Quality of Life
Health
Development

NORAH Knowledge No. 10

NORAH Noise Impact Study

Aircraft noise and nocturnal sleep

Results

forum flughafen & region
umwelt- und nachbarschaftshaus

NORAH

Knowledge No. 10

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Results

"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 researched. 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 investigated the effects of aircraft, road and rail traffic noise on humans.

von Aichberger

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

The NORAH Study examined the long-term effects of traffic noise on health, quality of life and early childhood development in the Rhine-Main Region. The initiator of the study is the Airport and Region Forum (ARF). The scientists were accompanied from the start by an external Scientific Advisory Board for Quality Assurance (WBQ). This is what distinguishes NORAH from similar, predecessor studies. The study addressed some of the most topical important issues currently being dealt with by international noise impact research. It also covered a wider range of investigation aspects than previous studies. In order to find out more about how human beings respond to traffic noise, the NORAH scientists also looked at the medical histories of more than one million people, and reconstructed 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 one built on the current international state of research. In addition to this, extremely complex and innovative techniques were used to calculate the acoustic exposure. In this edition of "NORAH Knowledge" we present the results of the Sleep Study, one of the five sub-studies.

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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OVERVIEW OF THE SLEEP STUDY

We sleep on average just over seven hours every night. Just how important this rest phase is, is clear to anybody who has ever had too little sleep at night. It is not always easy for people living in the proximity of airports to settle down at night and find sleep. The NORAH Sleep Study examined how nocturnal flights affect people's sleeping habits. The study paid special attention to the effects of two new measures, which changed the noise background in the Rhine-Main Region in October 2011. Since then there has been a curfew at Frankfurt Airport on scheduled take-offs and landings between 11 p.m. and 5 a.m. At the same time, the new north-west runway began operations. A comparison of the sleep measurements from 2011 and 2012 shows how the changes affected residents with otherwise healthy sleep patterns.

Measuring sleep quality in the proximity of the airport

In order to answer their research questions, the scientists carried out sleep measurements directly in the bedrooms of residents around Frankfurt Airport in the summers from 2011 to 2013. Over 200 persons took part in the measurements, many of them over two or all three years. The study participants spent three to four successive nights with several electrodes attached to their bodies. While they were sleeping, the electrodes recorded the brain activity, the heartbeat and other physical signals. A sound level meter also registered all nocturnal noises reaching the ears of the sleeping individuals. This allowed the NORAH team to calculate how overflights affect people's sleep. All of the participants provided other information in questionnaires – including how they subjectively perceived their sleep and how positive or negative their attitude was towards air traffic.

Quieter nights improve sleep quality

The curfew on scheduled flights between 11 p.m. and 5 a.m. since October 2011 has had a positive effect: as fewer overflights could be perceived in the bedrooms in 2012, people generally woke up less frequently (glossary "Wake-up reaction"). Persons who went to bed between 10 and 10.30 p.m. and got up between 6 and 6.30 a.m. woke up on average less frequently than those who went to bed and got up one hour later. The latter were more frequently woken on average in the early morning hours by aircraft noise.

Increased tiredness in the morning

Although the measurements show that the study participants in 2012 woke up less frequently on average than in 2011, this positive development is not reflected in the perception of the people themselves: they felt somewhat more tired and sleepy in the mornings than in the previous year in each year of the investigation at the same noise exposures, but in all years in the middle range of the tiredness scale. The scientists are unable to derive any explanation for this effect from the data. It must, therefore, be due to factors not examined by the study.

People with a critical attitude towards air traffic tend to sleep less well

Some of the questions asked by the NORAH team addressed the attitude of the participants towards air traffic. On the basis of the responses and the sleep measurements it was shown that people who have a more negative attitude towards air traffic slept less well. They needed longer to fall asleep, lay awake for longer at night, and spent less time in deep sleep. Whether the poorer quality of sleep is the result or the cause of the negative attitude towards air traffic cannot be established on the basis of the data.

Results from Cologne/Bonn not reliably transferrable to Frankfurt

As far back as 2001 and 2002 the German Aerospace Center (DLR) had measured the sleep quality of residents around an airport, not in the Rhine-Main Region, however, but in the area of Cologne/Bonn Airport where a lot of freight planes are taking off and landing more or less continuously during the night. Noise abatement calculations and indices (glossary "Frankfurt Aircraft Noise Indices") at several airports are based on the results of this investigation. Within the framework of the Sleep Study, the NORAH team has now found out that the results from then cannot be readily transferred to the current situation at Frankfurt Airport. The people in Cologne/Bonn slept less well in 2001 and 2002 than the participants in the Rhine-Main Region in 2012 after the introduction of the curfew on scheduled flights between 11 p.m. and 5 a.m. At the same time, the NORAH participants felt more annoyed by nocturnal aircraft noise.

