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Effects of low-frequency pressure fluctuations, noise and vibrations on humans

A study published in April 2023 with 37 participants should give the all-clear that low level infrasound is not hazardous to health. The study was conducted between April 2017 and March 2020 /1/. Journalistically, the scientific results are immediately used to give the all-clear for the residential environment of wind turbines /2/. The group of people whose health is affected by infrasound is definite small. Nevertheless, there are "those affected" and there are scientists who have carried out robust studies to investigate causes and effects. Is this work obsolete? Are "those affected" untrustworthy and only imagining effects? It is conspicuous that the topic of infrasound is so absolute and that effects are doubted in their entirety and causes are supposedly excluded unambiguously. In 2007, the Robert Koch Institute summarised a state of knowledge that has not been scientifically expanded in the last 15 years [3]. The natural frequencies of individual body parts and organs listed by the Robert Koch Institute in Figure 1 are possibly one approach to explaining the effects of infrasound on the human organism. There is no scientific evidence or sufficient research yet.

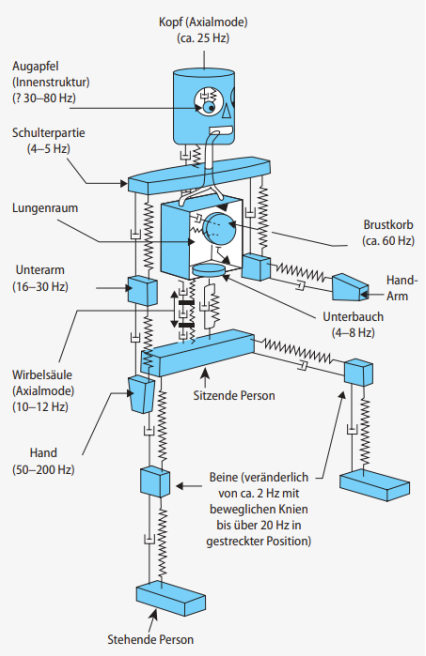

Figure 1: Simple mechanical model of the human body with its resonance frequencies (after Bruel&Kjaer from [3]).

How is infrasound interpreted by humans?

According to the Robert Koch Institute, the affected persons suffer from compulsive attention, due to which they have to constantly concentrate on this low-frequency sound as soon as it reaches the hearing threshold and is not covered by higher-frequency sounds. Among other things, they report chronic exhaustion ("fatigue") [3]. Schlüter [4] interpreted in 2014 that the human organism only ignores infrasound when it occurs as noise. Infrasound can be perceived if it is a narrowband frequency component that exceeds the noise. The tonality of infrasound is recognised by humans. The noise level at the respective frequency would then be relevant as a threshold value. As scientifically proven, one can neither name threshold values for levels nor describe the perception of sounds in narrow frequency bands or in octave or third octave bands, as it is not doubted in the hearing range for music and speech in humans.

Statistical evidence is not yet available, but it has been "observed" that women react more sensitively to infrasound than men. Slim people are affected more often - mass is known to dampen, possibly this also affects humans in terms of low-frequency vibrations. Older people lose hearing in the high frequency range. This may increase sensitivity to lower frequencies. The geometric dimensions of the

auditory apparatus in humans vary from person to person, so that cut-off frequencies are also different depending on the individual dimensions.

Explaining the variety of non-auditory symptoms reported by those affected should actually be a field of further application-oriented research. Presumably, secondary effects must also be taken into account, since the reported sound levels are very low and not only the auditory system is an adequate system for this.

It is also known that infrasound is often present for a long time before it has any effect on health. Thus, in the dissertation by Laura Buchwieser-Gremme 2022[5], one finds: "Infrasound is much more likely to be tolerated over a long period of time. ... Finally, it must be stated that an assessment of the effects of infrasound on the human organism must not be made lightly."

Dick Bowdler writes in 2018 as an experienced engineer and consultant in "A short history of the dangers of infrasound" [6] that " There is something about infrasound that invokes an air of mystery. Because it is not well understood it is easily sensationalized. Some of the events I have related may be amusing but people who are ill near wind farms are genuinely ill. It is a public health issue, albeit not a large one in terms of numbers but nevertheless it is one and it needs to be addressed. Focusing on infrasound is not helping those people."

Continuous exposure to low-frequency pressure fluctuations leads to a quota of tolerable exposure being exceeded and from a certain point on the person is sensitive and feels ill. Perhaps similar to an equivalent continuous sound level, which is often used in exposure control: short and loud or long and quiet are evaluated the same and possibly felt the same by the person.

