Quality of Life
Health
Development

NORAH Knowledge No. 5

NORAH noise impact study

Sleep Study: Effects of aviation noise on sleep

Objective and method

forum flughafen & region
umwelt- und nachbarschaftshaus

NORAH

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NORAH Noise Impact Study

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Objective and method

"NORAH Knowledge" provides information on the methods and results of the NORAH noise impact study. The aim of this series is to communicate to as many people as possible what exactly NORAH is researching. This is why there is an explanation in the glossary at the end for all terms marked "Glossary".

If you would like to receive further issues of "NORAH Knowledge", please use the enclosed order form.

The NORAH Study investigates the effects of aviation, road and rail noise on people.

von Aichberger

NORAH ("Noise-Related Annoyance, Cognition, and Health") is the most extensive investigation into the effects of exposure to aviation, road and rail traffic noise that has ever been carried out in the German-speaking countries. It is being conducted by nine independent scientific institutes from all over Germany. The client is the Umwelt- und Nachbarschaftshaus, a subsidiary of the Land of Hessen and part of the Frankfurt Airport and Region Forum. Alongside the land of Hessen, communities, Fraport AG and Lufthansa were also involved in the financing.

The NORAH Study examines the long-term effects of aviation noise on health, quality of life, sleep and early childhood development in the Rhine-Main Region. The initiator of the study is the Airport and Region Forum (ARF). An external Scientific Advisory Board for Quality Assurance (WBQ) advises the scientists from the very start. This distinguishes NORAH from previous studies. The study addresses some of the most topical issues currently occupying international noise impact research. It takes into consideration more investigation aspects than earlier studies. In order to find out more about how the human being responds to traffic noise, the NORAH scientists, among other things, surveyed the medical histories of around one million people, and calculated the noise exposure at around 900,000 addresses in the Rhine-Main Region.

A total of five sub-studies form the core of the NORAH Study. Each of them builds on the current status of international research. In this edition of "NORAH Knowledge" we explain the objectives and methods of the sleep study, one of the five sub-studies. The publication of the results of this and all the other outstanding sub-studies is scheduled for autumn 2015.

Contents

Further information on the NORAH Study is available on the Internet at **www.laermstudie.de**. There you can also subscribe to the newsletter "NORAH Brief".

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WHAT EFFECTS DOES AVIATION NOISE HAVE ON SLEEP?

Getting a good night's sleep is very important for a healthy life. If we wake up frequently in the night, we will most likely feel the effects the next day: we feel less rested and lack energy. If our night's sleep is disturbed regularly and over long periods, this can lead to the development of chronic illnesses. Nocturnal take-offs and landings of aircraft can be a source of sleep-depriving noise for people who live near an airport. For this reason, many airports – including Frankfurt Airport – have to severely restrict or completely suspend operations during the night.

But to what extent do the take-offs and landings during the night actually disturb people's sleep? As of which volume is there an increased probability of someone being woken by aviation noise? The team around the NORAH scientist Dr. Uwe Müller at the German Aerospace Centre (DLR) in Cologne attempted to answer these questions in the sleep study – specifically for the region around Frankfurt Airport.

Dr. Uwe Müller is director of the NORAH sleep study.

Müller

Previous investigations

Many of the studies up to now on the impact of noise on sleep were based exclusively on questionnaires. The study subjects themselves provided information every morning about how they had slept. Alongside this subjective perception, however, it is also important to make objective measurements of the various physical reactions during the night. These so-called polysomnographic investigations (Glossary "Polysomnography") of sleep are much more complicated, especially if they are not carried out in the sleep lab (Glossary), but in the homes of the study subjects. Only a few noise impact studies before NORAH used this method outside of the sleep lab. The most extensive study of this kind to date was carried out in 2001 and 2002, examining the sleeping habits of a total of 64 people in the proximity of Cologne/Bonn Airport. The results of this study are taken into account among other things in the so-called Frankfurt Night Index (Glossary "Frankfurt Aviation Noise Indices"). This is used regularly to calculate at which places in the Rhine-Main Region and how frequently people experience additional, measureable wake-up reactions (Glossary) between 22.00 and 06.00 hrs because aircraft are taking off or landing in the proximity. It is entirely unclear, however, whether the situation at Cologne/Bonn Airport with an almost constantly high number of nocturnal freight flights in the years 2001/02 can even be applied to the Frankfurt region more than ten years later. Answering this question is also one of the tasks of the NORAH sleep study.