Wavebreakmedia/Shutterstock

The curfew on scheduled flights between 11 p.m. and 5 a.m. since October 2011 has had a positive effect: as fewer overflights could be heard in bedrooms in 2012, people woke up less frequently.

METHOD AND QUESTIONS OF THE SLEEP STUDY

How severely do take-offs and landings of aircraft during the night disturb people's sleep? When and how often are residents around airports who actually have healthy sleeping habits woken up additionally by overflights? Dr Uwe Müller from the German Aerospace Center (DLR) in Cologne and his team searched for answers to these questions in the region around Frankfurt Airport. Alongside Germany's largest airport, the region also offers another special feature: since October 2011 Frankfurt Airport is subject to a curfew on scheduled flights between 11 p.m. and 5 a.m. Also, in the same month the new north-west runway began operations. The NORAH team was thus able to examine whether the residents slept any differently after these changes in the noise levels.

Noise as a participation criterion

More than 200 persons took part in the study between 2011 and 2013; the criterion for their selection was the noise that reached their bedrooms. Aircraft noise had to be clearly audible, but with hardly any road or rail noise. Another criterion: the study participants had to have a regular sleeping rhythm and healthy sleeping patterns. People who worked shifts or suffered from disorders that influence sleeping patterns were not accepted as participants. This rigorous selection was important in order to rule out as far as possible causes for sleep disorders other than noise.

Precise sleep measurement

The sleep measurements of all the participants formed the core of the study. Just like in a sleep lab (glossary), in 2011 and 2012, before going to bed in the evening the men and women were visited by the NORAH team, who "wiring up" them with several electrodes on their heads and bodies. This allowed the team to record various physical signals while the people were sleeping. At the same time a sound level meter registered all noises that reached the ears of the sleepers during the night. The data allowed the scientists to analyse precisely how deeply the participants were sleeping, and when and how they reacted to overflights.

Three measurement phases

The first measurements took place in the summer of 2011, i.e. before the introduction of the curfew on night flights between 11 p.m. and 5 a.m. and the opening of the north-west runway. There were further measurement phases in the summers of 2012 and 2013. For three to four nights in a row the NORAH team recorded the sleep of each participant.

Questionnaires surveyed the personal sleep perception

In addition to the sleep measurements, the scientists also asked the participants to assess their own sleep after each measurement night – for example whether they felt tired and sleepy in the morning. The respondents also provided information on, among other things, their noise sensitivity and their attitude towards air traffic.

Knost, DLR

A project worker attaches the electrodes to a study participant before he goes to bed. The participants slept with the electrodes attached to their body for three or four nights in succession.