Infrasound and wind turbines

In Germany, the effect of wind turbines on people tends to be a technical issue. A comparison of amplitudes and frequencies is used to sort out whether people's complaints are only based on imagination. Technically, it would be obvious that wind turbines cannot be responsible for health effects. A controversy among German scientists in the journal ASU Arbeitsmedizin, Sozialmedizin, Umweltmedizin (ASU Occupational Medicine, Social Medicine, Environmental Medicine) in 2021 clarifies the extreme positions that, on the one hand, there would be no danger for the population and, on the other hand, findings from affected people very much speak for a health relevance [7]. The group that considers the indications of those affected to be valid formulates a clear need for research, since there are "uncertainties in mammals and humans". Both "scientifically proven and plausible points of attack" exist for this. Different hypotheses should be pursued and already formulated causal chains should be continued. Evidence is lacking, although arguments are obvious. There would therefore be tasks for future research arising from this state of research. "The data available so far substantiate a considerable health risk that requires health policy action in the sense of preventive medicine."

With regard to the technically discussed amplitudes of Holzheu et al [7], our own investigations from 2011 to 2015 show that very low amplitudes do indeed lead to reactions in people [8; 9]. At the time, a doctor interviewed those affected personally and summarised that there were indications of constantly increased blood pressure, sleep and concentration disorders and reduced performance due to infrasound. In some cases, this went as far as suicidal thoughts [10]. The affected couple could no longer sleep in their own flat. "They felt oppressed and worried about their health" [10]. In another place, the affected person could not sleep. She moved out of the apartment building, which immediately led to an improvement in her health [9]. In each case, the cause was technical equipment and not wind turbines - in some cases, the mechanisms that led to the complaints were not localised [9].

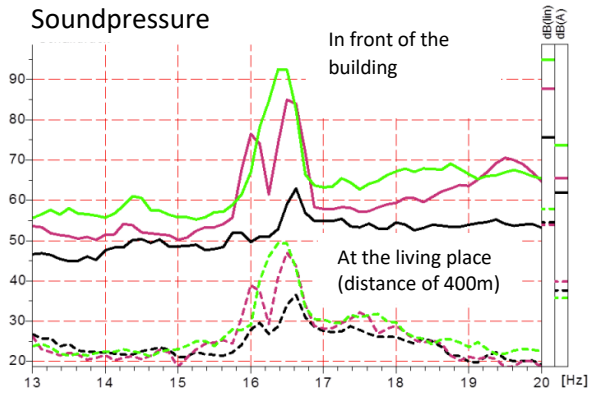

Figure 2: Sound pressure measurement 13 to 20 Hz [9]. The perception threshold of the human ear is 79 dB in the 16 Hz third octave.

Figure 2 shows examples of sound pressure levels above the frequency at one of the locations on the premises of an industrial company and at a distance of about 400 m in a flat in the living room with closed windows. Three operating conditions are shown. Even the lowest levels below 40 dB at 16.5 Hz were perceived. In [11] Kameier compares the data with the measurements of Holzheu [12]. In both investigations, the levels were always below the perception threshold of the average population. The industrial plants operated within the legal limits - a weaving mill around the clock 24/7 and a foundry also in three shifts 7 days a week, depending on the order situation. A small number of people were affected and complained of malaise, numbness in the limbs, insomnia or headaches. The continuous exposure to the foundry's grinding mill has such a long-lasting effect that an immediate shutdown of the machines is not perceived by the affected persons, which is not an unusual phenomenon for medical experts in the case of low-frequency noise. The time the inner ear needs to recover from low-frequency noise is longer than the time it is exposed to the sound itself. This may also be true for low-frequency vibrations. Medical professionals in general are not new to these complaints. Sources or source mechanisms were not known to the affected people, so bias did not influence the health complaints.

A purely psychologically motivated explanation pattern, as is often attributed to opponents of wind turbines, can be very definitely ruled out in our own investigations. Of course, people can be psychologically influenced - but to dismiss the entire infrasound problem with the perception threshold in the auditory range and a sleep disorder driven by imagination or other health complaints leads to withdrawal, silence or even possibly suicide in those affected [10,13].

Effects and damage of infrasound

In his 2017 dissertation [13], Zou estimated the economic damage caused by the commissioning of wind turbines in the USA. He correlated suicides with data from over 800 new large wind turbines. As an economist, he has calculated 33000 years of life lost from 997 suicides considered to a damage total of $3.3 billion as of 2010, or as much as $16 billion between 2000 and 2013. His work takes into account a great many conceivable influences and cross-comparisons with other death outcomes. His research is technically and economically sound and his statistical calculations are comprehensible. Figure 3 shows Zou's core result - the details of the analysis can be read in his dissertation. It is quite obvious that over the observation period of 3 years there is a change in the suicide rate with the commissioning of wind turbines.