New noise backdrop, new sleep patterns?

In the areas around Frankfurt Airport, there have been two major changes since 2011 in the nocturnal volume of air traffic: in October 2011 "night flying restrictions for scheduled flights" were introduced from 23.00 to 05.00 hrs. During this time the air traffic comes to an almost complete standstill. Only delayed arrivals or departures are then allowed on the basis of precisely specified exceptions. It used to be different: The previous rules led to 50 to 60 flight movements at peak times between 23.00 and 05.00 hrs. In addition to this, the new North-West runway has been in operation since October 2011. Due to the altered flight routes, the noise exposure has changed in some of the regions around the airport.

The NORAH sleep study shows how these changes have affected the sleep of the residents. To do this, the scientists measured the sleep quality of more than 200 persons in the Rhine-Main Region a total of three times on three to four nights in each case. The study subjects were sleeping in their own homes but with several electrodes attached to their body – just like in a sleep lab (Glossary). At the same time a sound level meter recorded all noise reaching the ears of the sleeping person during the night. The device also precisely registered the loudness. The first measurements took place in summer 2011, i.e. before the night flying restrictions were introduced and the new runway opened. The other measurement phases took place in the summers of 2012 and 2013.

In this edition of "Norah Knowledge" we explain how the study is structured, which questions the scientists are seeking to answer, and which methods they used for this purpose.

The first measurements took place in summer 2011, i.e. before the night flying restrictions were introduced and the new runway opened.

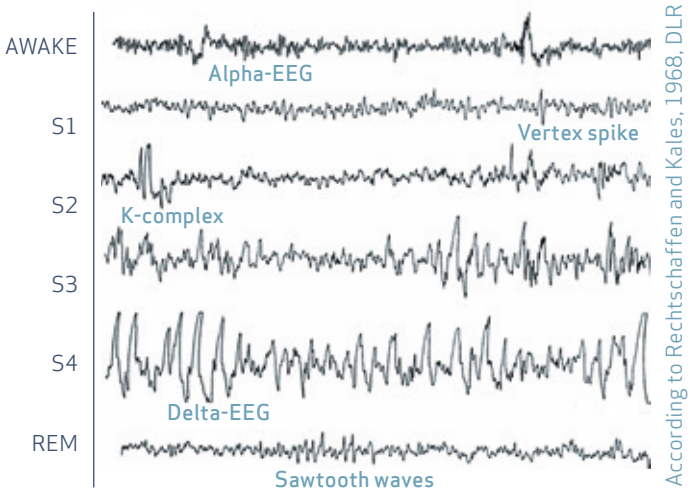
HEALTHY SLEEPING

Anyone who has ever had to get up after just a few hours of sleep will know exactly how it feels. If we do not get enough sleep, we have less energy. If we do not sleep sufficiently deeply, we do not feel rested the next day and are less able to cope. If this only happens rarely and only on individual nights, the body has no problem compensating for the lack of sleep. Regular sleep disturbances, however, can be damaging in the long term. It is suspected that in some people it can, among other things, increase the risk of cardiovascular disease. This is strongly suggested by scientific studies.

Five sleep studies

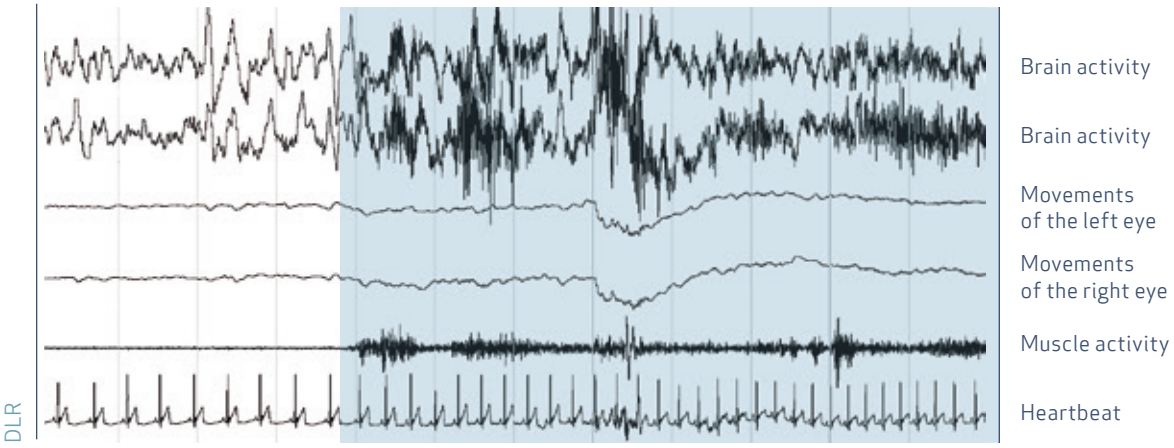
Different people require different amounts of sleep. Some are happy with six hours, others need eight in order to feel fit the next day. The average sleeping duration in Germany is around 7.5 hours. During this time we are repeatedly moving from one sleep phase to the next. Scientists make a distinction between five different sleep phases, known as S1 to S4 and REM. Stage S4 stands for the deepest sleep. At the start of the night, these deep sleep phases are especially long and frequent. The lightest sleep phases are S1 and S2. These are more frequent in the early morning hours. This is also the reason why we wake up more easily in the morning than at the start of the night. REM sleep is distinguished in particular by Rapid Eye Movement and occurs usually towards the end of the night. Most dreams take place during REM sleep.

