

NORAH – Study on Noise-Related Annoyance, Cognition and Health: A transportation noise effects monitoring program in Germany

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INTRODUCTION

Since the announcement of the expansion of Frankfurt Airport (including the construction of the 4th runway) in 1998 there have been discussions among stakeholders including but not limited to the health-related effects of aircraft noise in relation to other noise sources.

In order to get more insight into the effects of transportation noise in general (not only aircraft noise) the state-owned Environment & Community Center (ECC) of the Forum Airport and Region (FFR) commissioned the authors of this contribution to develop and conduct a noise effects monitoring program at Frankfurt Airport and comparative studies at other German airports. The objectives of this study, called NORAH study (Noise-Related Annoyance, cognition and Health) are to investigate

- noise annoyance and health-related quality of life (HQoL): Aircraft noise annoyance and HQoL before and after the opening of the 4th runway in comparison to annoyance and HQoL at other airports; comparison of HQoL and annoyance

due to aircraft, railway and road traffic noise; effects of combined transportation noise exposure on annoyance and HQoL;

- effects of transportation noise on hypertension and cardio-vascular diseases including the relationship between noise exposure, noise reactions, and health effects;
- effects of transportation noise on hypertension and cardio-vascular diseases and the causal structure of noise exposure, noise reactions, and health effects;
- effects of changing nocturnal noise exposure at Frankfurt Airport on sleep;
- noise effects on cognitive performance and HQoL in children.

The study started in April 2011 and is initially projected for three years. In this contribution the concept and methods of the monitoring program are presented.

BACKGROUND AND WORKING MODEL

Environmental noise, particularly transportation noise, is one of the main environmental burdens in modern society. According to the World Health Organization (WHO 2011) the core outcomes of environmental noise in terms of disability-adjusted live years (DALYs) are sleep disturbance, annoyance, cardio-vascular diseases, and cognitive impairment in children. The health-related effects of long-term exposition to environmental noise are regarded as an example of the distress-inducing impact of environmental burden. According to noise-related stress models (e.g. van Kamp 1990) the above mentioned noise effects are interrelated and can be understood as parts of the distress-inducing process. When imposed demands of an environmental stressor (noise) exceed the ability of the individual to cope with it this results in acute psychological and physiological strain (Henry & Stephens 1977; Lazarus & Launier 1978). Perceived control, noise annoyance, cognitive impairments, and sleep disturbances going along with physiological reactivity are well-known stress reactions to noise (Westman & Walters 1981). On a long-term level, the chronic imbalance between demands due to noise and coping abilities may trigger the risk of health problems, in particular cardiovascular diseases including hypertension, coronary heart disease, and myocardial infarction, but the epidemiologic evidence is limited and the underlying pathophysiological mechanisms require further investigation (Babisch 2006; Babisch & van Kamp 2009).

The effects of environmental noise are co-determined by personal (e.g. noise sensitivity, age), attitudinal (e.g. attitudes toward the source and authorities), and situational factors (house insulation, window position length of exposure) (Guski 1999). These non-acoustical factors are assumed to affect the perceived control and the ability to cope with noise, and, finally, may contribute to further stress-related health effects (Hatfield et al. 2001). The NORAH study aims to improve the understanding of these causal paths. It includes longitudinal elements in terms of prospective panel studies as well as a retrospective case-control study combined with an analysis of insurance data linked with data on transportation noise of previous years.

The impact of noise gets even more complex when a change in noise exposure emerges as it is the case at Frankfurt Airport with regard to the upcoming airport expansion. After the opening of the new runway, the number of operations increases stepwise from current capacity of 83 to 120 flight movements per hour estimated for the year 2020. Besides changes in the number of flyovers, the airport expansion includes the relocation of flight paths and the implementation of active noise control measures (optimized approach and departure procedures) in order to minimise the

aversive effects of aircraft noise. It is well known that reactions to changes in noise exposure, in particular noise annoyance, cannot be predicted by exposure-response functions obtained under steady-state conditions (Brown & van Kamp 2009). Often an excess in noise responses relative to those under steady-state conditions is reported (change effect). However, because within the context of the airport expansion multiple changes occur, partly with contradictory effects on noise exposure, it is almost impossible to formulate any hypothesis on the extent of any change effect or adaptation process in noise reactions of residents living in the vicinity of Frankfurt Airport.

