Effects of Nocturnal Aircraft Noise - Overview of the DLR Human Specific Investigations

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Abstract [497]   OBJECTIVES Studies on the effects of aircraft noise on sleep with a large subject sample as well as with high methodological expense are lacking, and hence statistically reliable recommendations for the protection against aircraft noise can presently not be made. However, scientifically based investigations are necessary for providing proper guidelines for authorities and users. METHODS DLR studied human reactions to nocturnal aircraft noise in laboratory and field experiments: In total, 192 healthy volunteers (m/f), aged 18 to 65 years, underwent 2240 study nights. In the isolation facility of the institute, 128 subjects were examined during 13 consecutive nights. 16 subjects served as control. For 112 subjects, aircraft noise events have been applied between 4 and 128 times per night ($45 \leq L_{AS,max} \leq 80$ dB(A)). Sleep disturbances were assessed by EEG, EOG, EMG and EKG, by respiration, finger-pulse amplitude and position in bed. These signals were simultaneously recorded with the acoustic signals for calculating event-correlated reactions. The concentrations of cortisol, adrenalin and noradrenalin were determined from all night urine samples. At evening and morning, performance tests and questionnaires (fatigue, mood, annoyance) were applied. These data and results were examined in two field studies with 64 volunteers during 9 consecutive nights at their homes near Cologne airport. CONCLUSIONS The investigations will be concluded in March 2004. They are very ambitious and unique, even on a world wide standard. DLR wants to contribute by profound experimental knowledge to the very controversial disputes about the degree of impairing effects on human specific reactions to nocturnal aircraft noise.

1 INTRODUCTION

The steady increments of air traffic volume in the past are very likely to continue in the future. The big aircraft manufacturers estimate a global growth of 5% per year for passenger air traffic and of 6% per year for cargo within the next 10 to 15 years. The number of starts and landings will presumably double. In the past, the noise sensitivity of residents living close to airports has increased. It can be expected that with the growth of aircraft operations, the tolerance to such increments will further reduce, if the noise emissions cannot be substantially abated.

Although good knowledge is available on the annoying effects of aircraft noise [1], the impact of aircraft noise on human physiology and performance is much less clear. Particularly, investigations into human sleep by classic polysomnographical methods are rare and were performed with small subject samples and led to divergent results. Studies on human specific influences of aircraft noise with large numbers of subjects as well as a high methodological expense are necessary in order make statistically reliable recommendations for the protection against aircraft noise, since scientific

investigations are the basis to provide proper guidelines for authorities and users, and technical advances for noise abatement procedures. Therefore, the DLR-Institute of Aerospace Medicine has been investigating the influence of nocturnal aircraft noise on sleep, subjective well-being and performance since 1999. These investigations are performed within the frame of the DLR project "Quiet Air Traffic" in which a catalogue of different measures is developed to significantly reduce aircraft noise.

2 METHODS

The human specific reactions to nocturnal aircraft noise were studied in laboratory and field experiments (i.e. at the subjects' homes). In total, 192 healthy volunteers underwent 2240 study nights during these studies.

2.1 Laboratory Studies

The first group of 32 subjects was studied in 1999, the second in 2000 and the third in 2001, followed by the last group of 32 volunteers in 2003. The age of subjects (males and females) was between 18 and 65 years (mean 38 years). In the isolation facility of the institute, 128 subjects were examined for 13 consecutive nights. 16 subjects served as control, i.e., they did not receive any aircraft noise. For the other 112 subjects, aircraft noise events have been played back between 4 and 128 times per night with maximum sound pressure levels between 45 and 80 dB(A). This corresponds to an equivalent sound pressure level between 30 and 53 dB(A) within the interval of eight hours of sleep. Occurrences of sleep disturbances (primary effects of aircraft noise) are assessed by electrophysiological parameters containing the electro-encephalogram (EEG), electro-oculogram (EOG), electromyogram (EMG) and electro-cardiogram (EKG), respiration, finger pulse amplitude and position in bed. These signals have been recorded together simultaneously with the acoustic data in order to calculate event-correlated reactions.

