A comparison of the effects of night time air traffic noise on sleep at Cologne/Bonn and Frankfurt Airport after the night flight ban

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ABSTRACT

In the STRAIN study (2001/2002) the German Aerospace Center (DLR) measured the sleep of 64 residents (19-61 years) around Cologne/Bonn airport for 9 consecutive nights each with polysomnography. Cologne/Bonn airport has no night time restrictions for chapter 3 airplanes and is one of the busiest airports in Germany during the night.

Frankfurt is the airport with the highest traffic volume in Germany. A night flight ban (11 p.m. - 5 a.m.) was implemented in October 2011. Traffic density during shoulder hours is high. DLR examined 83 Frankfurt airport residents (18-77 years) with polysomnography as part of the NORAH study in 2012. In both studies sound pressure level (SPL) and noise events were recorded with microphones near the sleeper's ear. Participants filled out questionnaires each morning.

The analysis shows that aircraft noise associated awakening probabilities were 3.8-7.5% higher for maximum indoor levels from 30-70 dB(A) at Cologne/Bonn Airport whereas night time aircraft noise annoyance was higher in Frankfurt. The results of both studies are compared, and limitations of the comparisons are discussed.

INTRODUCTION

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 perceives acoustic stimuli even while asleep and the brain is able to process the incoming stimuli and cause the organism to arouse.

Aside from the airport in Leipzig/Halle, Cologne/Bonn is the only airport in Germany with nearly continuous night time traffic due to many cargo operations. The area around this airport is densely populated so that a special focus has to be on residents' sleep and the effects of the nocturnal aircraft noise. In 2001/2002 the German Aerospace Center (DLR) initiated the field study STRAIN (Study on human Response on Aircraft Noise) investigating the aircraft noise effects on residents' sleep [1].

The airport with the highest traffic volume in Germany, Frankfurt airport, however has a nightly flight ban between 11 p.m. and 5 a.m. which was implemented in October 2011. Nevertheless, the "shoulder hours" from 10-11 p.m. and 5–6 a.m. are still quite busy and there are even areas around the airport where residents perceive the noise from two runways.

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 [2, 3, 4]. A special focus was led on the effect of the night flight ban on residents'sleep.

Night noise regulations in Germany up to now define protection zones for the night mainly by the energy-equivalent noise level, enhanced by NAT (numbers above threshold) criteria. In 2006 DLR proposed a night noise concept for the airport Leipzig/Halle [1], limiting additional aircraft noise induced awakenings by less than one per night. This criterion led to larger night protection zones around the airport than defined in the Air Traffic Noise Act. The data basis for this protection concept was the result of the STRAIN field study and an exposure response curve relating the maximum noise level of an aircraft noise event and the probability of an awakening. The additional aircraft noise induced awakenings of the night are then the sum of all probabilities of every aircraft noise event of the night.

A comparison of the exposure response curves of the STRAIN and NORAH 2012 field data now allow to analyse if the probability to awake from one aircraft noise event differs comparing an airport with continuous night time traffic to an airport with a night flight ban and being busy in the shoulder hours.

METHODS

The STRAIN field study was carried out in 2001 and 2002 with 64 residents near Cologne-Bonn airport. Subjects were investigated for 9 consecutive nights, each period starting on Mondays. They were selected in a multi-level process, and were between 19 and 61 years old (average: 38 years). 56 % of the participants were female. Sleep was measured by means of electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG), Electro-cardiogram (ECG), respiratory movements, finger pulse amplitude, position in bed and actigraphy were sampled continuously during the night. With the EEG, EOG and EMG signals (called polysomnography, PSG), sleep then was classified into different sleep stages according to Rechtschaffen and Kales [5]. The time of bed of the subjects was in so far restricted that they had to be in bed between midnight and 6 a.m and were not allowed to get up later than 8 a.m.. Results of this study currently represent the basis for the calculation of the Frankfurt Night Index FNI.