What damage do wind turbines now cause globally? Zou [13] also calculates the damage caused by killed bats, which can thus no longer contribute to the ecological balance of insects and pests and are said to influence cotton production in the USA, for example. Zou is virtually uncited in the scientific community. Zou's publication attempts [13] from 2017 to 2020 are listed as cited just 13 times on Google Scholar [14].

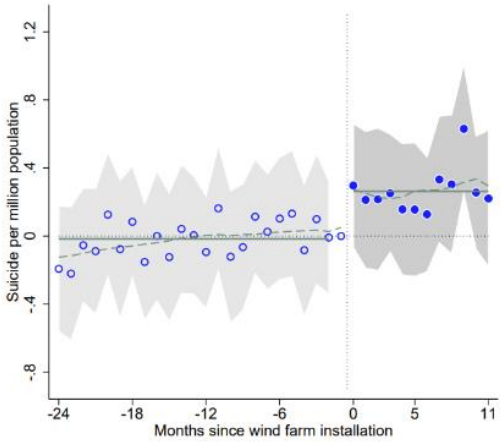

Figure 3: Is there a connection between the commissioning of wind turbines and suicide, Zou 2017 [13]?

In 2005, Wanka and Höppe [15] correlated low-frequency air pressure fluctuations with rescue service operations and traffic accidents in Munich. The background was meteorological aspects on the effect of Fön (falling wind from the mountains) in terms of weather sensitivity in people. Measurements were recorded with a precision barometer over a whole year in Munich. They correlated the number of daily emergency service calls caused by mental illness, suicide attempts and suicide with fluctuations in air pressure in the very low-frequency range. Schlüter [4] also interpreted this study as an infrasound study and submitted it to the Federal Environment Agency in 2013, which also responded and did not recognise any relevance for an infrasound problem in it [16].

Epidemiological perspective

The epidemiological studies are actually ignored in the infrasound assessment of the scientific world. The work of Wanka/Höppe [15] is only scientifically cited in 5 papers, possibly Schlüter [4] interprets too broadly. An update or a repetition of the Wanka/Höppe [15] study with a higher frequency range for the air pressure fluctuation could be initiated by the authorities or carried out by themselves. Is it not legitimate and understandable that one wonders why these considerable correlations between low-frequency pressure fluctuations and fatalities are not mentioned anywhere? Should a connection between infrasound, negative effects on humans and wind turbines be excluded in order not to discredit this fundamentally important technology of the energy transition?

Where criticism is voiced, industry interests prevail, as impressively described by Lagö and Persson 2019 [17]. It is about wind turbines that may be too loud. The highest court in Sweden claims that Lagö and Persson's [17] measurements is not valid because they are not certified by the Swedish authorities. "For certification, you usually have to be one of the companies that have large wind turbines. But these companies have no financial interest in showing that the wind turbines are louder - are louder than the technical documentation claims. ...” This international publication at a conference (Internoise2019) of acoustic engineers clearly shows that the sound levels are above the legal limit. The data was collected with professional equipment and expert sound engineers. The end result is that theoretical predictions (by the wind turbine owners and their experts) and measurements at the site of the house are in clear contrast to each other. The court believes that the manufacturer's calculations are correct because they show no deviation and are therefore trustworthy. Consequently, the homeowners lose in court, despite clear evidence.

Courts may also come to such judgments because untenable conclusions, e.g. of the Holzheu, Koch, Hundhausen group [7], are cited. of the Holzheu, Koch, Hundhausen group [7]: "There is not a single piece of evidence that infrasound below the perception threshold triggers reactions in people" -

Kameier's own investigations [8; 9] from 2015 and earlier show demonstrably and medically confirmed [10] something different, and the Robert Koch Institute also cites some cases from before 2007 [3] - confirmed by the courts, including psychiatric reports, that the affected persons are not to be assigned to a conspicuous group of people.

