
Noise Assessment and Control: Paper ICA2016-157

NORAH (Noise Related Annoyance, Cognition, and Health): Questions, designs, and main results

Rainer Guski^(a), Maria Klatte^(b), Ulrich Moehler^(c), Uwe Müller^(d), Anja zur Nieden^(e), Dirk Schreckenberg^(f)

^(a) Ruhr-University Bochum, Germany, rainer.guski@ruhr-uni-bochum.de

^(b) Technical University Kaiserslautern, Germany, klatte@rhrk.uni-kl

^(c) Moehler+Partner AG, Munich, Germany, ulrich.moehler@mopa.de

^(d) Deutsches Institut f. Luft- und Raumfahrt, Cologne, Germany, uwe.mueller@dlr.de

^(e) Inst. f. Hygiene u. Umweltmedizin, Giessen, Germany, Anja.z.Nieden@hygiene.med.uni-giessen.de

^(f) ZEUS GmbH, Hagen, Germany, schreckenberg@zeusgmbh.de

Abstract

The German multidisciplinary research project NORAH (Noise Related Annoyance, Cognition and Health) was aimed at providing a broad and scientifically reliable description of the effects of air, road and rail traffic noise on the health and life quality of residents in the vicinity of airports. Ten scientific institutes participated and performed surveys, secondary health data analyses, sleep quality registrations, blood pressure registrations, and special tests on children at school. Main results: 1. At all four airports studied, the percentage of persons highly annoyed by air traffic noise at comparable noise levels was larger than would be expected from the so-called "EU standard curves" [1]. 2. With respect to cardiovascular health risks, the effects of rail and road traffic noise on heart failure, myocardial infarction, and stroke were more clearly seen as compared to the effects of aviation noise. 3. There was no statistically significant increase of self-registered blood pressure values with increasing L_{pAeq} for the evening and night-time for transportation noise. 4. Night-time sleep of residents showed a diminished number of aircraft associated awakenings with the introduction of the night curfew at Frankfurt Airport for a group being in bed during 22:00-22:30 hrs until 06:00-06:30 hrs. The probability of awakening due to a single aircraft event, however, did not change before and after the night curfew. 5. Multilevel analyses revealed a significant linear association between aircraft noise levels at school and decreasing reading performance in second graders. A one month delay in reading was observed for an increase in noise levels by 10 dB L_{pAeq} .

Keywords: Noise, health, annoyance, exposure-response

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1 Introduction

In view of the enduring conflict situation about expansion plans at Frankfurt Rhine/Main International Airport, located in the German county of Hesse, the parliament of Hesse performed an expert hearing about noise effects in 2010, and declared at the end, it would support a large multidisciplinary research project on the effects of traffic noise, and the airport company, together with the airline Lufthansa and 8 local communities joined the group of financial supporters. Common workshops discussed the research questions, and a formal European call for proposals was published, won by a team of 11 scientific groups made up of acousticians, psychologists, medical doctors, and statisticians. This team gave their common project “Noise Related Annoyance, Cognition, and Health”, NORAH. The research took place between 2011 and 2014; and the main reports were published 2015 in German (see www.norah.de or www.laermstudie.de). An abridged summary report will be published there, too. The present talk will give a short overview of the studies undertaken.

2 Research questions and methods

The multidisciplinary research project NORAH generally aimed at providing a broad and scientifically reliable description of the effects of air, road and rail traffic noise on the health and life quality of affected residents. The following content areas were considered: annoyance and quality of life (module 1), health (module 2, including blood pressure regulation, cardiovascular diseases, breast cancer, depression and sleep disturbances) as well as cognitive development of school children (module 3). Where possible, effects of the changes due to the start-up of a new runway at Frankfurt International Airport were considered, as well as the implementation of a night curfew between 23:00 and 05:00 hrs and the rerouting of flights.

The primary research questions were

1. Are the noise effects in the Rhine-Main region in principle, comparable with those in other German regions, and what influence road, rail and air traffic noise has on the population?
2. Which influence had the changes in airport operations in autumn 2011 on the quality of life in the environs of the airport? Especially, does the annoyance expressed by the residential population near airports in expansion situations differ from that expressed by people near steady-state (or “low-rate change”) airports?