Concerning noise effects on children, in several studies noise-related impairments of HQoL and cognitive performance were found (Haines et al. 2001; Hygge et al. 2002; Stansfeld et al. 2005). It is assumed that underlying basic linguistic functions (phonological awareness and working memory) and speech perception are affected by noise, leading to impairments in reading performance (Klatte et al. 2010). In this study, it is intended to follow up on the West-London study (Haines et al. 2001), the RANCH study (Stansfeld et al. 2005), and the Munich Airport study (Hygge et al. 2002) and to assess the effects of aircraft noise on reading skills, episodic memory, and attention. With regard to HQoL in children, only few studies with inconsistent findings exist (e.g. Bullinger et al. 1999; van Kempen et al. 2010). To get more insight into the relationship between transportation (in this study: in particular aircraft) noise exposure, cognitive performance and HQoL as well as environmental quality of life (EQoL) in children, several complementary outcomes of noise will be assessed within the NORAH study.

METHODS

NORAH includes three main work packages with a total of 11 longitudinal, case-control and cross-sectional sub-studies (see overview in Table 1).

Table 1: Work packages (WP) and sub-studies of the NORAH study

WP	Sub-study		Source (primary , secondary)	Study type	N	Year		
						2011	2012	2013
1: Annoyance & HQoL	1.1	Rhine-Main Panel	air , road, rail	LS	7,000	X	X	X
	1.2	BBI Panel	air , road, rail	LS	5,000		X	X
	1.3	Steady-state 1	air , road, rail	CSS	2,500			X
	1.4	Steady-state 2	air , road, rail	CSS	2,500			X
	1.5	Rhine-Main road	air, road , rail	CSS	2,800		X	
	1.6	Rhine-Main rail/road	air, road, rail	CSS	3,200		X	
	1.7	Rhine-Main combi	air-road; air-rail	CSS	2x 1,200		X	
2: Health effects	2.1	Sec. analysis & CCS	air, road, rail	CCS	~ 2 Mio / 24'000		X	
	2.2	Blood pressure	air , road, rail	LS	2,000		X	X
	2.3	Sleep quality	air , road, rail	LS	40 to ~400 EEG-ECG	EEG	ECG +Acti	ECG +Acti
3: Children	3.1	Cognition & HQoL	air , road, rail	CSS	1,000		X	

LS = longitudinal study; CSS = cross-sectional study; CCS = case-control study; BBI = Berlin Brandenburg International

WP1: Annoyance and HQoL

WP1 includes longitudinal and cross-sectional telephone surveys on the effects of transportation noise on annoyance, disturbances and HQoL, in addition with reported diagnosed health diseases and sleep quality. For the address of each participant the

source specific exposure to aircraft, railway, and road traffic noise will be calculated on the basis of a detailed acoustic source and propagation model. The study population at each investigated airport includes all residents living within the 40 dB(A) envelope contour of the equivalent sound levels of aircraft noise for day and nighttime.

The main sub-study of WP1 is the **panel survey in the Rhine-Main area**. It focuses on the effects of aircraft noise before and after the opening of the new runway (in October 2011). Residential areas within the study area will be selected with aircraft noise as the predominant noise source and rail and road traffic as secondary sources. Initially, three annually repeated measurements are planned to study the development of noise reactions and possible adaptation to the changes in aircraft noise exposure. The first measurement takes place before the opening of the 4th runway, the second measurement 12 months, and the third measurement 24 months after the opening. A stratified random sampling procedure with aircraft noise exposure (L_{Aeq}) before the opening of the runway and predicted changes in exposure after the opening (3 categories: higher, lower, no change) as strata will be applied. Based on a power analysis and accounting for drop outs an initial sample size of 7,000 participants is intended for the first measurement. In the following years, the panel sample will be restocked to 5,000 participants for each measurement. This allows controlling for bias effects due to repeated measurements. The questionnaire for the telephone interviews includes questions on annoyance and disturbances due to aircraft, road and railway noise, health-related quality of life, diagnosed health diseases, coping to noise, noise sensitivity, attitudes towards the sources, and authorities, the perceived fairness of the procedure or the air traffic (noise) management, housing condition, insulation, etc., and socio-demographic characteristics.

Comparative studies will be done at three other airports. One airport, which is also in a change situation (expansion from a regional airport to an international airport), is Berlin Brandenburg International (BBI) with an expected opening in summer 2012. This airport has been chosen for a comparative study in order to replicate temporal trends in noise annoyance or any change-effect in annoyance found at Frankfurt Airport at an airport in another stage of planning and extent of expansion. Two other – not yet nominated – German airports under steady-state condition will be included for further comparison. At BBI Airport two repeated measurements will be done in 2012 and 2013 before and after the opening of the expanded airport (initial sample size: $n = 5,000$). At the other two airports, cross-sectional surveys will be carried out in 2013 with a sample of about 2,500 participants at each airport.