As possible further effects of aircraft noise on sleep, the concentration of electrolytes (potassium, sodium, magnesium, and calcium) and stress hormones (cortisol, adrenalin and noradrenalin) were determined from all night urine samples. Aliquots were if required acidified, immediately deep frozen for their respective determination of the concentrations of these hormones. Potassium and sodium were analyzed by ion-selective electrodes, calcium and magnesium by measuring their complexes photometrically. Catecholamines were analyzed by standard high performance liquid chromatography (HPLC) and electrochemical detector. Free cortisol analysis was done by a radio immuno assay (RIA) for laboratory studies I, III & IV, whereas a linked enzyme immuno assay (LEIA) cortisol kit was used in study II. From concentrations and collection periods mean flux rates (absolute and relative) for the appropriate stress hormones resulted. Statistical analysis was done by SPSS version 10.0.7 using tests for non-parametric pairs, and independent samples. We compared flux rates and respectively, equivalent sound pressure levels, maximum sound pressure levels and frequencies of aircraft noise events.

To investigate secondary effects of aircraft noise on human sleep, 24-h recordings of subjects′ activity, several computerized performance tests in the evening and in the morning were conducted, as well as questionnaires were applied with respect to fatigue, well-being, mood and annoyance. The four performance tests consisted of a "*Single Reaction Task* (SRT)" [2], two "*Memory Search Tasks*" (MST, of 4 and 6 letters, respectively) and an "*Unstable Tracking Task*" (UTT)" [3] with three minutes test time each, with the exception of SRT (10 min, in order to assess vigilance). Before subjects entered the facility, they intensively trained these four tests (at least 32 training sessions). In the SRT, a three digit running stopwatch (time in ms) suddenly appears on the blank screen of the test computer at random intervals. As soon as the subject hits the response key, the stopwatch shows the achieved reaction time for three seconds before the screen turns blank again

for the next trial. During the MST, a single letter appears on the monitor and the subject has to decide as quickly as possible if this is one out of the set of letters (4 or 6) which the subject had to memorize at the beginning of the test. The time of response and its correctness are recorded. The UTT is used to examine the dexterity by means of testing hand eye coordination. The task within this test is to keep a bar, which is unsteadily moving on the monitor to the left or to the right, in the center of the monitor controlled by a joystick. During this test the mean of deviation of the moving bar from the center of the monitor is recorded. All tests were performed in the same order at the same time in the morning (after getting up) and in the evening. In the morning each subject filled in questionnaires on individual's night sleep and subjective noise sensations as well as on fatigue, well-being, mood and annoyance [4-6]. Annoyance due to nocturnal aircraft noise was evaluated using a 5-point rating scale ranging from "1 = not annoyed" to "5 = very annoyed".

Moderators like age, sex, and degree of annoyance by nocturnal aircraft noise prior to the studies were considered in the statistical analyses of the data.

2.2 Field Studies

In the field studies, 64 volunteers aged 19-61 (mean age: 38) were investigated between September 2001 and November 2002 in the vicinity of Cologne Airport, which is one of Germany's airports with the highest number of nocturnal starts and landings. Each subject underwent a period of 9 consecutive nights.

Principally, all methods used in the laboratory, were also employed in the field. However, acoustical monitoring was performed outside (in 2 m distance from the window of the sleeping room), and inside the sleeping room near the sleepers ear: One meter (outside) recorded actual sound files when the external sound pressure level exceeded the external background noise by 4 dB(A) and triggered one meter inside; another inside meter recorded actual sound files when the internal sound pressure level exceeded the internal background noise by 4 dB(A).

3 RESULTS

Since the results of the acoustical recordings [7] and the findings with respect to sleep and sleep disturbances [8] will be reported elsewhere in the proceedings of this congress, this paper concentrates on the outcome of the investigations concerning stress hormones, performance and subjective ratings.

3.1 Stress Hormones

It is impossible to present all results of the stress hormones analyses in detail here. We restrict ourselves to the most relevant aspects and refer to the final report [9]. The stress model accepted in general assumes a reaction chain. The stressor "noise" is perceived and processed cerebrally, followed eventually by a secretion of hormones like catecholamines (adrenalin, noradrenalin) or cortisol. These hormones may lead to electrolyte shifts on the sub cellular level especially changing magnesium and calcium concentrations. Until recently, urine samples from all night collections were taken for the analyses of stress hormones, and this method was adopted for the current study [11].

Electrolytes: The nocturnal excretion rates of potassium, sodium, magnesium, and calcium were determined. A balanced food control, however, was not ensured in the evenings. A statistical significant relation with nocturnal aircraft noise is not detectable. There is a difference between excretion rates obtained in the laboratory and in the field. All mean excretion rates of electrolytes are increased under laboratory conditions.