Within the area of the three major groups of studies (modules), the major research questions were:

1. Module 1 ("Annoyance and quality of life")
 - a. Are well-known exposure-response relationships between acoustic and psychological variables, i.e. the so-called European Standard Curves for residential annoyance [1], still up to date? This question relates to all three types of transportation noise (aircraft, road, and rail).
 - b. How does the high-rate change of Frankfurt Airport (a new runway, the rerouting of flights, and a night curfew) influence the annoyance judgments, reported sleep disturbances, and reported quality of life of the residents in the Rhine-Main region?
 - c. Which effects have the combinations of two transportation noise sources (aircraft plus road, and aircraft plus rail) on the total annoyance of residents?
 - d. What are the statistical relations between noise annoyance and judgments about the health related quality of life?
 - e. How are personal, social and situational factors related to the effects of transportation noise?
2. Module 2 ("Health") generally asked to which extent chronic noise from air, rail and road traffic has an influence on the health of the persons concerned – particularly on the adult residents of the Rhine-Main region. The general research question was split up into three different research areas: Secondary data-based case-control study with detailed survey on health risks, "
 - a. The secondary data based case-control study investigated the effects of chronic acoustic exposure to noise from road, rail and air traffic on the health of the residential population in the Rhine-Main region. The study focussed on cardiovascular diseases (myocardial infarction, heart failure, stroke), mental illnesses (in particular unipolar depressive episodes) and cancer (especially breast cancer in women) as they are registered in the accounting and prescription data of health insurance companies.
 - b. The additional detailed survey assessed the significance of important confounders – here in particular the health behaviour (e.g. body mass index, smoking, alcohol) and social status. To do this, the risk estimates without consideration of these important confounders had to be compared with the risk estimates with consideration of these confounders registered in the survey. This comparison allows important statements on the extent and direction of possible distortions of the traffic noise-related risk estimates in the (exclusively) secondary data-based case-control study; the detailed survey thus allows more reliable statements on the level of the "true" risk estimates in the secondary data-based analysis. A secondary question of the detailed survey asked for the comparison between cardiovascular diseases and traffic noise-related indoor noise levels and outdoor levels.
 - c. The sub-study "Blood Pressure Monitoring" generally asked whether there is any relation between chronic noise exposure to any of the three transportation noise sources and chronic blood pressure. It was assumed that a chronic traffic noise exposure leads to a higher rate of disease, complaints and measurable physical reactions in the area of the autonomous nervous system which are reflected in the

- blood pressure level. This is based on the fact that cardiovascular diseases are closely linked with blood pressure regulation.
- d. A further question related to the influence of chronic acoustic exposure to transportation noise on the overall cardiovascular risk and the closely linked 10-year heart attack risk.
 - e. The "Sleep Study" was exclusively related to the disturbance of sleep due to actual night-time overflights from Frankfurt Airport. A main question was whether the formerly established exposure-effect curves compiled for air traffic related wake-up reactions from Cologne/Bonn could be transferred to airports with different night-time operations. Unlike the other sub-studies of the NORAH joint research project, "exposure" here refers primarily to the acute acoustic exposure to air traffic noise measured in the bedroom of the residents in the proximity of the airport.
 - f. The sleep study further asked, whether the exposure-effect curves for air traffic noise-related wake-up reactions at Frankfurt/Main airport changed over the course of time between 2011 and 2012. In October 2011 changes in the nocturnal operations of the airport came into effect (introduction of the night flight curfew and partial shifting of flight movements to the daytime or night-time shoulder hours), and this is why measurements of sleeping patterns were carried out before and after the operational changes.
 - g. In connection with the operational changes at Frankfurt Airport, the question arose as to whether these had a different or similar effect on the sleep of people who habitually go to bed or get up relatively early or relatively late. A third aim was, therefore, to compare the air traffic noise-related wake-up reactions at Frankfurt Airport between persons who go to bed earlier or later and get up accordingly earlier or later.
 - h. A further question of the sleep study was if and how the complicated polysomnography (PSG) could be replaced by a more simple method, and still allows the analysis of air traffic noise-related wake-up reactions in a larger number of persons with the exclusive measurement of the electrocardiograph (ECG) and the body movements.
3. Module 3 ("Cognitive development and quality of life of children") concentrated on chronic aircraft noise effects on the acquisition of reading skills and the development of reading-relevant speech skills as well as the quality of life of primary school children who were exposed to acoustic burdens due to air traffic noise both at school and at home.
- a. The most important question was whether there are exposure-response effect relationships between the extent of the contemporary chronic aircraft noise exposure at Frankfurt Airport and various cognitive development parameters or measures of the quality of life of the children.