Sleep phase qualification



Sleep researchers make a distinction between five different sleep phases: S1 is the lightest phase, S4 is the deepest. REM stands for "Rapid Eye Movement" – in this phase we are most likely to have dreams.

Wake-up reaction



During sleep the various electrodes on the body record graphs. The graph shown here shows a so-called wake-up reaction.

Frequent wake-ups mean poorer sleep

Everybody wakes up briefly several times during the night, even without external influences. In most cases we can no longer remember this by the next morning. Sleep researchers regard the frequency of the so-called wake-up reactions (Glossary) as an important measure for the assessment of the effects of noise. They calculate how probable it is that certain noise exposure will wake up more frequently in the night.

AVIATION NOISE CHANGING

For many people living in the proximity of Frankfurt Airport, the noise exposure has changed in recent years. Two events in particular had an effect on the distribution and the intensity of the noise: in October 2011 a new runway – the North-West runway – went into operation. Since the same time there has also been a restriction on flights between 23.00 and 05.00 hrs. The timeline shows that the first investigations within the framework of the NORAH sleep study took place before both of these events, while the last investigations took place almost two years later. This will allow the scientists to establish whether the changes in the noise exposure have had any influence on the physical reactions of the study subjects during sleep.

Chronology of the sleep study

May 2011

Start of the NORAH Study

Summer 2011

First investigation wave of the NORAH sleep study: 49 participants

October 2011

Opening of the North-West runway

October 2011

Take-off and landing ban for scheduled flights from 23.00 to 05.00 hrs ("night flight ban"): take-offs and landings are only allowed in precisely specified exceptions.

April 2012

The Federal Administrative Court confirms the validity of the airport expansion and the night flight ban.

Summer 2012

Second investigation wave of the NORAH sleep study: 83 participants. 42 thereof had already taken part in the measurements in 2011.

Summer 2013

Third investigation wave of the NORAH sleep study (new measurement method): 187 participants. 39 of these were examined three times (2011–2013), 36 persons twice (2012 and 2013).

WHO TOOK PART IN THE SLEEP STUDY?

A so-called field study (Glossary) such as the NORAH sleep study attempts to make scientific observations in an environment which is as natural as possible. This is why the NORAH scientists did not investigate the sleep of the study subjects in a sleep lab (Glossary), in which people normally sleep differently than at home, but in their own bedrooms. Before the measurements could begin, the scientists had to decide which requirements the study subjects had to fulfil. Then they went looking for suitable volunteers by flyer, newspaper advertisements and on the Internet.

49 men and women took part in 2011 in the first investigation of the NORAH sleep study. 42 of them took part again the following year – after the introduction of the night flying restrictions and the opening of the North-West runway. Another 41 persons took part in this second measurement. In the third and last measurement in 2013, the scientists used a new measurement method – the study subjects only had to attach two electrodes themselves to their bodies before going to bed. 187 people took part in this third wave of measurements, including 36 subjects from the previous year.

A decisive factor for the selection of participants was the location and the exact position of the house.