Adrenalin: Adrenalin excretion rates in all night urines are unchanged with night aircraft noise. They remain on extremely low levels. Under laboratory conditions, the adrenalin concentrations are below detection limit (1 ng/ml) in more than 2/3 of all collected urines, under field conditions in roughly ½ of all samples. There are no statistically relevant secretion rates that differ from those without aircraft noise.

Noradrenalin: Noradrenalin excretion in all night urine samples is statistically analysed constant and not influenced by nocturnal aircraft noise. There are no changes depending on the equivalent noise level $L_{AS,eq}$, nor the maximum noise pressure $L_{AS,max}$, nor the number of events. No difference is observed between results taken from the laboratory and the field (see figure 1). Also the elapsed number of investigated nights does not depend on a potential influence of noise on the excretion of noradrenalin.
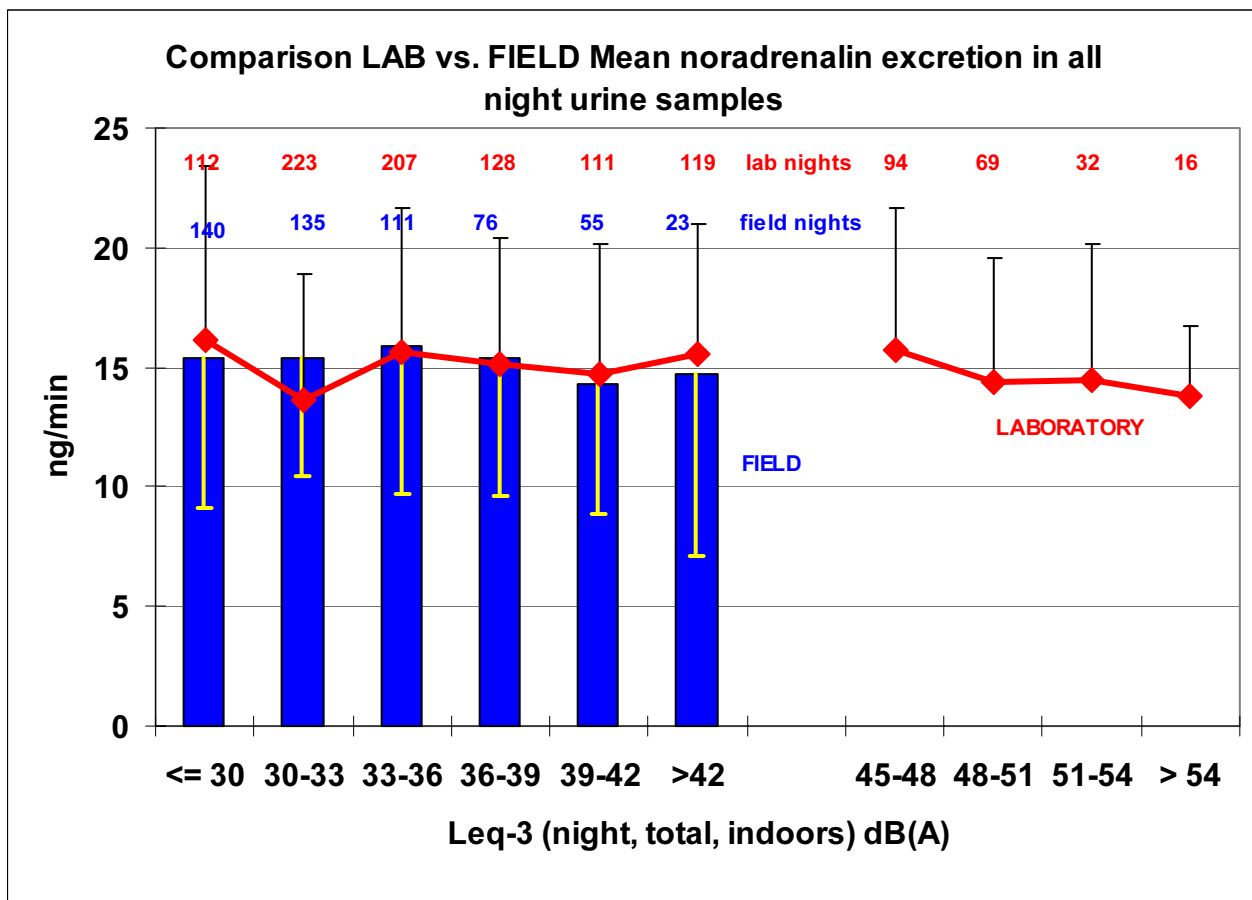