Search for a new method of sleep measurement

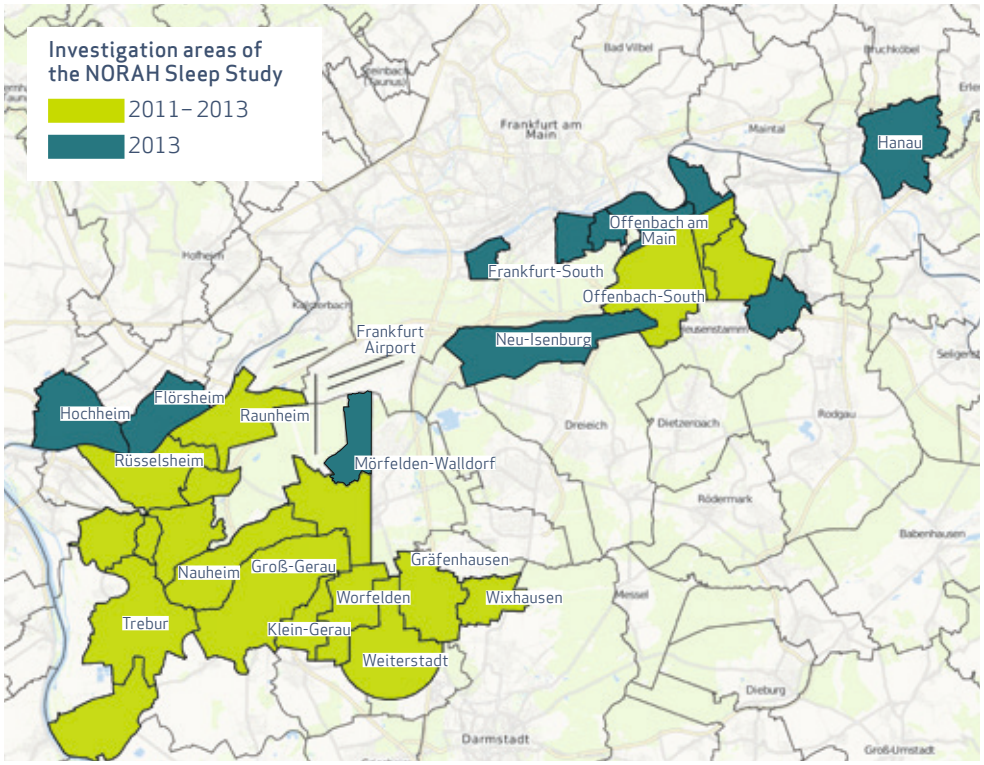
The study participants slept in their own beds during the measurements. For the investigations in 2011 and 2012 they wore ten electrodes on the head and two on the body. Because this type of investigation – sleep researchers refer to "polysomnography" (glossary) – is very complex, the NORAH team developed a simpler method for 2013. The scientists had already begun the preliminary work for such a method back in 2008. The new "vegetative-motor" method only needs two electrodes and is easier to evaluate. This is why more people could take part in the third year of the investigation than in the previous years. The new method, however, does not measure the same things as polysomnography, but only registers changes in the heartbeat and body movements.

The special feature of the NORAH Sleep Study

In the area of sleep research, NORAH goes further than many other studies: most investigations up to now had to make do with questionnaires. Only a few noise impact studies before NORAH used polysomnographic methods on residents on site – including a study carried out around Cologne/Bonn Airport in the years 2001 and 2002. Its results were used for the Frankfurt Night Flight Index (glossary "Frankfurt Aircraft Noise Indices"). One of the tasks of NORAH was to examine whether the results of this older study could be transferred to the Frankfurt region. No study anywhere in the world before the NORAH Sleep Study carried out polysomnographic investigations on such a large number of participants in their own homes.

You can read more about the method and tasks of the Sleep Study in "NORAH Knowledge" no. 5.

Areas where the NORAH Sleep Study was carried out



Open Street Map / UNH 2015

THE QUALITY OF SLEEP IN THE RHINE-MAIN REGION

The results of the NORAH Sleep Study show for the first time in detail how well people with otherwise healthy sleeping habits in the Rhine-Main Region sleep, and how aircraft noise affects their nightly rest. The first sleep measurements were carried out in 2011 before the curfew on scheduled flights between 11 p.m. and 5 a.m. came into effect. All of the participants went to bed between 10 and 10.30 p.m., and got up between 6 and 6.30 a.m. The second measurement phase took place in 2012. In this year, almost all of the participants from the previous year took part again. In 2012 the NORAH team also investigated another group of persons who went to bed an hour later, i.e. between 11 and 11.30 p.m., and also got up an hour later in the morning. Comparison of the two groups allowed the NORAH team to estimate how the six-hour night flight curfew affected the sleep of the residents, and whether when the participants went to bed and got up again made any difference in the second year.

Early sleepers benefit from the flight curfew between 11 p.m. and 5 a.m.

Due to the lower number of overflights in 2012, study participants who went to bed between 10 and 10.30 p.m. slept better in the second year of the investigation. In 2011 they awoke additionally on average 2.0 times per night at the time of an overflight ("aircraft noise-associated wake-up reaction"). In 2012, however, they woke up additionally on average only 0.8 times per night due to overflights.

Late sleepers wake up more frequently

The second group of participants in 2012, who went to bed between 11 and 11.30 p.m. and got up an hour later in the morning than the "early sleepers", woke up more frequently. On average 1.9 times per night they experienced an "aircraft noise-associated wake-up reaction", i.e. an interruption of their sleep during an overflight. The reason for the clear difference between early and late sleepers: the getting up time of the late sleepers was around two hours after the end of the curfew on scheduled flights. This meant that the people were exposed for longer to the resuming air traffic in the early morning.