The Dessau Federal Environmental Agency classifies infrasound as a tolerable nuisance [18], but admits in 2020 that "test persons have classified infrasound as "somewhat" to "moderately" annoying" [19]. The Bavarian State Office for Environment also presents the facts in a rather simplified way, quoting: "The case law of the Senate and other higher courts assumes that infrasound - as well as low-frequency sound - from wind turbines does not in principle lead to health hazards according to the current state of scientific knowledge (...)". OVG Münster (8th Senate), judgement of 22 November 2021 - 8A 973/15 [20]. At what point or with what perspective can or may the perception of a numerically small group of affected persons be interpreted as a health hazard? Zou's argumentation [13] - his attempt at proof - goes too far for courts, science and the press - the reaction is complete ignorance on the point of suicide.

Classification of infrasound

The "classification from an acoustician's point of view" by S. Müller 2022 [20] is alarming, as he concludes: "The facts on wind turbine infrasound are unambiguous and there is no need for further research in this regard". The need for interdisciplinary research on the effect of low-frequency sound and vibrations on humans will be discussed rather hypothetically in the following. Actually, there is sufficient evidence that one should be very cautious in judging infrasound and in condemning those who may be affected by infrasound. Many cries for help - from all over the world are not sufficiently followed up, exemplarily the film 'Infrasound' with Dr. Marianna Alves-Pereira [22] - the last three minutes are sufficient as argumentation for the plight of infrasound affected people. Furthermore, the original is quoted from Frey/Hadden (Australia 2007) [23]: *"At times it is difficult to fall asleep with the 'pounding' of the turbines. One is often awakened by the 'droning' noise of the turbines, finding it most difficult to fall back asleep. The noise becomes so disruptive; one can concentrate on nothing else but the constant droning. During the winter months, the noise is quite unbearable at times, sounding like drums beating constantly in the background. During the summer months, we cannot have our windows open ...' 'Advocates for these facilities will often compare this `threshing' noise to the `peaceful' sound of waves beating against the rocks at the seashore; but I ..."*

In 2015, before the Paris climate conference, Deutschlandfunk reported on health concerns in the wind power country of Denmark, citing that there are affected and unaffected people living in the immediate vicinity. Animals and humans, however, are unequivocally affected by health risks in Denmark as well. [24]

The infrasound sources localised by Kameier [9] were probably not a problem for years. However, the infrasound then at some point and somehow became a problem with sleep disturbances, tingling in the limbs and headaches. The example of the cloth factory shows that the levels over 250m from the machines causing the noise to the place of residence (inside - through windows or walls) of those affected only decrease by 15 dB. In the case of the foundry, it is 25 dB in quiet operating conditions (<40dB near the source) or 43 dB in loud operating conditions (>90dB near the source). The attenuation is therefore level and frequency dependent. The role of a tonality is evident in this context and would have to be studied in more detail in long-term investigations.

Perception of infrasound

Levels, or rather the height of the amplitudes, are not decisive, but the continuous exposure is. Furthermore, the "signature recognition" in the brain could cause the sound to appear abruptly on our

auditory surface at some point. This is preceded on the one hand by the continuous stress, but also by sensitisation, which takes place simultaneously. Like an earworm, as with music, our ear reacts to these now consciously perceived low level tones. Annoyance can have quiet but also loud levels, that is individual. But actually loud sound sources must also be taken into account. But what is loud, what is quiet? People are individual in this respect. Some people hear finely and react to nuances and little things, and many things are too loud for them. Body perception, i.e. being able to feel sounds, is also not unusual for some people. Exposed musicians can be mentioned as an example.

In human perception, it must be taken into account that the ear not only has two sides, not only left and right, but that there are also differences in the hemispheres of the brain that process the signals - meaning different microstructures. It is known that musicians often find one side (of the ears) more important for music than the other. One side may also be more important for speech and telephoning. It has been observed by sufferers that, in the case of a "buzzing sound", only the muffling of one ear reduces the effect of the sound. If the other ear is closed or muffled, the Hum remains almost unaffected. Perception is highly complex, so the concept of "loud level" is too thin in its statement. Tone sequences that generate absolute goose bumps are known from musical concerts. Some tones are barely audible, floating in space, very soft, but the body reaction is strong. In any case, the absolute level is less decisive for pleasant sounds than frequency and probably also conditioning. These experiences could be researched and compared in terms of positive and negative experiences.

What is difficult in the current observation is that mostly pure sine tones are used in artificial short-time studies. However, humans do not classically hear sine tones but rather frequency segments (ntel octaves) as sound and noise. In principle, continuous exposure is harmful and causes stress. Loud levels damage the hearing and also cause stress, which affects our entire organism. Think of the industrialist Krupp, whose villa leaned against the factory building with the steel presses. Every pounding was euphony for him and meant money, it drove his wife crazy.