Whereas in the panel study the focus is on aircraft noise, in the same study area residential zones with either predominant road or railway noise, respectively, will be selected for two **cross-sectional studies on the effects of railway as well as road traffic noise**. The aim of these studies in addition to the panel study is to get source-specific exposition-response curves for annoyance and disturbances for all three modes of transportation. Altogether 6,800 participants are targeted for both cross-sectional studies on railway and road traffic noise. The last sub-study in WP1 focusses on the **effects of combined noise from different transportation noise sources** (aircraft combined with either railway or road traffic noise). For this, the data of the previously mentioned sub-studies in the Rhine-Main area will be supplemented by data from areas of the same study region, where residents are exposed to two noise sources (air/road, air/railway) of similar noise levels. That is, altogether, the

effects of combined noise will be analyzed against variations of the dominance and noise level of the different transportation noise sources.

In all sub-surveys adapted versions of the questionnaire for the Rhine-Main panel survey will be used.

WP2 Health effects

WP2 studies health effects of transportation noise in more detail and includes the following three complementary studies: (1) an analysis of health insurance data of residents in the target area around Frankfurt Airport combined with a case-control study to investigate the relationship between noise exposure and adverse health outcomes such as incident cardio-vascular disease, depression, and breast cancer; (2) a longitudinal study about effects of aircraft noise on blood pressure, and (3) a longitudinal study about effects of nocturnal aircraft noise on sleep.

For the **analysis of health insurance data** ('claims data') of residents in the Rhine-Main area, data from health insurance funds about ambulant and inpatient diagnoses of diseases as well as drug prescriptions will be linked with address-related exposure to noise from aircraft, railway, and road traffic. It is expected, that claims data of about 2 Million insurants will be available for the period from 2000 to 2008/2009. The analysis will focus on identifying the relative risk of cardio-vascular diseases, cancer, and depression for aircraft, railway, and road traffic noise.

NORAH will extend previous secondary data analyses (e.g. Greiser et al. 2007; Greiser & Greiser 2010) on the relationship between aircraft noise and adverse health outcomes by linking secondary data with primary epidemiological data, by focussing on incident cases, and by aiming to estimate the noise exposure for each individual over time. Previously, Greiser and colleagues have also utilized secondary data to investigate the health effects of aircraft noise in the Cologne-Bonn Airport study (Greiser et al. 2007; Greiser & Greiser 2010). In this study the authors estimated the relative risk for health effects of aircraft noise in logistic regression models adjusted for road and railway noise exposure and demographical and socio-economic confounders on an individual and aggregate level. Greiser and colleagues reported an association between nocturnal aircraft noise levels and cardio-vascular diseases, stroke and – only for women – depression. However, information about confounders particularly important for cardio-vascular diseases, such as tobacco consumption, cholesterol level, blood pressure, physical training, body mass index (BMI), and diabetes was not available in the Cologne-Bonn Airport study due to using claims data alone. NORAH WP2 will **combine the analysis of insurance data with an analytic case-control study** focusing on myocardial infarction, cardiac insufficiency, and stroke. Incident cases and a control group without known cardio-vascular disease will be defined on the base of the insurance data. Power analyses indicated that for each disease entity 6,000 persons have to be investigated (total sample size: 24,000 insurants; 3x 6,000 cases, 1x 6,000 controls). The insurance companies will be asked to send questionnaires to the insurants identified as cases and controls. The questionnaire includes questions on social status, tobacco and alcohol consumption, BMI, history of residential living and occupation (last 10 years), life style, stress and life events, house insulation, sleep quality, HQoL, mental health, noise annoyance and sensibility, and attitudes towards the airport. For each insurant (either participants or non-participants of the additional case-control study) current as well as past address-related source specific exposure to aircraft, railway, road traffic noise will be calculat-

ed. In order to be able to quantify any potential selection bias, a non-responder analysis will be performed in addition to the main analyses.

In addition to the secondary data analysis combined with the case-control study, long-term effects of aircraft noise on average blood pressure will be assessed by means of a **blood pressure monitoring**. 2,000 participants will be trained to assess their blood pressure in the morning and evening on 14 consecutive days in 2012. In addition, they fill in a questionnaire on HQoL and cardio-vascular risk factors. The same participants would repeat this measurement one year later in 2013. The 2,000 participants will be recruited as a sub-sample from the Rhine-Main panel sample of WP1.

The method of self-administered measurement of blood pressure was already used in a time-series study by Aydin & Kaltenbach (2007), carried out with 53 residents living in the vicinity of Frankfurt Airport. The authors found, firstly, that the self-administered measurement of blood pressure provides reliable data and, secondly, that the average blood pressure was associated with changes in aircraft noise due to the alteration of east/west mode of flight operation. In this sub-study of WP2 the aim is to analyze, whether blood pressure averaged over all measurements within one 14-day-period as well as the risk of cardio-vascular diseases in total is associated with aircraft noise exposure, road traffic and railway noise and whether the changes in the flight operations due to the airport expansion correspond with changes in the average blood pressure over time.