Not every overflight causes the same degree of annoyance

Most of the overflights did not cause the sleepers to wake up. The NORAH team wanted to know more exactly whether some overflights annoyed sleep more than others. To do this they analysed, among other things, the maximum sound level (glossary), i.e. the maximum loudness of each overflight, and the time. They found out – unsurprisingly – that louder overflights lead to more frequent wake-ups. However, the difference between the general background noises and the maximum sound level of the overflight also played a role: if the background noises were louder and the difference to the overflight noise therefore less, the participants woke up less frequently. The time also plays a role: towards the end of the night, when the sleep pressure decreased, the participants were more likely to wake up than at the start of the night.

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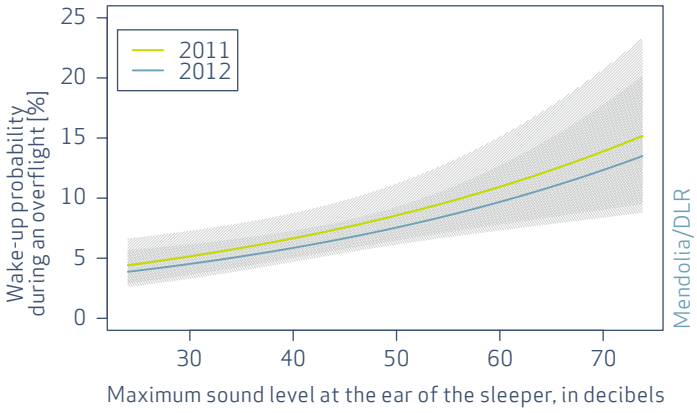
Aircraft noise-associated wake-up probability



The graph shows the probability of waking up during an overflight with a certain maximum sound level. The wake-up probabilities for 2011 and 2011 are not significantly different. This is apparent from the strong overlap of the shaded "confidence intervals".

How the participants slept

Despite the different noise exposure in the years 2011 and 2012, the scientists were unable to establish any significant differences in various sleep characteristic values between the two years. In order to track down possible effects of nocturnal aircraft noise, the NORAH team had measured, among other things, how long the participants lay awake at night and how long they needed to fall asleep.

In none of the investigated sleep characteristic values (see table) were the scientists able to establish any statistically significant differences between the years and groups. The table below shows an overview of the average values.

People with a more critical attitude towards air traffic sleep less well

The NORAH team also asked the participants how positively or negatively they viewed air traffic, and how necessary they believe it is. The answers hardly changed over the course of the three investigation years. However, in all three years the scientists were able to establish a connection between the sleep of the participants and their attitude towards air traffic: residents with a more negative attitude towards the airport needed longer to fall asleep, spent less time in deep sleep, and lay awake at night for longer. The scientists were unable to draw any conclusions from the data as to cause and effect: the negative attitude could be a result of the poor sleep, but it is also possible that it could be the cause.

None of these six investigated sleep characteristic values showed significant differences between the years or the groups.

	2001: Sleep time: 10/10.30 p.m. to 6/6.30 a.m.	2012: Sleep time: 10/10.30 p.m. to 6/6.30 a.m.	2012: Sleep time: 11/11.30 p.m. to 7/7.30 a.m.
Total sleep duration	7:06 hours	7:08 hours	7:07 hours
Time between going to bed and falling asleep	13.9 minutes	14.5 minutes	13.1 minutes
Sleep efficiency (proportion of sleep to time in bed)	90%	90%	91%
Duration of waking after falling asleep	36.7 minutes	34.4 minutes	33.8 minutes
Difference between planned and actual end of sleep	3.3 minutes	5.4 minutes	5.7 minutes
Waking proportion in percent between 4.30 a.m. and planned end of sleep	14%	14%	12%

Mendolia/DLR

Measurement of physical reactions to noise changes

In 2013, the third year of the investigation, the scientists used a less complicated measurement method with just two electrodes: this registers how frequently the participants react physiologically to overflights – with accelerated heartbeat and body movements. Unlike the polysomnographic investigations (glossary) of the previous years, the participants were able to attach the two necessary electrodes in the evening themselves. This meant that, with the same budget, the NORAH team could measure the sleep of considerably more persons than in 2011 and 2012.