According to the research questions, different **methods** were applied. In the case of noise annoyance and quality of life, systematic surveys were conducted: a telephone panel study made up of three waves between 2011-2013 in the area of Frankfurt Airport, cross-section

studies in the vicinity of the airports Cologne/Bonn, Berlin-Schönefeld, and Stuttgart. Cross-section studies were also carried out to compare the effects of road, rail and air traffic noises and on the combination of air and road traffic and air and rail traffic noise.

In the case of cardiovascular health risks, breast cancer, and depressive episodes, a secondary data-based case-control study with detailed survey was performed in the administrative district of Darmstadt, the rural districts of Mainz-Bingen and Alzey-Worms, as well as in the cities of Mainz and Worms.

With respect to the long-term effects of traffic noise on blood pressure regulation, daily self-administered blood pressure measurements were registered for three weeks in two waves (2012 and 2013) with residents in the vicinity of the Frankfurt Airport ("blood pressure monitoring").

In order to study the short-term effects of night-time air traffic noise on the sleep of residents, sleep quality investigations were carried out in the years 2011-2013 in the homes of residents in the vicinity of Frankfurt Airport.

The effects of chronic exposure to aircraft noise on the cognitive performance and quality of life of school children near Frankfurt Airport were studied by means of performance tests (especially reading tests) with children, as well as surveys with children, parents, and teachers.

Address-specific equivalent continuous sound levels of different reference times for air, rail and road traffic noise were available for all study participants (except for participants in the sleep study where the participants' own measurements were used) (to some extent, maximum levels as well as the numbers of loud events) and were used in the evaluations.

3 Main results

1. At all four airports studied, the percentage of residents highly annoyed by air traffic noise was larger than would be expected from the curves [1] presented by Miedema & Oudshoorn (2001) at comparable noise levels. In the vicinity of Frankfurt Airport, in 2011 (before the implementation of a new north-west runway) higher annoyance responses were observed than during a comparable survey performed in 2005 [2]. The annoyance response increased in 2012 (after the implementation of the new runway), and decreased marginally in 2013. In the cross-sectional studies, it turned out that aviation noise was associated with higher noise annoyance than with road or rail traffic noise at comparable long-term levels. The height of road and rail noise annoyance was very similar at comparable noise levels. In the cross-sectional studies on noise combinations (aviation plus road traffic noise, or aviation plus rail traffic noise) it was observed that the total annoyance followed mainly the aircraft noise-related annoyance.

2. With respect to noise-related health risks, the largest risks connected to the 10-dB level increase were observed for unipolar depressive episodes – statistically significant with all three traffic noise sources. With respect to cardiovascular health risks, the effects of rail and road traffic noise on heart failure, myocardial infarction, and stroke were more clearly seen as

compared to the effects of aviation noise. Road traffic noise showed the highest (statistically significant) risk increase per 10-dB level increase with depressive episodes (4.1%), myocardial infarction (2.8%), heart failure (2.4%), and stroke (1.7%). Rail traffic noise showed the highest (statistically significant) risk increases with a 10-dB level increase on depressive episodes (3.9%), heart failure (3.1%), and stroke (1.8%). Air traffic noise showed the highest (statistically significant) risk increases with 10-dB level increase on depressive episodes (8.9%), and heart failure (1.6%). However, it should be mentioned that the linear function does not fit optimally for aircraft and railway noise. The use of indoor noise levels partially showed a statistically significant increase of health risks, as compared to outdoor noise levels, but it should be kept in mind that indoor noise levels were estimated rather roughly. Breast cancer showed a statistically significant association with aviation noise levels during the night (23-05 h).

3. Residents who were exposed to long-term aviation noise levels <40 dB but had night-time maximum levels >50 dB, showed higher health risk estimates – statistically significant with respect to stroke and heart failure. Results of this type indicate that the consideration of night-time maximum levels may be relevant for estimating the health risks of aviation noise. On the other hand, such results need further tests from independent studies.

4. The mean systolic and diastolic blood pressure values of residents increased slightly (statistically not significant) with increased aircraft noise levels. Railway noise levels showed a slight (statistically not significant) increase of the systolic blood pressure. There was no statistically significant relation between traffic noise levels and pulse frequency, blood pressure amplitude, hypertension, and 10-year heart attack risk (PROCAM-Score).