The effects of nocturnal aircraft noise on sleep at Frankfurt Airport, in particular aircraft noise-induced awakenings, will be assessed physiologically and by means of questionnaires within a longitudinal study with repeated measurements in 2011, 2012, and 2013. For this, the methods used in the study on the effects of nocturnal aircraft noise by the German Aerospace Center (DLR; Basner et al. 2004) will be adopted. The aim of this sub-study in WP2 is to monitor potential changes in the probability of awakening against the maximum sound level of nocturnal flyovers before and after the opening of the new runway. According to agreements between the airport and communities and the official approval of the expansion plan, it is expected that the number of night flights will be reduced if not banned between 11 p.m. and 5 a.m. after the opening of the 4th runway. As the total number of flights between 10 p.m. and 6 a.m. (German night period) will amount to about 150 movements (current agreement), the operation constraints between 11 p.m. and 5 a.m. imply an increase in flight movements in the evening and morning shoulder hours. It is expected that these operational changes will lead to an increase in awakenings and problems to fall asleep in the second round (first measurement after the runway opening). The purpose of the third measurement, 24 months after the opening of the new runway, is to find out whether residents in the long run will habituate to the new situation. A power analysis showed that polysomnographical measurements (PSG) of awakenings with 40 persons (minimum: 35) on several consecutive nights following a habituation night would be sufficient to establish an exposure-response curve for the probability of aircraft noise-induced awakenings. According to a re-analysis of laboratory data of the Nocturnal Aircraft Noise Effect study of DLR, there is evidence that EEG awakenings assessed with invasive and sumptuous PSG correspond with automatically detected cardiac activations (ECG), which is a non-invasive cheaper method compared to the PSG (Basner et al. 2008). However, it is still unclear whether the developed ECG-based algorithm for the automatic identification of cardiac activation

is suitable for the study of noise effects on sleep in the field. Nevertheless, it is assumed that combining the ECG measurements with actigraphy for the measurement of body movements during sleep allows to reliably predict noise-induced EEG awakenings. This will be tested in the first measurement with 40 participants living in the vicinity of Frankfurt Airport. If the combination of ECG and actigraphy turns out to be a reliable and sensitive method for the assessment of noise-induced awakenings, the study would continue with this method to estimate the effects of aircraft noise on sleep of about 200 to 400 participants in the second and third measurements. For each participant the nocturnal aircraft noise events will be measured and recorded at the ear of the sleeping person. As it is the case for the participants of the blood pressure monitoring the participants of the sleep study will be recruited as a sub-sample from the Rhine-Main panel sample of WP1.

WP3 Noise effects on children

Following the study design of the RANCH study the children in the NORAH study will be sampled via primary schools within the Rhine-Main study region. A stratified random sampling procedure will be used to select the schools. Stratum is the aircraft noise exposure of the schools indicated by the equivalent sound level for daytime (five noise level classes between 40 and about 65 dB(A)). It is intended to draw a sample of about 1,000 pupils from 50 classes of 25 schools. The measurements will take place as group tests in the schools. They will include a reading test, tests of non-verbal intelligence, verbal long-term memory, phonological processing, speech perception, and attention. In addition, the children fill in questionnaires on noise annoyance, perceived EQoL and HQoL, and on the social climate in the school class. A questionnaire, filled in by the parents, includes questions on the child's life situation and circumstances (school achievement, health, developmental disorders) and the assessment of the child's HQoL. Confounding factors such as socio-economic status and teaching methods are assessed via parents and teacher questionnaires. For the address of each school and the home address of each pupil the exposure to aircraft, road traffic, and railway noise (schools: L_{day} inside and outside; home: L_{day} , L_{night} outside only) will be calculated.

CONCLUSIONS

The NORAH study, a 3-years-monitoring program on transportation noise in the vicinity of Frankfurt Airport and – for comparison – at three other German Airports, started in April 2011. NORAH includes three work packages on noise annoyance, HQoL, cardio-vascular health diseases as well as sleep of adults, and cognition and HQoL in children. As Frankfurt Airport is in a change situation (opening of a new runway, implementation of several measures of active noise control) the specific aim of NORAH is to study the aircraft noise effects over time (in relation to the effects of noise from road and railway noise) under change condition.

NORAH includes cross-sectional, case-control and longitudinal sub-studies with a wide range of methods for the assessment of the transportation noise effects in adults and children: Interviews, psychological tests, physiological measurements, and secondary data analysis combined with a case-control study. An interdisciplinary team including scientists of acoustics, environmental and social medicine, epidemiology, physics, psychology, and sociology has been formed to carry out this noise effect monitoring program.

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