Aviation noise in the bedroom

A decisive factor for the selection of participants was the location and the exact position of the house. Aviation noise had to be clearly audible in the bedroom of the participant; this is why the measurement points were selected in the proximity of the flight paths. Other traffic noise would have made it more difficult to clearly attribute the sleep disturbances caused by aviation noise. For this reason the study subjects ideally lived at locations where there was hardly any road or rail traffic noise.

Residents of Gräfenhausen, Klein-Gerau, Nauheim, Offenbach-Süd, Raunheim, Rüsselsheim, Worfelden and Wixhausen took part in the measurements in 2011 and 2012. Other communities were added in 2013. This was due, among other things, to the flight paths of the new runway. Some of the study participants in the third year of the investigation were living in Flörsheim, Frankfurt-Süd, Hochheim, Mörfelden and districts in Offenbach previously not included.

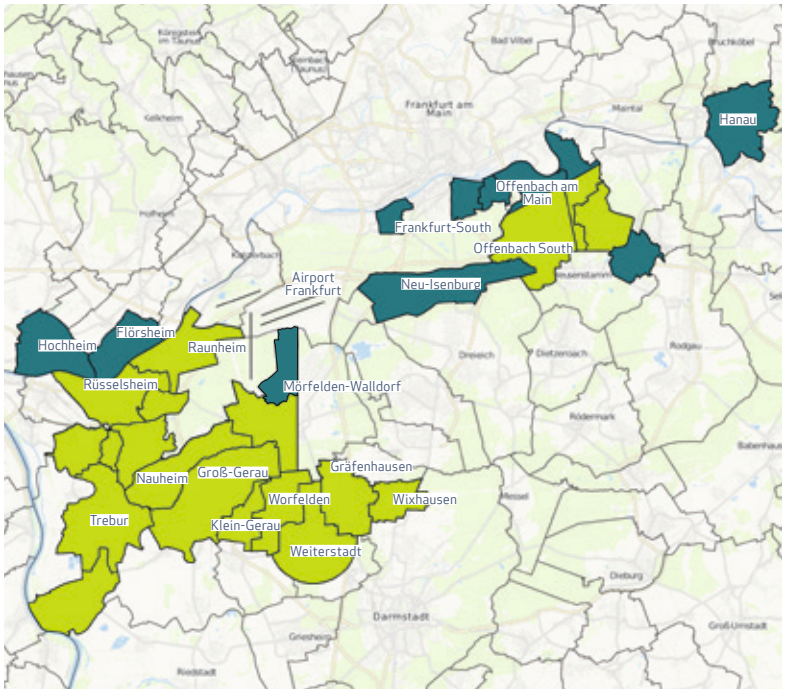
Health and living circumstances of the participants

In addition to the noise exposure at the home, previous illnesses, living circumstances and lifestyle can play a role in determining the quality of sleep. In order to attribute possible sleep problems directly to aviation noise, the scientists excluded persons with illnesses that could change sleeping patterns. This included, for example, persons suffering from allergies, whose medication often causes them to need more sleep, or people suffering from sleep apnoea, a sleep disorder characterized by pauses in breathing or heavy snoring, causing the sufferer to wake up more frequently in the night. Families with small children under six years old were also excluded.

The study participants also had to fulfil a third criterion: they had to have a regular sleeping rhythm. The people who took part in the investigation in 2011 normally went to bed between 22.00 and 22.30 hrs and got up between 06.00 and 06.30. In 2012 and 2013 people also took part who went to bed and got up on average one hour later. These sleeping rhythms were decisive for the scientists in order to investigate the sleep quality in the so-called shoulder hours directly before and after the night flying restrictions: the periods in the evening between 22.00 and 23.00 hrs and in the morning between 05.00 and 06.00 hrs. Legally these count as night, but the night flying restrictions do not apply. Shift workers were also excluded from the study due to their irregular sleeping rhythm.

Why were people whose sleep is already impaired not included in the study? Answer: the scientists can only assess to what extent aviation noise disturbs sleep in "healthy sleepers" with a regular sleeping rhythm. If, for example, a person is sleeping badly for health reasons, it is very difficult to establish exactly why he wakes up in the night: due to the noise, due to an illness or a combination of both?

Areas where the sleep study was carried out



Investigation areas of the NORAH sleep study
2011–2013
2013

Open Street Map / UNH 2015

THE METHODS OF THE SLEEP STUDY

To what extent does aviation noise disturb sleep? In order to find out, the scientists measured the quality of sleep and the noise exposure in the bedrooms of the study subjects.

