Noise annoyance

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27.11.2023

Definitions of noise

- *Sound which is annoying or has adverse effects on hearing.*
- *Unwanted sound.*
- *Any sound, which is unpleasant, loud, or disturbs the current activity.*

- Judgment depends on the **environment** (what people expect) and on-going **activity**/job demand (what people can stand).

- In addition, there are personality features that affect the judgment.

Environment

- Home
- Home yard
- Nature, forest
- School
- Office
- Factory
- Theatre
- Gym
- Restaurant
- Vehicle

Activity/job demand

- Sleep
- Relaxing
- Studying, working
- Relaxed reading
- Communication
- Listening
- Sport
- Driving

Describe the situations where you have perceived noise to be annoying?

Non-auditory effects of noise on human

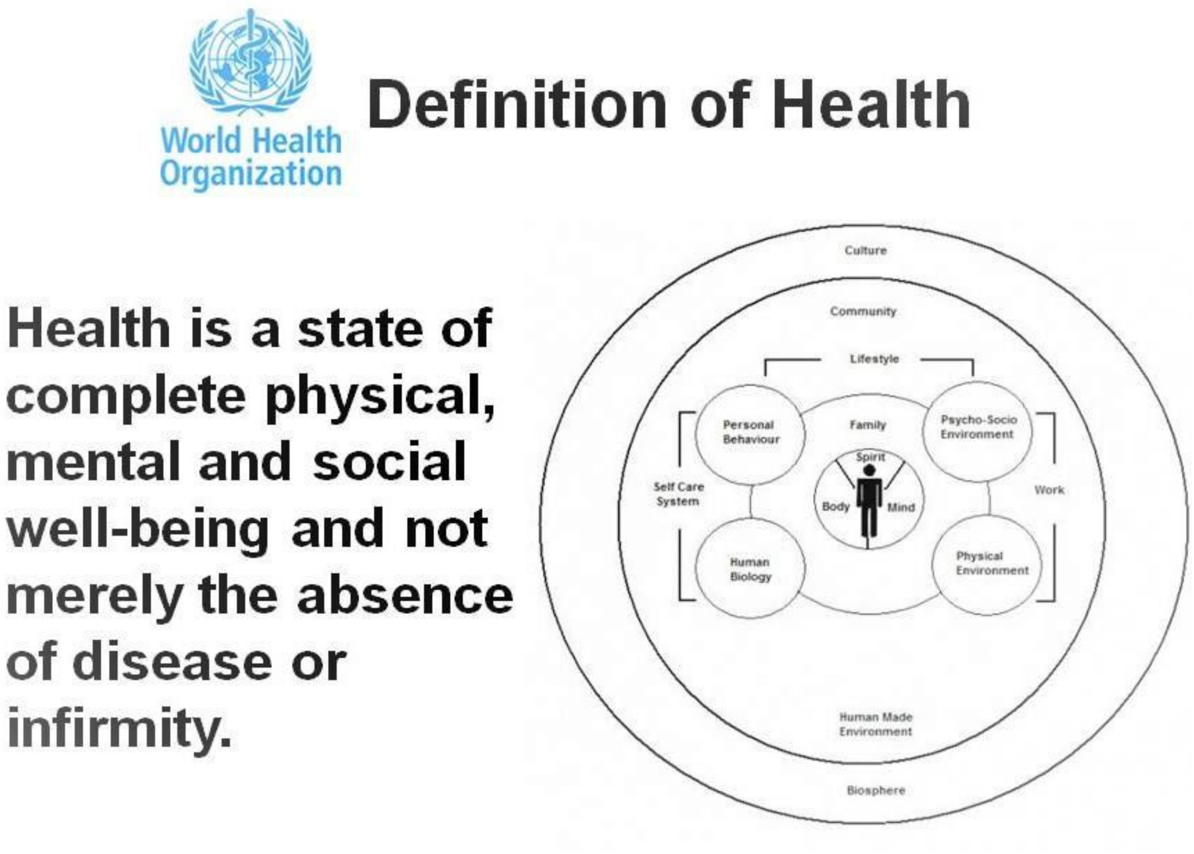
- Annoyance (noisiness)
- Disordered body function: sleep disturbance
- Deterioration of cognitive functions
  - Concentration
  - Attention
  - Short-term memory
  - Long-term memory
  - Learning
- Communication
  - Hearing, Speech intelligibility
  - Speaking
- Stress-induced body responses
  - Cardiovascular functions (heart rate, heart rate variation)
  - Endocrine system (stress hormones)
  - Metabolism
  - Immune system
- Vocal disorders

Long exposure to highly annoying noise increases the morbidity in several diseases.