Figure 1: *Mean noradrenalin excretion (± SD) in urine collected all night under laboratory conditions (n = 112, no control groups, experimental groups only, bold line) and under field conditions (n = 64, bars) separated by equivalent noise levels classes of 3 dB(A).*

Cortisol: During the laboratory studies a change of determination methods occurred. Thus, absolute results from this single study phase are not immediately comparable. Under laboratory conditions the excretion rates of cortisol are influenced by noise. There is a significant trend (Jonckheere test) depending on maximum noise pressure $L_{AS,max}$ and the number of noise events. Also with increasing equivalent noise levels $L_{AS,eq}$ a significant trend is shown (figure 2). At the same time, however, a trend of increasing cortisol excretion is detectable with the time of investigation in the laboratory without any noise. These trends are not observed in the field. Since cortisol excretion shows a pronounced circadian rhythm, this property has to be taken into account, especially during

the field studies. On the weekends, cortisol excretions are considerably higher: this is not a matter of increased stress by aircraft noise (since air traffic was low during weekends) but rather of much longer mean sleeping times (mean waking-up times on Saturday/Sunday: 07:48 h; on all other days: 06:11 h). Therefore, for the comparison of cortisol excretion under laboratory vs. field conditions only those nights are included when latest wake-up times are 07:00 h; this pattern corresponds with the laboratory study design. However, the mean wake-up time in the field is approximately 50 min earlier than in the laboratory. From this fact alone a difference between lab and field results is predictable, due to the circadian rhythm of the cortisol excretion, which is highest in the early morning. The figure 2 shows the mean excretion rates of cortisol from laboratory and field studies obtained by identical determination method and exclusion of nights, when subjects slept longer than 07:00 h. Results show a significant difference between laboratory and field conditions, where results from the laboratory are elevated.
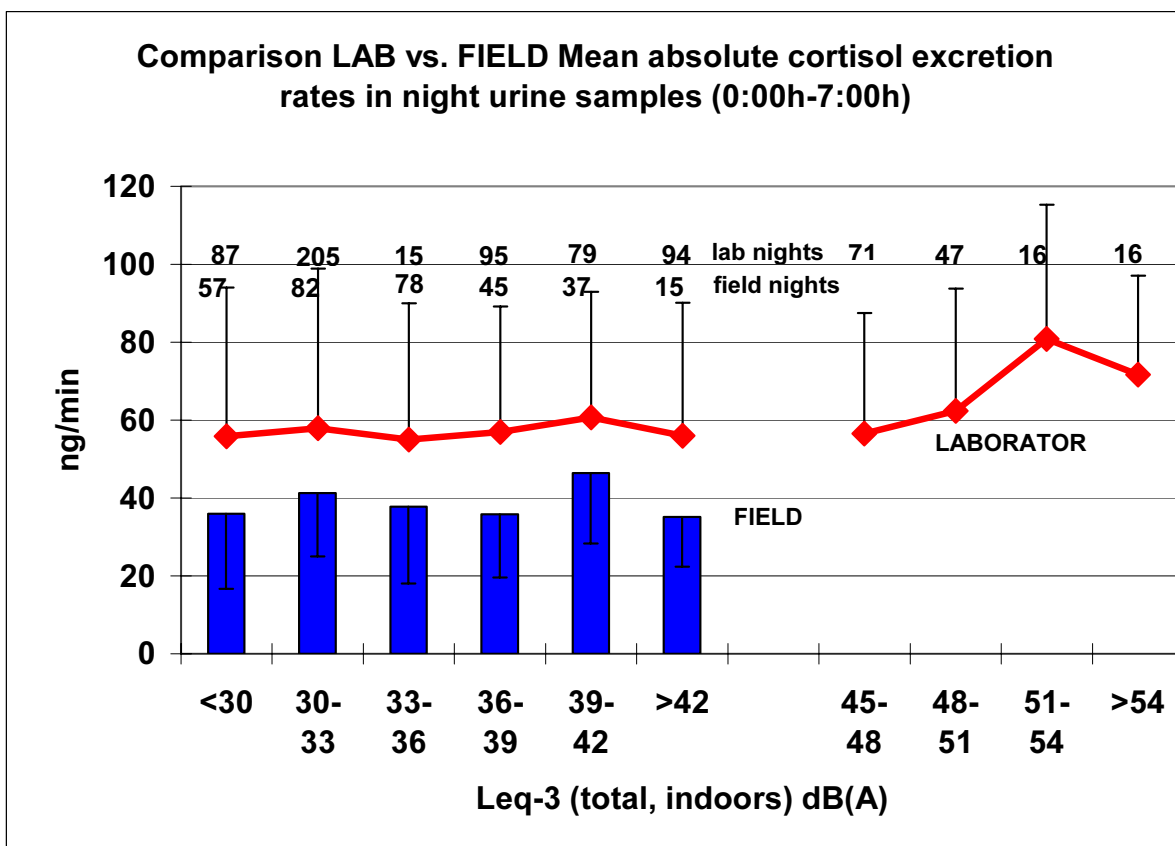