Polysomnography – the measurement of sleep

A total of ten electrodes on the head and two more on the body are required for a polysomnographic investigation (Glossary "Polysomnography"). This is a technique for recording various body functions during sleep. Measurements include heart frequency, brain activity and muscle tension. With this and other information the scientists are able to track when a person goes through which sleep phases in the course of the night. The NORAH team also used this method to investigate the sleep of the participants in the years 2011 and 2012. This required a certain amount of work: before going to bed on the four investigation days, the participants were visited at home by a project team member who attached the electrodes to their bodies. This "wiring up" – along with completing the questionnaire and starting all of the measuring devices – took about one hour. The project team members came back the next morning to liberate the participants from the many cables and to secure the measurement data. The measurements from the first night in each case were not used, however, for the study – this "acclimatization night" was necessary to accustom the participants to the electrodes.

With the aid of the measurement data from 2011 and 2012, the NORAH team was able to develop a new, less complicated method to measure the relevant physical reactions to noise during sleep. This requires just two electrodes that the participants can attach to their bodies themselves. The measurement device used registers the heart frequency and the body movements. By comparing these measurement values with the noise recordings, the scientists can recognize when aviation noise disturbed the sleep of the study participants during the night.

Wavebreakmedia/Shutterstock

Noise measurements at the ear of the sleeper

When a plane flies over a house, depending on the speed and the distance of the plane away from the house, the noise can rarely be heard in the bedroom for more than one minute. Earlier studies have shown that it is mainly the so-called maximum sound level (Glossary) of the overflight, i.e. the highest volume and the increase of the volume per unit of time that causes people to wake up. In order to determine these and other values, a noise level meter in the bedroom recorded with accuracy to the second all of the noises including their sound pressure level (Glossary). By comparing this with the sleep data, the scientists can determine exactly which noise woke the sleeper at which time. Other noises, of course, can also cause a person to wake up: a police siren or early birdsong, for example. Such measurements were excluded from the evaluation. The scientists also registered whether the study participants slept with the window open or closed in the respective measurement night. The participants could choose freely which window position they wanted, but they had to leave it in the chosen position for the night.

The questionnaire

Sleep is a very individual matter. Some people need a lot of sleep, others can get by with less. Some people start to feel tired early in the evening, others still feel fit into the late evening and would like to spend longer in bed in the morning (Glossary "Chronotype"). Personal characteristics like this are important for sleeping patterns, but cannot be measured with devices. This is why the scientists use various questionnaires in their investigation.

On all of the four investigation days, after they got up in the morning, the participants had to assess their sleep quality and the disturbances by aviation noise during the night from their own subjective perspective. There were other questionnaires at the end of the study. These addressed various personal, social and living situation-related factors which could have an influence on how the participants evaluate their sleep and their disturbance by aviation noise. All of the questionnaires are scientifically tested and have already been used in many other studies.

An overview of factors covered by the questionnaires:
Personal influencing factors

- general disturbance by aviation noise before the study
- noise sensitivity
- subjective habituation to aviation noise
- participation in activities against aviation noise
- determination of the chronotype