Further procedure and research perspectives

It is difficult to have an open discussion on the topic of infrasound, as what can be described as "unresolved" relevance for wind turbines can be found in many publications and also peer-reviewed dissertations. Is there a need for research or is everything known? Are previous studies and their research designs helpful for those affected? Does it make sense to address the cries for help from those affected? Could those affected by infrasound be compensated if they cannot be helped or are the problems of humans and animals not really induced by infrasound but can only be specifically explained from person to person? Do we really need any research at all to investigate the effects of infrasound or is it impossible to explain it anyway because of the psychologically explainable nocebo effects? What can be declared as proven according to the current state of affairs?

For energy transition and transformation, wind turbines are a central aspect for the provision of electrical energy. Compensation for the (infrasound) victims of this technology should be financially feasible and protection against "free riders" can be developed.

Studies on infrasound are necessary as long-term studies. The short-term exposure of test persons to sound has so far not been able to help those affected by industrial infrasound. It makes no sense at all to experiment with people on the subject of infrasound. Only epidemiological studies can lead the way when it comes to the design of further studies. Exposing test persons to infrasound is dangerous and studies based on it have not led to any usable results to help the group of people affected by infrasound. It helps those affected if the public debate is conducted objectively and causes and effects are not categorically excluded [28,29].

Experience, opinion and hypotheses

- The larger wind turbines are, the stronger their effect on people presumably is. About two-thirds of the momentum of the incoming flow can be used and is redirected into a swirl in the wake of the wind turbine. This influence on the flow is accompanied by an interaction of the rotating blades and the wind of the incoming flow. Non-optimal alignment of wind direction and the blade profiles in the rotating relative system cause flow separation, an audible whoosh-whoosh sound with tonal frequency components from infrasound across the entire audible range is produced.
- When it comes to the tonality of an event, how far the amplitude of the sound protrudes from the noise of the background sound plays a clearer role than the height of the absolute level.
- The audible noise of wind turbines is no longer the focus of research or manufacturers, as legal requirements are consistently met. Quiet noises can be disturbing due to periodicity or continuous fluctuation of levels and thus lead to psychological stress. Third-octave spectra are not suitable for low frequencies, as tonalities are masked in noise [12]. The digital third-octave filters, which are based on analogue technology, assign pure sine tones not only to one third-octave band but to several bands due to the finite slope and the overlapping cut-off frequencies. The amplitudes of the low frequencies are thus distributed over several one-third octaves and are lower than with a linear narrow-band observation by means of FFT analysis.
- With regard to the description of low-frequency pressure fluctuations, it must be taken into account in the signal analysis that quite long time segments are required for the Fourier analysis for a very fine frequency resolution. For example, in some of our own investigations, the energy was averaged over a whole hour [8]. With fine frequency resolution and averaging, the character of an amplitude modulation, which is present in rotating machines, is lost [11,26,27]. The loudness, i.e. the sound pressure level, varies significantly from its level at the distance of the modulation frequency [11]. In the case of wind turbines, the modulation frequency is the so-called blade passing frequency (typically <0.5 Hz) as the speed multiplied by the number of rotor blades (3 as a rule). The clearly audible noise of a wind turbine in the immediate vicinity is probably due to a non-optimal flow around the rotor blade profiles and generates a broadband noise (white noise). The rotation generates Doppler frequencies as sum and difference frequencies with that blade passing frequency [27]. In order to induce structure-borne vibrations through airborne sound, cf. Figure 1 [3], countless tonal frequency components are available over the entire frequency range [11]. "Resonant catastrophes" require little energy to excite mechanical structures, human organs or the human corpus itself. In terms of human or mammalian organisms, there is a lack of studies on this topic as far as continuous 24/7 exposure is concerned. Comfort studies in the automotive sector or occupational health and safety, especially of truck drivers, could possibly be usefully exploited from this point of view.
- On-shore wind energy technology is only a bridging technology of the transformation. Companies may have recognised this long ago and are focusing on the off-shore market. The rotor of an on-shore turbine (5 MW) covers an area of about 1.5 football fields. The rotor of an off-shore turbine (12 MW) covers an area of about 5 football fields. Onshore wind turbines will gradually disappear by 2050, presumably for purely economic reasons.
- Weather sensitivity and infrasound sensitivity may be correlated [25].
- According to Zou [13], there is no epidemiological study to date that clearly establishes a link between low-frequency noise and sleep disorders. The "new" study [1] from 2023 (conducted in 2017 to 2020) does not provide a sufficiently comprehensive database with only 37 people included.

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