In the NORAH sleep study, three measurement waves were conducted between 2011-2013 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, in 2011 and 2012 subjects were investigated with polysomnography (PSG), while in 2013 an alternative method was applied measuring heart rate and body movements. For the comparison in this paper, the 2012 PSG data are used, measured 8-11 month after the implementation of the night flight ban. In 2012 83 airport residents (18-77 years, 60 % female) participated in the study, measured for 3 consecutive nights each. Each measurement period started on a Monday. The subjects could choose between bed time group 1 (42 subjects) from 10-10.30 p.m. to 6-6.30 a.m. (with aircraft noise at the beginning and the end of the sleep period) and bed time group 2 (41 subjects) from 11-11.30 p.m. to 7-7.30 a.m. (with aircraft noise only at the end of the sleep period).

The polysomnographic data of the STRAIN study were visually scored by several investigators whereas the NORAH data were scored by just one different evaluator according to the rules of Rechtschaffen and Kales. In both studies the first night was included in the data analysis in order to avoid a possible first-night effect in the analysis.

In a morning questionnaire in STRAIN and in NORAH (only in year 2013) subjects were asked to rate their acute nocturnal annoyance using the ICBEN five-point scale [6].

Subjects in both studies had to be free of intrinsic sleep disorders, cardiac insufficiencies and had to have normal hearing thresholds according to their age.

Sound pressure level and every noise event were recorded continuously with class-1 sound level meters at the sleeper's ear both studies. In the analysis, every noise event was marked and commented by an evaluator. Event-correlated analysis in both studies included all undisturbed aircraft noise events ANEs (no other noise was present during the overflight) using a random effects logistic regression model taking into account repeated measurements for the same subject. The models included the maximum sound pressure level and the duration of the aircraft noise event, the number of preceding aircraft noise events, the energy-equivalent noise level during one minute before the aircraft noise event (i.e., background level), elapsed sleep time, current sleep stage, and the age of the subject. Awakening was defined as a transition from the current sleep stage to S1 or Awake.

Both study protocols were approved by the local ethics committee (Ärztekammer Nordrhein). Subjects were instructed according to the Helsinki declaration, gave written informed consent, participated voluntarily, and were free to discontinue their participation at any time without explanation.

RESULTS AND DISCUSSION

The NORAH sleep study was not primarily designed to make comparisons with the STRAIN study at Cologne-Bonn airport (as there were e.g. different bed times in both studies). However, both studies had identical polysomnographic and acoustical methodology, except the guidelines for the time in bed were more restrictive for the subjects at Frankfurt Airport than for the subjects at Cologne-Bonn airport. Nevertheless, subjects of both studies spent nearly the same duration in bed with an average of almost eight hours. The subjects at Cologne-Bonn airport slept significantly less during this time than the subjects of bedtime 1 (-17.6 min, $p < 0,05$) and 2 (-16.7 min, $p < 0,05$) at Frankfurt airport. This result is also reflected in the mean sleep efficiency (Total Sleep Time / Time in bed) of 87% (Cologne/Bonn), 90% (Frankfurt, bed time 1) and 91% (Frankfurt, bed time 2). The sleep efficiency of many subjects of Cologne/Bonn airport was below the mean of 87 %, so that their overall sleep quality cannot be regarded as “quite good” [7].

The sleep onset latency in Cologne was significantly prolonged to bed time group 2 in Frankfurt (5.2 min) resp. (3.8 min, not significant). The accumulated time awake from falling asleep to getting up proved not to be significantly different as also there were no significant differences found for the REM sleep durations. Residents at Cologne/Bonn airport, however, showed a significant ($p < 0,05$) lower percentage of deep sleep divided by the total sleep time (14% compared to 25% (bed time group 1) resp. 24% (bed time group 2) in Frankfurt. The duration of deep sleep is an important factor for the overall recovery during sleep.

Subjects at Cologne Bonn airport were exposed to more ANEs per night than the subjects at Frankfurt airport. They had significantly more aircraft noise associated awakenings than the subjects of both bed time groups in Frankfurt. Subjects at Cologne/Bonn airport woke up in 9.8% of the overflights, whereas subjects in Frankfurt woke up in 6.9% (bed time group 1) resp. 8.1% (bed time group 2) of all overflights.