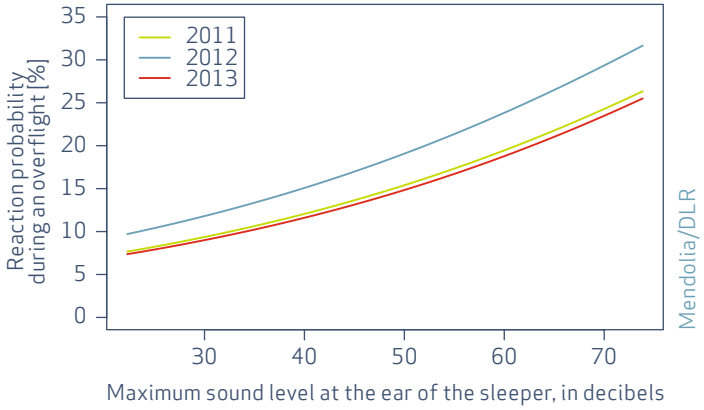
The results show that the physical reactions to overflights increased substantially from 2011 to 2012: in 2011 the participants reacted to 10.7 percent of the overflights with no interference from other noise, and in 2012 to 16.2 percent. In 2013 the proportion was 13 percent, i.e. it had fallen back again. The scientists cannot rule out that this may have to do with what is called a change effect. This is what noise impact researchers call it when people temporarily react more strongly to expected or actual noise changes, for example after the expansion of an airport.

The term "wake-up reaction"

In the years 2011 and 2012 the study examined how probable it is that the participants displayed a so-called wake-up reaction due to the influence of aircraft noise. This is what the scientists call the change from a deeper sleep phase either to the lightest sleeping phase or waking up.

Wake-up reactions are caused not only by noise. Even in a quiet environment, sleepers will wake up several times in the night. Usually they cannot remember this in the morning. In previous studies in the sleep lab (glossary), the NORAH team was able to demonstrate that people generally only remember wake-up reactions if they last for longer than 90 seconds.

Aircraft-noise-associated probability of a "vegetative-motor" reaction



The graph shows the probability of reacting with increased heartbeat and body movements during an overflight with a certain maximum sound level. The reaction probability increased from 2011 to 2012, and then fell back in 2013 to the level of 2011.

THE SLEEP EXPERIENCE FROM THE POINT OF VIEW OF THE PARTICIPANTS

In addition to the sleep measurements, the NORAH team asked all of the participants how they would assess their sleep themselves – after all, the sleep experience and annoyances by aircraft noise are to a large degree a question of personal perception.

2011: frequent overflights cause tiredness

The morning after each night of measurements, the NORAH team asked all participants how sleepy and tired they felt. They used several scales for the answers, which are standard in scientific sleep studies. The researchers had expected that the residents subject to a higher noise exposure would also make a more negative subjective assessment of their sleep. And, in fact, for the investigation year 2011, when regular night flights were still taking place, the respondents felt subjectively more tired after a night with a lot of overflights.

2012 and 2013: tiredness increases despite less frequent waking

The scientists were more surprised by the answers of the participants in the second and third year of the study. Because although the sleep measurement showed that the number of overflights and wake-up reactions (glossary) had decreased, the participants felt increasingly tired and sleepy in the mornings. The introduction of the curfew on scheduled flights between 11 p.m. and 5 a.m. had thus not caused the people to make a more positive subjective evaluation of their sleep. This result can also be expressed in figures: at the same number of overflights, the negative perception of sleep rose from 2011 to 2013 by five to eleven percent. In total, the subjective sleepiness and tiredness evaluations in all three investigation years were in the middle range of the tiredness scale used. The result was also the same for persons who took part in all three years. The NORAH team thus assumes that uninvestigated and probably non-acoustic factors led to this result.

In 2013 the participants felt more tired and sleepy in the morning than in the previous years.

Sleepiness in the morning after rising

1 → fully awake
8 → very tired, major problems staying awake, fighting against sleep

Tiredness in the morning after rising

0 → wide awake
20 → dead tired

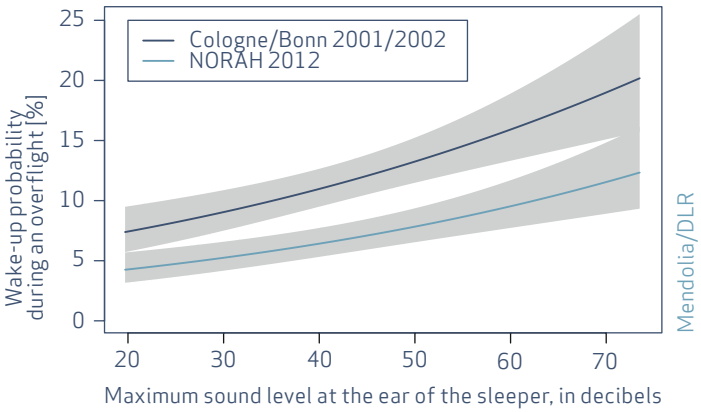
DO RESIDENTS AROUND FRANKFURT AIRPORT SLEEP BETTER THAN THOSE IN COLOGNE?

