Ears Project **Communiqué:**

Assessment and safety of non-audible sound

June 2015

Introduction

In our daily life and at workplaces many sources emit airborne ultrasound or infrasound either intentionally or as a by-product of their operation. There are numerous indicators that infrasound and airborne ultrasound events influence human beings and that sound at such frequencies can be perceived. However at present, the precise mechanisms of sound perception at these frequencies are unknown and this lack in understanding is reflected by the status of limiting existence of regulations, exposure limits and standards. Evidence and relations of linking energy content to hearing hazard has not been available so far and the need for conclusions and mitigating safety criteria and a risk assessment protocol exists.

During the last 3 years the project EARS which was funded by the European Union within the European Metrology Research Programme investigated perception mechanisms of infrasound and airborne ultrasound by the aid of objective methods from audiology and neural imaging to improve the rationale and evidence base for assessing sound exposure within these frequency ranges. This communiqué will summarize most of the important results and conclusions for a presentation to the public. The intention is to contribute to and expand the available knowledge in this field although the project team is well aware of the many tasks and problems and questions still in need of further research.

Infrasound

Data

For a quantitative description of hearing at infrasound frequencies subjective data were determined as threshold and loudness values. From investigation of a sample of test persons hearing threshold data were determined and average values were obtained which are summarized in table 1.

Table 1: Average monaural hearing threshold for eighteen normal hearing subjects aged between 18 and 25 years.

Frequency (Hz)	Hearing threshold (dB re 20 µPa)
2,5	120,66
3,15	117,85
4	112,56
5	109,75
6.3	104,05
8	99,15
10	95,42
12,5	89,50
16	82,82
20	76,18
40	49,10
63	39,42
80	35,10
125	26,40

Further experiments dealt with the determination of equal-loudness-level contours which are published in [1].

Perception mechanisms

Through use of neuroimaging techniques such as magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) contributions to an understanding of the perception of infrasound by the hearing organ have been obtained. It was shown that infrasound with sound pressure levels higher than the hearing threshold activates the auditory cortex down to frequencies of 8 Hz. First evidence could be delivered that below about 20 Hz the mechanism of perception possibly changes so that other sensory processes produce input into the auditory cortex. By fMRI resting state experiments, perception was detected for sound pressure levels slightly below the hearing threshold in addition to activation of regions where the brain processes emotional activity.

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Assessment strategy

Since the health risk linked to infrasound exposure is most probably more due to annoyance and arousal, than to real damage of the cochlear amplifier, we recommend that the exposure limits are set along the hearing threshold itself. As does the German standard DIN 45680, the 'sensation threshold' should be set to represent 90% of the population; i. e. the exposure limit should be set at the 10 % percentile of a subject group representing the part of the population with healthy hearing.

This strategy is of course still under discussion with respect to the result of emotional response also for sound pressure values below hearing threshold. Further data are required for a rigorous and authoritative estimation.

Limit values

Following this strategy and the current knowledge the limit values of table 2 are recommended:

Table 2: Proposed acceptance levels based on the 10 % percentile hearing threshold values determined in the EARS project.

3rd octave midband freq. (Hz)	2,5	3,15	4	5	6,3	8	10	12,5	16	20
Acceptance level (dB re 20 µPa)	114	108	108	102	99	96	91	85	76	68

Airborne ultrasound

Metrological basis

To improve the metrological basis of measurement at ultrasonic frequencies a primary standard for ultrasound calibration of microphones has been established. Traceable measurement of airborne ultrasound output of devices is now possible for the first time, using a newly developed measurement set-up and measurement methods for the characterisation of typical sources. Sound pressure levels with peak-values up to 147 dB were detected from commercially available devices.

Data

As in the case of infrasound, hearing thresholds were determined from a group of test persons. Only a limited subset of test persons was able to hear the signals within the technical and ethical restrictions of the presented sound pressure level. Table 3 summaries the values obtained.

Table 3: Average monaural hearing threshold (with overall minimum and maximum) for normal hearing subjects aged between 19 and 33 years.

f (kHz)	Hearing threshold (dB re 20 µPa)			Number of ears
	Minimum	Median	Maximum	
14,00	18,1	32,9	67,1	26
15,75	23,5	59,3	94,8	26
16,90	35,4	75,1	109	26
19,10	59,6	98,5	114	24
20,70	84,1	109	117	21
21,50	96,5	105	109	8
22,40	101	106	110	8
23,75	109	109,5	110	4
24,20	109	110	111	3

Perception mechanisms

Brain imaging methods were also used to study ultrasound perception, but in contrast to the infrasound stimulation no activation could be detected for frequencies at 16.9 kHz and higher. This holds also for the few cases where test persons reported to hear an audible tone. Owing to the limited data set, this result is interpreted only as a first indication that perception of airborne ultrasound by the auditory system is limited. Note that no assumption can be made for perception of ultrasound by bone conduction, as this was not tested.

After the hearing experiments all test persons were asked to rate the annoyance of the test stimuli. All test persons who heard sound above 16 kHz reported that this had been rather annoying.

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Assessment strategy

The findings of this study lead to the proposal of a strategy for the assessment of ultrasonic noise: Prevent any annoyance as fundamental impact on humans by avoiding even the perception of airborne ultrasound. The basis for this strategy is the measured hearing threshold data. At high frequencies between 10 and 20 kHz hearing thresholds show significantly more variation between individuals than at conventional audible and even at infrasound frequencies. Additionally, the age related effect that younger adults and children perceive frequencies between 10 and 20 kHz at lower levels than older adults do [2], is also much more pronounced in comparison to conventional audible and infrasonic frequencies. For ultrasound above 18 kHz, this effect lessens, but there the thresholds are very near to loudness levels that cause annoyance. To account for this, the 1 % percentile or the minimum threshold of an appropriate data set should be used. It is also proposed to provide extra margins for groups of individuals with specific ultrasound hearing sensitivity.

Limit values

Applying this strategy and the current knowledge [3] the limit values of table 4 are recommended.

Table 4: Proposed acceptance levels based on Lawton[a] [3] and the minimum hearing thresholds[b] from literature [2, 4, 5] and the EARS project (table 3).

3rd octave midband freq. (kHz)	10	12,5	16	20	25	31,5	40	50
Acceptance level (dB re 20 µPa)	75[a]	75[a]	75[a]	77[b]	102[b]	110[a]	110[a]	110[a]

All data presented and conclusions drawn are a first attempt to improve the scientific rationale for noise assessment in the frequency ranges of infrasound and airborne ultrasound. The project team is well aware that many problems still have to be solved in future research.

Literature:

[1] Kühler R, Bauer M, Hensel J, Sander-Thömmes T, Koch C: Auditory Cortex Activation by Infrasonic and Low-Frequency Sound of Equalized Individual Loudness. Proceedings of 10th EuroNoise, 2015, Maastricht, NL

[2] Lee J, Dhar S, Abel R, Banakis R, Grolley E, Lee J, Zecker S, Siegel J.: Behavioral Hearing Thresholds Between 0.125 and 20 kHz Using Depth-Compensated Ear Simulator Calibration. Ear Hear 2012; 33(3): 315–329

[3] Lawton BW: Exposure Limits for Airborne Sound of Very High Frequency and Ultrasonic Frequency. ISVR Technical Report No 334, University of Southampton, April 2013

[4] Ahmed HO, Dennis JH, Badran O, Ismail M, Ballal SG, Ashoor A, Jerwood D.: High-frequency (10-18 kHz) hearing thresholds: reliability, and effects of age and occupational noise exposure. Occup. Med. 2001; 51(4): 245-258

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