5. The sleep study showed a diminished aircraft noise related probability of physiological night-time awakening associated with the introduction of the night curfew at Frankfurt Airport for a group being in bed during 22:00-22:30 hrs until 06:00-06:30 hrs. On average, the number of awakenings decreased from 2.0 to 0.8 (2011 vs. 2012). This shows that the curfew had a positive overall effect on sleep. In general, there was a significant effect of the number of aircraft noise events on the number of aircraft noise-related awakenings which lead to a fragmentation of the sleep (diminished continuity), without shortening the total sleep time. In a second group, being in bed from 23:00-23:30 hrs until 07:00-07:30 h, an average aircraft noise-associated awakening frequency of 1.9 was observed in 2012. The difference to the former group is due to the longer time (one hour) of aircraft noise exposure in the morning hours. At background noise levels of 28.8 dB(A), the odds of awakening increased by 23 % with an increase per 10 dB increase of the maximum level of an aircraft overflight. Total sleep time, sleep latency, sleep efficiency, waking time after falling asleep, and the percentage of waking after 04:30 hrs did not differ statistically significantly between 2011 and 2012.

6. Persons with a positive attitude towards air traffic did show less (objectively) measured sleep disturbances. The direction of causality is unclear, i.e., the question whether a disturbed sleep is due to negative attitudes to air traffic, or the other way round, could not be determined. The (subjective) evaluations of the residents with respect to sleepiness and tiredness in the

morning are in a medium range in all of the three groups observed between 2011 and 2013. The self-assessed habituation to aircraft noise, the loudness of the residential area, the age as well as the chronotype of the participants all show a statistically significant influence on the individual assessment of sleepiness and tiredness. The subjective assessment of a good sleep diminished in spite of the introduction of the night curfew statistically significantly between 2011 and 2013 by 5 % and 11 % respectively, independently of the aviation noise exposure. This effect is also true for those participants who took part in all of the three measurement waves. This effect is probably due to factors not assessed in the study.

7. In the child study a statistically significant decrease of reading performance was observed with increasing aircraft noise levels: a one-month retardation of reading performance was observed for a 10 dB increase of the equivalent continuous sound level. The teachers in highly exposed schools concordantly report about considerable disturbance of the classes by aviation noise. In addition, there were statistically significant connections - although of lower effect size - between equivalent continuous sound levels and less positive assessments of the physical and mental well-being and children's attitudes towards school.

Seen from an interdisciplinary perspective, two parallel results seem remarkable:

1. Medically diagnosed depressive episodes show the strongest increase with increasing aircraft noise levels, and self-assessments of mental quality of life (Mental Component Summary (MCS), including depressive tendencies) were lowest in the panel group expecting or experiencing an increase of noise levels in 2011-2013.

2. Both the physiological sleep measurements and the survey on annoyance and quality of life found an improvement of sleep through the night after the implementation of the night curfew during 23:00-05:00 hrs, although the night-time equivalent sound level $L_{pAeq,22-06h}$ decreased by only 0.6 dB between 2011 and 2012 in the panel sample. At the same time, both studies showed an increase of negative evaluations of the participants with respect to the morning time (e.g. disturbances of late sleep, tiredness and sleepiness).

4 Conclusions

The NORAH joint research project is one of the largest research projects ever undertaken in Germany on the subject of noise impacts. Even in the international comparison it is a very large project, and similar, subject to some restrictions, to the "Health Impact Assessment" [3] carried out 1992-2005 before and after the opening of the fifth runway in Amsterdam-Schiphol. The expectations prevailing in the state of Hessen and in Germany as a whole are accordingly high and diverse. Even though it is clear that no single project can fulfil all of the possible demands, the NORAH team is certain that they have made a major contribution towards our understanding of the effects of air, road and rail traffic noise. In terms of their objectives and research questions, the studies are more extensive and more diverse than earlier investigations, and the care taken in planning, execution and analysis is (also thanks to the Scientific Advisory

Board for Quality Assurance) exemplary. Special credit is also due to the care with which the acoustic exposures to the three traffic types were calculated on a precise, address-specific basis for all of the participants of all of the sub-studies (with the exception of the sleep study, which had its own acoustic measurements).

NORAH covered more than the four largest areas in which the World Health Organization [4] sees potential for the impairment of health due to environmental noise: sleep disturbances, annoyance, cardiovascular diseases and cognitive development of children. The NORAH Study added breast cancer and depression as "end points". A wide range of questions was processed in each area, including, in particular, the question as to the exposure-effect relationship between the noise exposure levels and the level of the effect.

Acknowledgments

The NORAH study was granted by the "Umwelthaus" (Kelsterbach), a 100 % daughter of the county of Hesse.

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