Around ten years before the NORAH Study, the DLR investigated the sleep quality in the area around Cologne/Bonn Airport. The director of the NORAH Sleep Study, Dr Uwe Müller, was also one of the researchers who investigated the quality of sleep in the Rhineland in 2001 and 2002. The results of the Cologne/Bonn study still have concrete significance, also for the residents around Frankfurt Airport: they provide the basis for the calculation of the Frankfurt Aircraft Noise Indices (glossary). However, the noise situation in Cologne/Bonn at the start of the millennium was different in important respects to the situation in the Frankfurt region at the time of the NORAH Study: in 2001/2002 there were continuous flights through the night in Cologne/Bonn; in addition to this, the proportion of older freight aircraft was considerably higher. This type of aircraft generates more noise in other frequency ranges than the passenger aircraft which currently make up most of the flights in and out of Frankfurt Airport. One of the tasks of the NORAH Sleep Study was to examine to what extent the Cologne/Bonn results could be transferred to the Frankfurt region. The researchers established differences in the sleep quality of the previous and present study participants.

People in Cologne/Bonn wake up more frequently

Due to the higher number of nocturnal flights, the residents around Cologne/Bonn Airport woke up more frequently. The probability of being woken up by an overflight with a certain sound level was also higher at Cologne/Bonn Airport.

Aircraft-noise-associated wake-up probability at Frankfurt and Cologne/Bonn Airports



The NORAH participants were less likely to wake up during an overflight than the participants of a study carried out in the Cologne/Bonn region in 2001/2002.

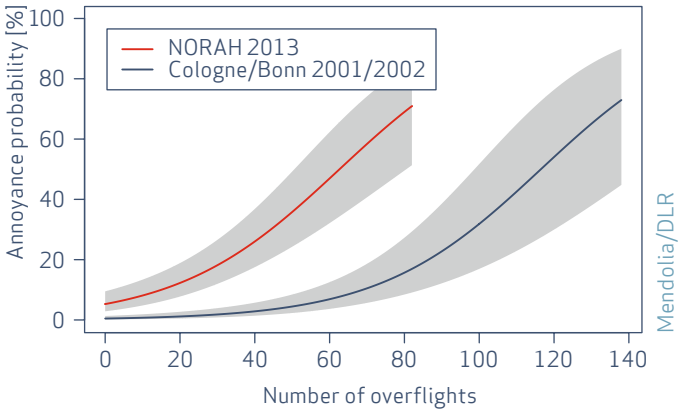
Less time in deep sleep

The residents around Cologne/Bonn Airport got less rest when they were asleep than the Frankfurt study participants after the introduction of the curfew on scheduled flights between 11 p.m. and 5 a.m. According to the sleep measurements carried out in the Rhineland, the participants spent less time per night in the deep sleep phase which is so important for rest. There could be several reasons for this difference, which is why the results must be interpreted with care. The NORAH team regards it as possible that they had trouble reaching the deeper sleep phases due to frequent interruptions at the start of the night. The different frequencies of the aircraft types may also have played a role. The NORAH team also regards it as possible that the investigated groups are different. A fourth possible explanation has to do with the fact that the evaluation of sleep recordings is not carried out automatically, but requires a human eye. This is why the people evaluating the two studies may not have interpreted the sleep recordings in an entirely standardised manner.

Annoyance higher in Frankfurt than in Cologne/Bonn

In addition to the sleep measurements, the scientists also asked the participants in both studies how severely they felt annoyed by the aircraft noise of the previous night. Here they established that the study participants in the Frankfurt region felt considerably more annoyed by similar noise levels and a similar number of overflights than the respondents ten years before in the Rhineland. It is not possible to derive an explanation for this result from the data. It does, however, correlate with the results of the NORAH Quality of Life Study.