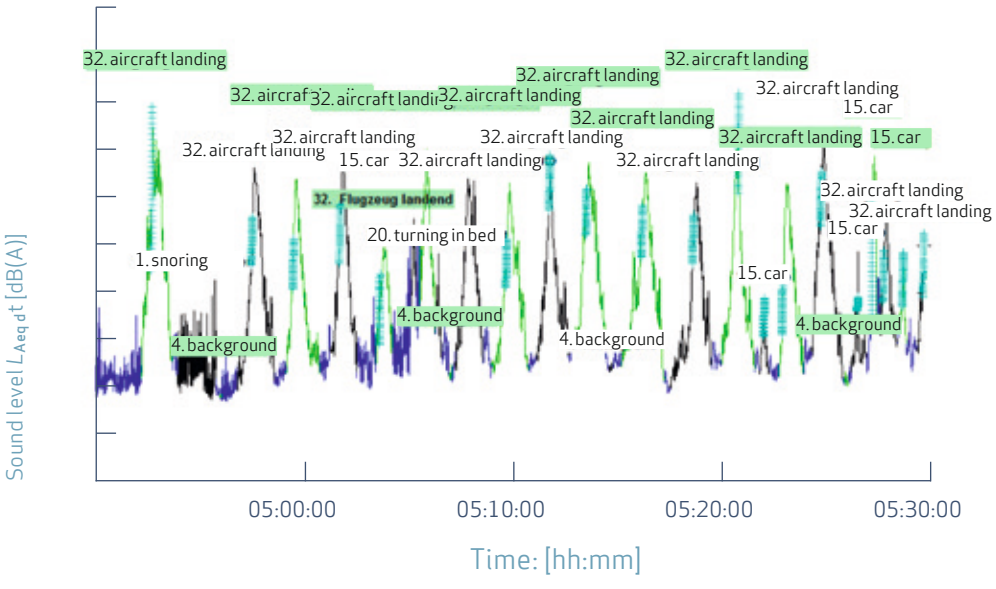
Social influencing factors

- general attitude towards air traffic
- belief that the aviation noise exposure can be successfully reduced

Situation-related influencing factors

- general noise perception in own neighbourhood (not restricted to aviation noise)
- satisfaction with the noise levels of air traffic in own neighbourhood

Acoustic evaluation



A sound level meter recorded all noises in the bedroom during the night. A human ear is necessary for the evaluation: project team members listen to every sound and enter into the computer whether it is aviation noise or, for example, snoring.

A DAY AS PARTICIPANT IN THE SLEEP STUDY

How did the measurement of the NORAH sleep study go? The pictures show how the project team members of the sleep study prepare two study participants for a polysomnographic sleep measurement in 2012 (Glossary Polysomnography")

Knost, DLR

19.30 hrs

Preparation for the house visit: A NORAH team member packs her case with the measurement devices in the Umwelt- und Nachbarschaftshaus in Kelsterbach.

Knost, DLR

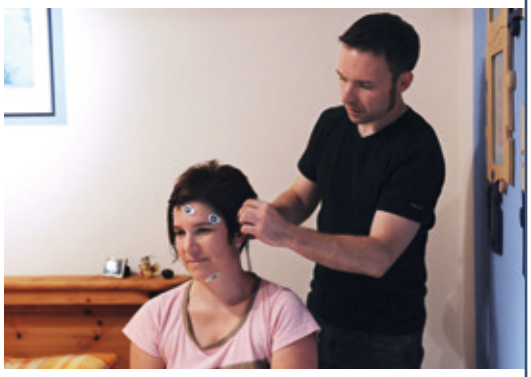
Knost, DLR

21.00 hrs

Arrival at the participant's house. The NORAH team has already established that loud aviation noise regularly reaches the bedroom here in a nighttime test measurement at the house. Now they want to find out how the aviation noise affects the sleep of the residents.

21.15 hrs

The measurement instruments are ready. The scientists carried out a polysomnographic measurement on all participants in the first and second year of the study – this requires a whole lot of cables and electrodes.



Knost, DLR

21.20 hrs

A project team member applies electrodes to the head of a study participant. A total of ten electrodes on the head are necessary to measure brain activity and eye movements.

Knost, DLR

22.00 hrs

A noise level meter is set up at the head of the bed for the night. It records the sound pressure level (Glossary) and all the sounds that occur in the night.

22.10 hrs

Time to go to bed. As soon as everything is ready for the measurements, the project team members say good night. They will return next morning and help the study participants to remove the electrodes.

21.55 hrs

The attachment of the electrodes is almost complete. There are also two electrodes on the body, to measure the heartbeat.

Knost, DLR

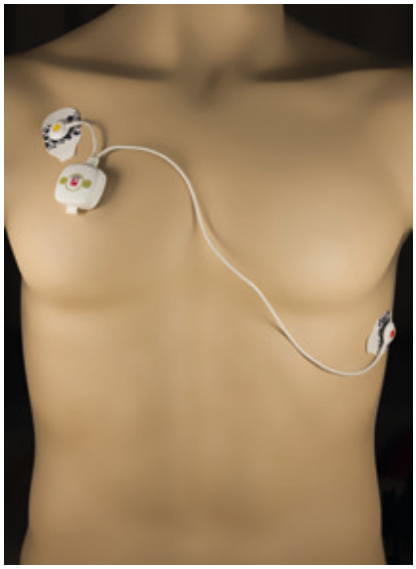
Knost, DLR

A NEW METHOD FOR EVALUATING THE NOISE EXPOSURE DURING SLEEP

Eyes closed in slumber: the state into which we fall every night involves more than just "switching off" our consciousness. From breathing to brain activity, right up to the heartbeat, the body changes many of its activities while we are sleeping. This can be measured; the results provide information on the depth, course and quality of the sleep. Using the recordings of a polysomnographic investigation (Glossary "Polysomnographic"), sleep researchers can tell, for example, when someone has slept particularly deeply and when he changed from one sleep phase to the next.

