concomitant reduction of the number of overflights in the considered time period the frequency of awakenings associated with aircraft noise decreased on average from 2.0 per night in 2011 to 0.8 per night in 2012. Thus, an important objective of the night flight ban has been reached.

In 2012 bed time group 2 had an average aircraft noise associated awakening incidence of 1.9 per night. The difference compared to bed time group 1 can be explained by the overlap of the sleep period with early morning high air traffic hours in bed time group 2. Hence, going to bed early (the end of the night overlaps as little as possible with the busy air traffic hours in the morning) had a protective impact.

Exposure-response curves were calculated, representing the awakening probability for an overflight depending on the maximum sound pressure level. The statistical model further included the duration of the aircraft noise event, the number of preceding aircraft noise events, the age of the subjects, elapsed sleep time and background noise level. The probability for waking up due to an overflight with a certain maximum sound pressure level did not differ significantly between the years 2011 and 2012. Considering a background level of 28.8 dB (A) for both years the odds for an awakening increased by 23% per 10 dB(A) increase of the maximum sound pressure level of an overflight. Total sleep duration, sleep onset, sleep efficiency, wake time after sleep onset and the percentage of time being awake after 4.30 a.m. did not differ statistically significantly between the two years. These values did not differ significantly when comparing the two bed time groups in 2012 either.

Subjects who evaluated air traffic more positive showed less objectively measured sleep disturbances. The causality of the relationship, i.e. whether the disturbed sleep results in a negative attitude, or vice versa, cannot be determined.

Subjective drowsiness and fatigue ratings were at an intermediate level in all three study years. Adaptation to aircraft noise, perception of ambient noise in the residential area, age and chronotype of volunteers influenced the drowsiness and fatigue ratings statistically significant. The subjective

experience of sleep worsened statistically significantly from 2011 to 2013 by 5% and 11%, respectively, despite the introduction of the night flight ban, regardless of the aircraft noise exposure. This effect must therefore be attributable to factors. This finding also applies to those subjects who participated in all three years.

An additional survey in 2013 showed a statistically significant effect of the number of overflights and the aircraft noise energy equivalent average sound level of the previous night on the acute nocturnal annoyance. This effect was substantial. There was no statistically significant relationship between long-term aircraft noise annoyance on the one hand and subjective quality of sleep respectively the acute nightly aircraft noise annoyance on the other. The factors "ambient noise perception in the residential area" and "adaptation to aircraft noise" in turn had a statistically significant impact on the acute short-term annoyance.

In the years 2001/2002 DLR carried out a field study with 64 subjects who were investigated for 9 nights each at Cologne / Bonn airport using the same PSG methodology (3). At this airport there were no night flight restrictions at the time. The nightly air traffic was made up of about two-thirds of older cargo aircraft. Results of this study are currently the basis for the calculation of the Frankfurt Night Index FNI.

The NORAH sleep study was not primarily designed to make comparisons with the Cologne-Bonn study (as there were different bed times in both studies; the samples were inherently different despite the same selection criteria for the volunteers; cargo aircraft from 2001 / 2002 differ in sound frequency spectra compared to today's passenger airplanes independent from the maximum levels; the PSG recordings were analyzed by different evaluators). Nevertheless, it is of interest to compare an airport with night flight ban (Frankfurt 2012) with an airport without such a night flight ban period (Cologne-Bonn 2001/2002). Due to a partial data loss in the NORAH measurements in 2011, only the PSG data from 2012 could be used for this comparison. It was found that sleep efficiency, total sleep time and deep sleep time per total sleep time at Cologne-Bonn airport were decreased statistically significantly. Sleep onset, however, increased statistically significantly compared to at Frankfurt Airport in 2012. Rapid-Eye-Movement (REM) sleep time and time awake after sleep onset were not significantly different in the two studies.

The probability of awakening by a flyover noise with the same maximum level was higher in the Cologne-Bonn study than in NORAH 2012 – e.g., at a maximum level of 45 dB (A) it was increased by 5.0%.

Keeping the above mentioned caveats in mind, the results suggest positive consequences of the introduction of a night flight ban for the residents' sleep at Frankfurt airport. It can also be concluded that the exposure-response relationship that was established 2001/2002 at Cologne-Bonn Airport, might not be transferable to Frankfurt Airport with a night flight ban period in a 1:1 fashion. However, as spontaneous awakening probability at Frankfurt Airport was lower than that at Cologne-Bonn Airport, the difference in noise-induced awakening probabilities between the two airports is rather low.

A limitation of both studies is that due to methodological reasons only adult subjects were studied who did not have any disease that influenced sleep. This restricts generalizability of the results to vulnerable groups.

PSG is a very labor- and cost-intensive method which explains the small number of investigated subjects. However, compared to other international field studies using PSG, the NORAH study had the highest number of volunteers so far. In order to realize larger sample sizes with no further increase in effort and budget, a loss of information concerning the measurement of sleep parameters has to be necessarily accepted. For this, DLR together with the University of Pennsylvania (UPenn) developed a method for predicting aircraft noise associated awakenings based on heart rate increases and body movements. NORAH 2011 and 2012 data have been used for further improving this method. In contrast to PSG, this vegetative-motoric method (VMM) has the advantage that an examiner does not have to be present at the subject's home every evening and every morning. Instead, the subjects can

apply the equipment themselves. In addition, data analysis can be carried out fully automatically.

The VMM optimized evaluation model shows that the probability of a vegetative-motoric response as a function of increasing maximum sound pressure levels of overflights and elapsed sleep times increases nonlinearly. This is quite similar to the exposure-response curve for awakening probability using PSG data. Nevertheless, the two exposure-response curves are not identical. The probability of a vegetative-motoric response at the same maximum level of a flyover noise is higher than the corresponding awakening probability. There are several plausible explanations for this. For example, the VMM method sometimes detects shorter activations in the EEG that are not classified as awakenings, but nevertheless may have physiological significance for sleep recovery. The sensitivity of the VMM is therefore higher than that for awakenings derived from PSG. Furthermore, in the model aircraft noise associated awakenings were only considered when the subject was previously in a sleep stage and not awake. This distinction cannot be made in the VMM, which also considers reactions that have occurred in a period of wakefulness. In addition, heart rate accelerations, which are typical for REM sleep, may be misclassified as arousals.

The developed VMM is an appropriate method to describe vegetative-motoric body reactions during sleep due to aircraft noise exposure. It allows, in contrast to PSG, an automated and evaluator-independent analysis of the data. With the same budget a significantly higher number of subjects can be studied than with the PSG method. Taking into account that the VMM measures heart rate accelerations, this method possibly reflects a mechanism which could be causally responsible for cardiovascular diseases, potentially occurring after many years of nocturnal noise exposure. The VMM, however, cannot provide insights on sleep structure (e.g. sleep stage distribution) or aircraft noise associated awakenings as the PSG method does. In principal, one can expect a higher participation rate of local residents for field studies when measuring with the VMM due to the reduced invasiveness.

#### **4. CONCLUSIONS**

Especially those residents at Frankfurt Airport who went to bed early benefited from the night flight ban as reflected in the reduced noise-associated awakening frequency per sleep episode. The probability to awaken from a single noise event did not change, however. Nevertheless, the acute nightly short-term aircraft noise annoyance was high and the subjective experience of fatigue and drowsiness worsened statistically significantly from 2011 to 2013 by 5% and 11%, respectively, despite the introduction of the night flight ban. The vegetative-motoric reaction probability was increased after the implementation of the night flight ban in 2012 to return in 2013 to the original level.

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