Aircraft-noise-associated wake-up probability at Frankfurt and Cologne/Bonn Airports



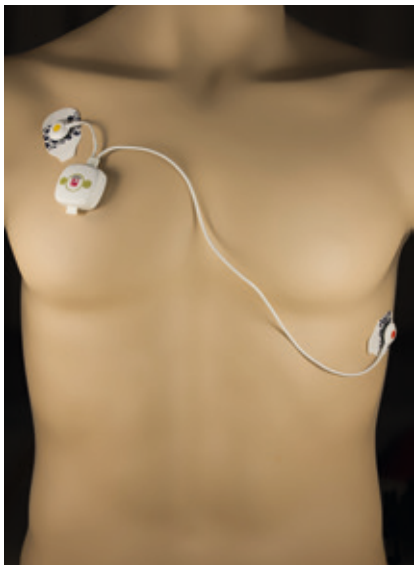
Compared with a study in the area of Cologne/Bonn Airport in 2001/2002, the participants of the Sleep Study in 2013 felt considerably more annoyed by the same number of nocturnal overflights.

NEW METHODS FOR THE ASSESSMENT OF REACTIONS TO NOISE DURING SLEEP

Sleep is much more diverse than most people are aware: during the night, we go through various phases of sleep. Dreams and dreamless phases alternate. Sleep research can measure all these various phases. Polysomnography (glossary) is regarded as the "gold standard" method here: with the aid of several electrodes attached to the head and upper body of a sleeping person, it is possible to determine precisely which sleep phases the sleeper has reached and when. The method has many advantages – but also a decisive disadvantage for many research projects: it is very complicated. This is why sleep studies often have to make do with very low numbers of study subjects. In order to overcome this obstacle, the NORAH team developed a simpler method in collaboration with US scientists from the University of Pennsylvania which could also be used in the future to analyse noise-impaired sleep – this will, however, require further research. The so-called "vegetative-motor" method requires just two electrodes. The method measures the nocturnal heart frequency and the body movements of sleepers. The US researchers already used the method in 2014/2015, after the NORAH measurements, in a study at the airport in Philadelphia. Further US airports are to follow.

Reactions to aircraft noise even during sleep

Scientists cannot draw the same conclusions from the measurement results of the "vegetative-motor" method as from the results of a polysomnographic analysis. It is not possible to tell, for example, which sleep phase a person is in. The measurement results are nonetheless very valuable for NORAH: they show that sleepers react physiologically to noises, for example aircraft noise – with accelerated heartbeat and increased body movements. For many overflights the scientists were able to determine in a comparison of the polysomnographic and the "vegetative-motor" measurement data that, although the sleepers did not wake up, they still reacted physiologically. Whether these nocturnal reactions have consequences for health will have to be the subject of future studies. The NORAH team regards it as possible, however, that the regularly accelerated heartbeat could, in the long term, increase the risk of cardiovascular disease.



Schmidt, DLR

In the "vegetative-motor" method only two electrodes have to be attached to the body. They measure the heartbeat of the study subject as well as record the physical movements.

INTERVIEW WITH STUDY DIRECTOR DR UWE MÜLLER: “THE HEART NEEDS TO REST AT NIGHT”

Dr Uwe Müller from the German Aerospace Center (DLR) in Cologne directed the NORAH Sleep Study. In an interview the physicist talks about whether the results surprised him, and about how he slept himself during the research project.

Schmitt/DLR

Dr Uwe Müller directed the NORAH Sleep Study.

NORAH Knowledge: Dr Müller, what do people need in order to sleep well?

Müller: A dark and quiet environment is very important. They should be able to lie comfortably and switch off from the worries of the day. It also helps to go to bed at roughly the same time every night and with the same routine. We also know from research that the light in the evening should be quite dim so that the sleep hormone melatonin can be released.

Apropos “the worries of the day”: worries also play a role in NORAH. People who had a more negative attitude towards air traffic were less likely to sleep well. Do you have any explanation for this?

No, that’s like the chicken and the egg. The study design of NORAH does not allow us to determine what was there first. Nonetheless, there is a clear connection: people who objectively sleep less well generally have a more negative attitude towards aircraft noise or the airport.

The NORAH participants slept better than the study participants ten years previously in the Cologne/Bonn area. But they still felt more annoyed by aircraft noise. How can this be reconciled?

Our results here correlate with those of the NORAH Quality of Life Study. There it was also shown that people felt more annoyed today by aircraft noise than they did several years ago. The annoyance depends only to a certain extent on the actual noise exposure. There are also non-acoustic factors that play a role – lack of confidence in the authorities, for example, or in the information provided by the airport, could have an influence. We do not know whether this was the case here. I regard it as plausible, however, that the responses of the Quality of Life Study also apply to our participants.