Figure 2: *Mean cortisol excretion (± SD) in urine collected all night under laboratory conditions (n = 88, only experimental groups with identical determination method, no control groups, bold line) und under field conditions (n = 64, wake-up time before 07:00h, bars) separated by equivalent noise levels classes of 3 dB(A).*

The study of the stress hormones and electrolytes does not exhibit unambiguous results. Especially, the excretion rates of electrolytes and catecholamines did neither show changes with various noise conditions (neither equivalent noise level $L_{AS,eq}$, nor maximum noise pressure $L_{AS,max}$, nor number of events), nor are there any differences between laboratory and field conditions. Possibly a single measure for the entire night is too insensitive to shed light on minute and short time excretions of catecholamines during the complete nocturnal phase. From the literature contradictory results are reported [12]. Electrolyte determinations from all night urine samples are futile, unless a controlled and balanced intake of food and beverages is ensured. Any possible mobilisation of

electrolytes by stress hormones under noise are covered by renal regulation of the electrolytes after food and beverage intake during dinner and the evening. Cortisol is a parameter that correlates by trend with noise, but only under laboratory conditions. The influence of cortisol's endogenous circadian rhythm aggravates a final conclusion. If subjects wake-up on weekdays much earlier, as they do in the field, lower excretion levels of cortisol are detected and a correlation with nocturnal noise is not observed. The significant difference between laboratory and field results is partly founded on this fact. Additionally, high noise events, as applied in the laboratory, were not recorded under field conditions. They simply did not occur in the field. The trend of increasing cortisol levels with time of investigation in absence of any noise (as observed in the laboratory control group) has to be taken into account as well. An explanation might be a prolonged sleeping time in the laboratory in contrary to the subjects' homes and usual sleeping habits, and the consecutively earlier onset of endogenous secretion (and excretion) in the morning. To obtain more reliable data several samples taken during the night are indicated. For the current study, however, special attention was focused on sleep without additional intrusions by investigators, and exclusively on sleep which may be disturbed by noise events.