But this type of investigation is complicated. And not all of the information gained is necessary for every type of sleep study. When it is a case of nocturnal disturbances caused by noise, some of the physical reactions of the sleeper are particularly informative – alongside waking up, this includes in particular the acceleration of the heartbeat and the body movements. Within the framework of the NORAH sleep study the scientists developed a method to register both of these reactions. This means that the study participants now only have to attach two electrodes to their body.

The measurement device used records the heartbeat and the movements of the sleeper. Even during vivid dreams our muscles generally stay relaxed. When there is a wake-up reaction, however, the heart generally beats faster and the sleeper moves. The scientists have shown that these two measurements together are sufficient to identify whether the sleep of the individual was interrupted. The NORAH team calls the new technique the "vegetative-motor method" in short VMM.



Schmidt, DLR

When does a person wake up in the night? With the new measurement method, two electrodes on the upper body are sufficient to answer this question.

The advantages of the new method

Even though VMM does not provide as much information as polysomnography, it has two major advantages for science. On the one hand, it is possible to investigate a lot more people because there are fewer technical complications. On the other hand, the evaluation of the data is much easier: the analysis of a polysomnographic investigation requires the experience of a sleep expert, the data of the simplified measurement method can be evaluated by a computer.

Other sleep researchers are also keen to take advantage of this: since 2011 the scientists of the NORAH sleep study at the German Aerospace Centre have been involved in cooperation with a scientist team at the University of Pennsylvania in the USA. The new method is their joint development. The American researchers have been using the VMM since 2014 – it was used first for the sleep measurements in the NORAH study in summer 2013. The US team is using it to investigate the physical reactions of residents around the Philadelphia Airport to aviation noise.

Glossary

You will find further explanations in the glossary at **www.laermstudie.de**.

Wake-up reaction

When a sleeping person changes from a deep sleep into the lightest sleep phase, or wakes up completely, the sleep researchers of the German Aerospace Center (DLR) speak of a wake-up reaction. Even in a quiet environment, sleepers will experience such a wake-up reaction around 20 to 30 times a night. Usually they cannot remember this in the morning.

Chronotype

The chronotype tells us how a person's inner clock ticks. Colloquially, we speak of "larks", early risers who are tired early in the evening, and "owls", who are fit well into the late evening and like to sleep longer in the morning. Depending on the preferred sleeping times, biologists distinguish between a total of seven different chronotypes.

Field study

A field study collects scientific data in a natural environment. This has the advantage that the results describe the reality particularly well. For example: as people sleep differently in a strange bed and with unaccustomed ambient noise than they do at home, the results of a field study on sleep quality are more reliable than the results of a study carried out in the sleep lab.

Frankfurt Aviation Noise Indices

The Frankfurt Aviation Noise Indices developed by the Airport and Region Forum (ARF) calculate the aviation noise exposure during the day and night in the area around Frankfurt Airport. They take into account the overall landing and take-off situation on the basis of the six busiest months for air traffic. The Frankfurt Aviation Noise Indices are based on dose-effect relationships that were identified within the framework of studies in the Rhine-Main Region and at Cologne/Bonn Airport.

Maximum noise level

The physical value which best describes how strongly nocturnal aviation noise impacts on sleep is the maximum noise level. It shows to what extent the aircraft noise stands out from the existing background noises. The annoyance effect overall depends on the height and the frequency of occurring maximum noise levels.

Polysomnography

A polysomnographic investigation registers several physical measurement values during sleep, including the brain activity and eye movements, the heartbeat and the breathing rhythm. This information helps doctors, for example, to identify the causes of sleep disorders.

Sound pressure level

The sound pressure level is stated in decibels – "dB(A)" – and is a measure of the loudness. The decibel scale from 0 to 120 dB(A) reflects the range from the absolute threshold of hearing to the pain threshold. The scale is not linear. We perceive an increase of ten decibels as roughly a doubling of the loudness – in the lower and at the upper ends of the range.

Sleep lab

In sleep labs scientists can measure and observe the course of a person's sleep and when he changes from one sleep phase to another.

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