Which results surprised you in particular?

I was looking forward to seeing whether the wake-up probability in Frankfurt after the introduction of the night flight curfew would differ from the results of the Cologne/Bonn study. In Cologne/Bonn there was continuous night flight operation at the time. There are some moderate differences, which, however, due to the different study conditions, have to be interpreted with great care. For me the result is a further indication that the aircraft noise laws for determination of the nocturnal abatement zones in Germany have to finally move away from purely physical and acoustic values towards physiological values such as, for example, the wake-up reaction. And I was delighted that the "vegetative-motor" method worked so well. Although it does not measure the wake-up reactions, it is possible to determine when the heartbeat is accelerated due to aircraft noise even if the person does not wake up. The method is therefore more sensitive than the sole consideration of the wake-up reaction. We may have even found one of several possible further explanations of how nocturnal aircraft noise could increase the risk of cardiovascular disease. Whether this is actually the case will have to be the subject of future studies.

What might this connection look like?

The "vegetative-motor" method measures heart frequency accelerations and body movements. The heart needs to rest at night. We have found out, however, that overflights interrupt this rest and accelerate the heartbeat. This could lead to cardiovascular problems after long years of noise exposure.

How well did you actually sleep yourself during the NORAH Study?

It was quite mixed! For example, the stress was high in the summers of 2011 and 2012; that also had an effect on my sleep. I was on site at the time to recruit study participants and carry out preliminary investigations. I think it is very important to be on site personally. Sitting at a desk studying noise charts is completely different to experiencing the noise for yourself. At this point I would also express my sincere thanks to all the participants in the Sleep Study for their interest, their patience and endurance and their time. And thank you also to the project workers and students at the University of Gießen, who gave us decisive support by taking care of the study participants on site in the evenings and in the mornings, as well as the colleagues at the University of Pennsylvania for their valuable and intensive collaboration in the development of the new method.

Dr Müller, thank you for talking to us!

OUTLOOK

The NORAH Sleep Study investigated how people slept in the Rhine-Main Region during the investigation period, how aircraft noise influenced their sleep, and how they themselves assessed the quality of their sleep. The scientists also developed a method which could make it possible in the future to carry out studies with more participants than has hitherto been the case. The Sleep Study also raised new questions, which will have to be clarified by future studies.

What effects does accelerated heartbeat at night have on health?

With the new "vegetative-motor" method used by NORAH, the focus of the scientists was brought back to the fact that nocturnal overflights can, in many cases, increase the heartbeat of sleepers. It even happens that people appear to continue sleeping peacefully, but still show a physiological reaction. The Sleep Study was able to document these direct reactions. It cannot, however assess whether these reactions can have a negative impact on health in the long term and, for example, increase the risk of cardiovascular diseases. Further studies in the future will have to clarify this.

How often does aircraft noise cause waking up?

Even though the "vegetative-motor" method within the framework of NORAH shows a lot of potential for future sleep studies, researchers still attach great importance to the "wake-up reaction" (glossary) – the transition from a deeper sleep phase to the lightest phase or to waking up. The question as to how frequently aircraft noise triggers such a wake-up reaction is not easy to answer. This is because even in a quiet environment sleepers can wake up "spontaneously" during the night. This is why scientists in noise impact studies such as NORAH have to try to find out which wake-up reactions of their study participants can be attributed to noise, and which are just part of the normal sleep pattern. Thanks to the curfew on scheduled flights between 11 p.m. and 5 a.m. during the NORAH Study, the scientists were able to analyse much more precisely than in earlier studies how the timing of wake-up reactions changes with and without aircraft noise. Nonetheless, further studies could contribute towards a better understanding of how often we wake up spontaneously at night without any external influences, and how flexible the body is in adapting its wake-up reactions to noise influences.

With the new "vegetative-motor" method used by NORAH, the focus of the scientists was brought back to the fact that nocturnal overflights can, in many cases, increase the heartbeat of sleepers.

Glossary

You will find further explanations in the glossary on **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.

Frankfurt Aircraft Noise Indices
The Frankfurt Aircraft Noise Indices developed by the Airport and Region Forum (ARF) calculate the aircraft 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 Aircraft 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 sound level
The physical value which best describes how strongly nocturnal aircraft noise impacts on sleep is the maximum sound level of the overflight noise. The annoyance effect overall depends on the height and the frequency of occurring maximum sound 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.

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. Almost all of the investigations carried out in sleep labs use polysomnography.

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