3.2 Performance

All monitored performance parameters show a substantial difference between morning and evening sessions due to a distinct circadian variation. The results of the four test were usually better in the evening than in the morning. Since an influence of noise events on sleep could be mainly expected on the morning data, they are subject of this report. Like for cortisol excretion rates, the morning sessions during weekends of the field data were not considered in the analysis, because of long sleep durations and late wake-up times a strong circadian influence existed.
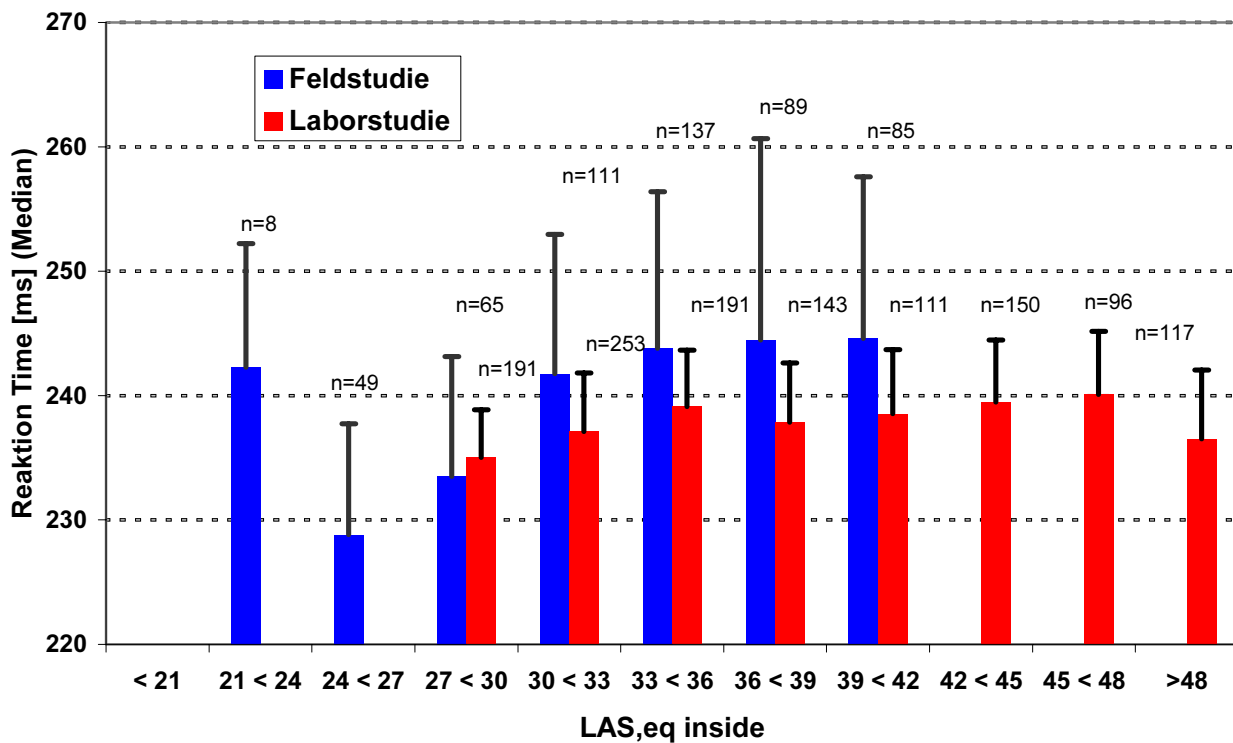

Figure 3: *Reaction time of SRT (median, 95% confidence interval) separated by equivalent noise levels classes of 3 dB(A): N=112 (laboratory), N=64 (field).*

The single reaction task (SRT) [2] enables a basal estimation of performance capability. In this test, a running stopwatch (in ms) is presented on a computer screen at irregular intervals and the subject has to react as fast as possible; the reaction time is counted and presented. This simple task primarily requires alertness and vigilance. Prolonged reactions reflect reduced concentration and elevated sleepiness. One result of the SRT is presented in figure 3. Generally, averaged reaction times were between 230 and 245 ms. Deviations from the median were high due to the inhomogeneous subject sample (with respect to age and gender). A relation between nocturnal noise strain and prolonged reaction times is not observable and statistically not found.