The sleep data from the two studies were combined to test if the probability to awake due to an ANE differed between the two airports. Therefore, a multivariable logistic regression model with random effects was employed, corresponding to the model that was used for the Frankfurt Night Index and the Zurich Aircraft Noise Index [8]. It can be shown, that the modeled probability of awakening between the two airports differs. It was found that the modeled awakening probability was 3.8-7.5% higher for maximum indoor levels from 30-70 dB(A) at Cologne/Bonn airport than for Frankfurt airport. However, on the assumption that the spontaneous awakening probability at Frankfurt Airport is presumably lower than the one at Cologne-Bonn airport, the remaining difference for the modeled aircraft noise-induced awakening probability is low.

Miscellaneous reasons are conceivable to explain the differences in the macrostructure of sleep and the probability of awakening due to an ANE. The aircraft noise pattern at Cologne/Bonn airport was fundamentally different from the one in Frankfurt. The flight movements occurred essentially during two periods in the night, between 11 p.m. – 1 a.m. and 3 a.m. – 5 a.m.. The increased occurrence of ANEs at the beginning of the night could have prevented the subjects from going to deep sleep stages as a result of an increased number of awakenings. This is supported by the results of the macrostructure analysis and could have led to an increased probability to awake during an ANE.

As already described, the statistical model adjusted for several acoustics and sleep parameters. However, the complexity of the noise pattern (i.e. the temporal distribution of ANEs with different sound pressure levels and their interaction) is difficult to parameterize. It has also been reported that the frequency spectra of the ANEs could play a role for the probability of awakening [9]. During the Cologne/Bonn study 2001/2002 mainly older generations of freight aircraft were in use, which usually came along with a more unfavorable frequency spectrum than for those aircraft that were flying at Frankfurt Airport in 2012.

In addition, the fact that sleep stages were visually scored by different investigators is another potential reason for the observed discrepancies in sleep macrostructure and exposure – response functions. Visual sleep stage scoring is known to be prone to both inter- and intra-observer variability [10, 11]. The observed difference in awakening probability of 3.8-7.5% translates to ca. 1 additional awakening out of 20 scored aircraft noise events, which could be explained by inter-observer variability. While the NORAH study was visually scored by only one evaluator, the Cologne-Bonn study was analyzed by several different evaluators. The evaluators used the same criteria for sleep evaluation [5], but due to the ten year period between the two studies, they were not specifically trained for the highest possible degree of consensus. Whereas the stage Awake shows the highest correlation between different evaluators (> 80%), it is known that the evaluation of stage S1 and deep sleep shows a higher variance in different evaluators. As a result, the observed differences in the reported deep sleep and awakening probabilities could have been significantly lower when evaluated by only one evaluator.

Some of the differences in the probability of awakening could also be due to random differences in the study sample, which was not conducted under the specific requirements of a matching. However, since the samples of both studies were very similar from their age as well as from their gender structure, this probably only plays a minor role.

As field studies with a complex study design are very costly, the number of subjects that can be examined are limited. However, exposure response curves of both studies show reasonable confidence intervals which is a good argument for the precision of the data. It should be mentioned that 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. Due to methodological reasons only healthy adult subjects were studied. This, of course, restricts generalizability of the results.

An additional survey in 2013 in the NORAH study showed a 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. Comparing the acute nocturnal annoyance exposure response curve to the results of the STRAIN study in 2001/2002, it can be found that annoyance in Frankfurt was up to four times higher in Frankfurt despite the night ban. This effect was substantial. In the NORAH study the factors "ambient noise perception in the residential area" and "adaptation to aircraft noise" in turn had a significant impact on the acute short-term annoyance.

CONCLUSIONS

The sleep of residents near an airport with a night flight ban (Frankfurt airport, 2012, night ban: 11 p.m. - 5 a.m.) was compared to the sleep results of a field study at an airport with many cargo flights throughout the night (Cologne/Bonn airport, 2001-2002). In both field studies sleep was measured by means of polysomnography. Exposure response curves for aircraft noise associated awakening probabilities were 3.8-7.5% higher for maximum indoor levels from 30-70 dB(A) at Cologne/Bonn Airport. However, as spontaneous awakening probability at Frankfurt Airport was presumably lower than that at Cologne-Bonn Airport, the difference in aircraft noise-induced awakening probabilities between the two airports is rather low.

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