The memory and search task (MST) examines mental capabilities by comparing symbols in a choice and reaction test. In contrast to SRT a decision has to be made before using different reaction keys. With respect to the Sternberg paradigm a group of letters is presented in the preparation phase, these letters have to be recalled during the test. In this study, a group of either 4 or 6 letters was used. After start of the test, a letter is presented which can be "true" or "false" with respect to the 4 (or 6) previously learned letters. The next letter is shown immediately after a response (whether correct or not). With increasing numbers, the reaction time increases simultaneously. The task is directed to the functioning of the work- and short time memory. The mean reaction times in the morning sessions of this study were about 500 ms (4-letter MST) and 560 ms (6-letter MST), respectively. The variation was 20 – 30 ms. The results of this study did not show any prolongation of reaction times as a response to nocturnal aircraft noise.
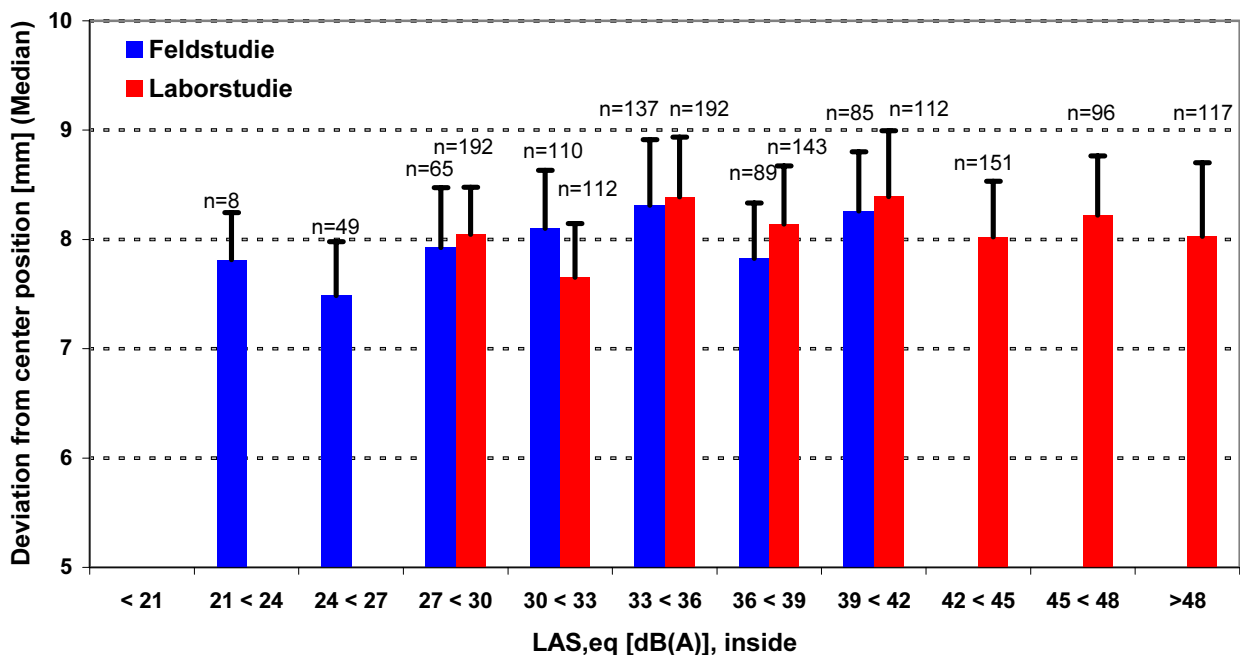

Figure 4: *Deviation (RMS) of the UTT (median, 95% confidence interval) separated by equivalent noise levels classes of 3 dB(A): N=112 (laboratory), N=64 (field).*

In the unstable tracking task (UTT) a cursor which appears in the center of a computer screen and is shifted by the computer program to the right or left, has to be kept in the center by a joystick. The distance from the center (root mean square RMS in mm) and the loss of control (at the horizontal edges of the screen) is recorded. This task studies the coordination auf eye and hand as well as the dexterity; it is typical for an operator task in technical systems. The results of this tests is illustrated in figure 4. Median values (RMS) are in a range between 7.5 mm and 8.5 mm and are located in the

deviation interval of about 0.5 mm. As for the other performance tests, a significant change with increasing aircraft noise during the preceding night was not detected.

The described results do not indicate relevant effects of nocturnal aircraft noise events on the performance as investigated in this study. Since the results from sleep research of this study show a non-significant reduction of total sleep time under the noise condition [8], a significant influence on performance in the next morning could be not expected. Since the presented data are average values of all subjects, a separated analysis of data from those volunteers who were especially sensitive to noise events may be useful. Furthermore, an analysis of data from this subject sample with respect to the number of noise induced awakenings may elucidate a subtle elevated vulnerability on performance.

3.3 Psychology

Psychological effects of nocturnal aircraft noise were investigated by the different questionnaires concerning subjective sleep quality, fatigue, mood, stress and recuperation as well as annoyance [5, 6]. These parameters were analyzed in relation to the exposition to nightly aircraft noise (in terms of maximum noise pressure $L_{AS,max}$, equivalent noise levels $L_{AS,eq}$, and number of events).
Significant dose-effect curves were not found for following psychological parameters: sleep quality, fatigue, mood, and stress and recuperation. However, annoyance – the main psychological variable for noise effects – a significant relation between dose and effect was detected under laboratory as well as under field conditions by using the method of logistic regression with random effects (EGRET software, version 2.0.31). For the generation of a dichotomized dependent variable of annoyance, the categories 3 to 5 of the 5-scale questionnaire of annoyance were condensed ("annoyed"), and the categories 1 and 2 ("not annoyed"). Since only 20% of the responses of the laboratory study and 4% of the field study fell in the categories 4 and 5 (figure 5), a further analysis of the "highly annoyed" [10] was not performed.
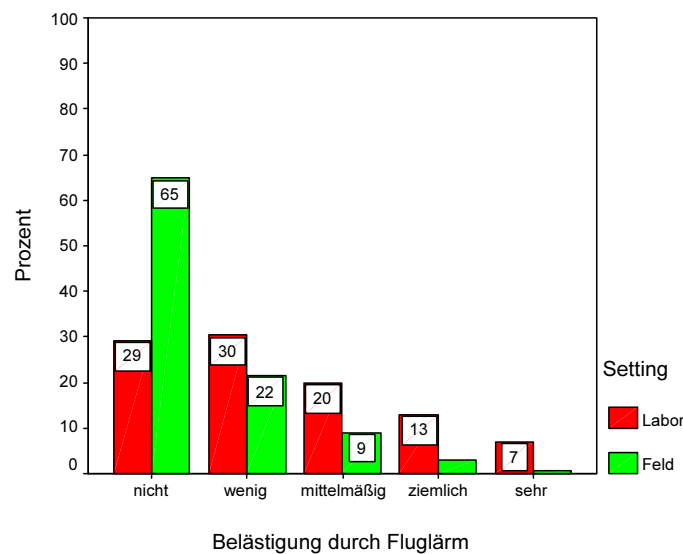

Figure 5: *Distribution of annoyance responses (Question: "How strong were you annoyed by aircraft noise during the last night?") in the laboratory (N=112) and the field (N=64). Categories are "not at all" (nicht), "little" (wenig),"moderate" (mittelmäßig), "strong" (ziemlich) and "extreme" (sehr).*

The dose-effect curves of annoyance are shown in figure 6, separately for the laboratory and field investigations. In these curves personal moderators (e.g. age, gender, noise sensitivity) and those which were related to aircraft noise specific aspects (e.g. ratings concerning health effects, attitude towards air traffic), were considered and examined with respect to their significance. The curves indicate that annoyance increases with elevated noise load. Furthermore, the dose-effect curve from the laboratory specific investigations lies substantially (and significantly) above that from the field specific investigations. At the lower end of the presented scale, the predicted amount of annoyed people is nearly the same (12% to 15%). At the far end, 30% of the field population are annoyed, whereas in the laboratory population this proportion is 70%. Thus, the subjects in the laboratory were significantly more annoyed than those in the field.
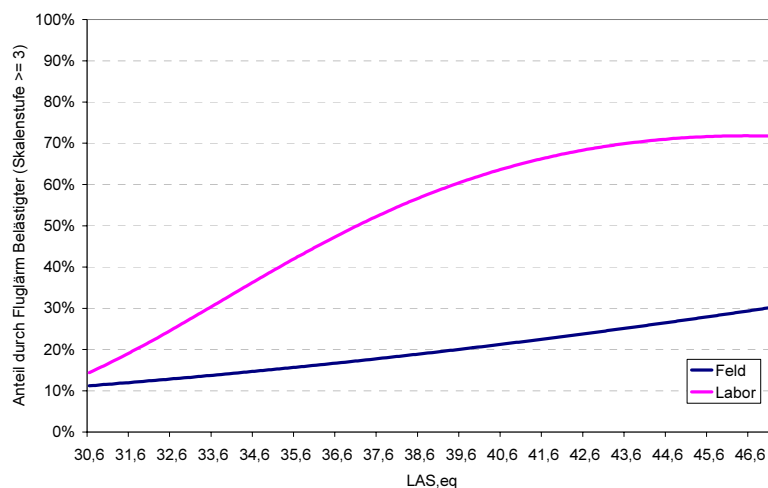

Figure 6: *Predicted proportion of by aircraft noise annoyed people under field and laboratory conditions, depending upon equivalent noise levels LAS,eq ("at sleeper´s ear").*

Subjects living and sleeping in their own familiar environment is one reason which may explain the differences found between the laboratory and the field conditions. The findings of the sleep research of this investigation which showed similar results [8] support the conclusion that the nocturnal aircraft noise scenarios encountered in the field have much lesser effects than those experienced in the laboratory.

4 SUMMARY

The DLR-Institute of Aerospace Medicine investigated various physiological and psychological effects of night aircraft noise on a large population. This investigation was conducted with 192 subjects in 2240 nights. Laboratory and field studies were performed using the same extensive and expensive methods, including acoustical, polysomnographical, biochemical, and psychological methods as well as performance tests. This and complementary [7, 8] papers give an overview of the study design and methods and summarize the main findings.

ACKNOWLEDGEMENTS

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