Jauhiainen et al, (2007) Suomen ympäristö

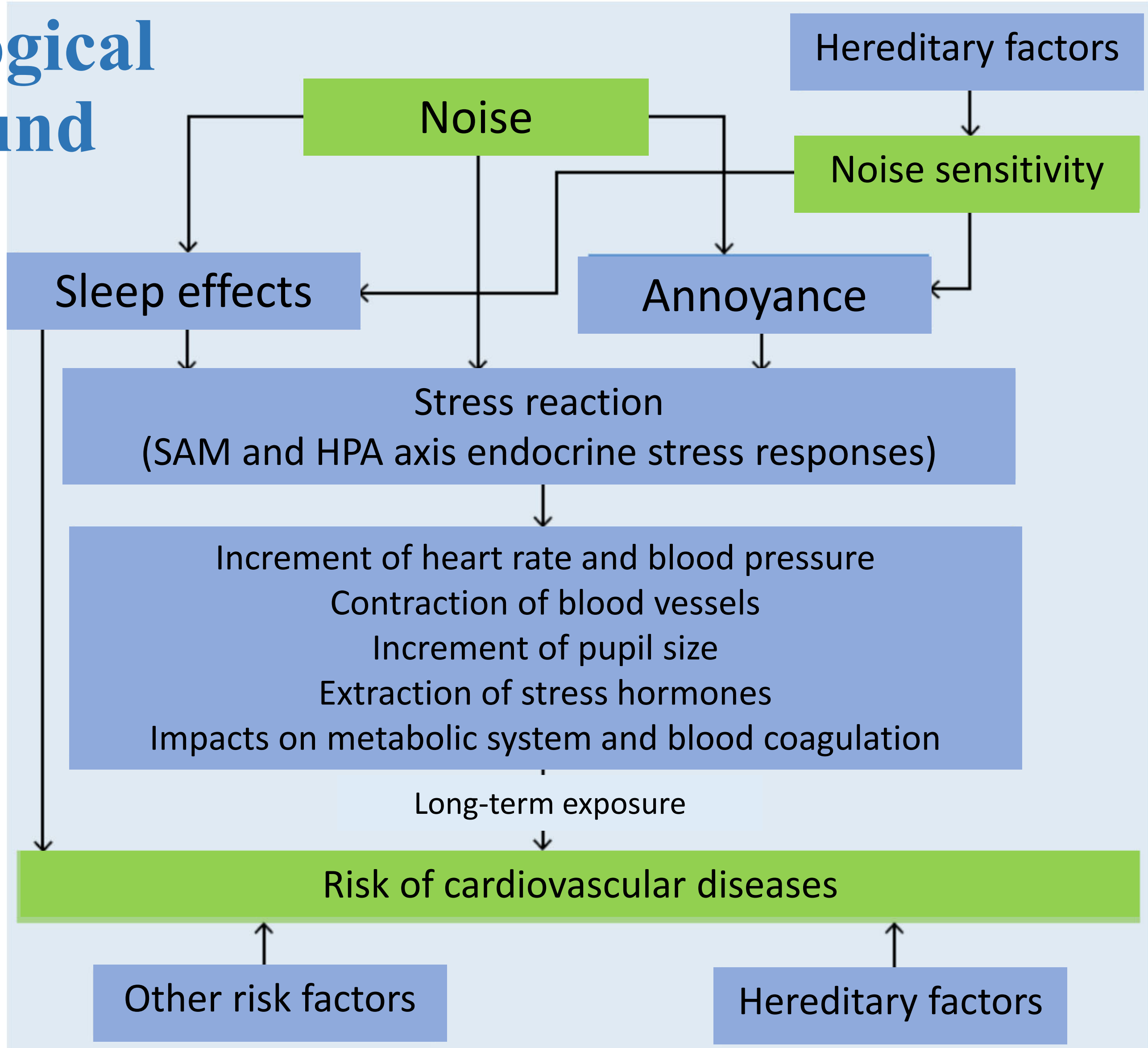
Noise annoyance

- WHO (1948) definition of health:
  - ”*Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity*”.
- It is, thus, not necessary to focus only on diseases or symptoms of impaired health, but to also to measure *well-being* in a wider sense.
- Responding to noise by **high annoyance** is, in the light of the WHO definition, itself an adverse effect that should be avoided in order to retain well-being.



Non-auditory physiological effects of annoying sound

- Hearing is a warning system
- Sound increases the arousal which affects the central nervous system to assess the threat and plan the survival reactions.
- **Noise,** i.e., **annoying sound,** produces **stress**, when the individual has no other means to avoid the noise.
- Prolonged exposure to stress may lead to permanent increment of blood pressure and more severe effects.
- Long-term exposure to noise leads to the increased risk of cardiovascular diseases.
- High noise sensitivity increases the risk of morbidity
- Noise sensitivity is also a risk factor



Heinonen-Guzejev (2012) Suomen lääkärilehti

Measurement of noise annoyance (ISO/TS 15666)

How much the noise of source X has bothered, disturbed or annoyed you?

0	1	2	3	4	5	6	7	8	9	10
Not at all										Extremely

Annoyance is usually measured using an 11-step scale.

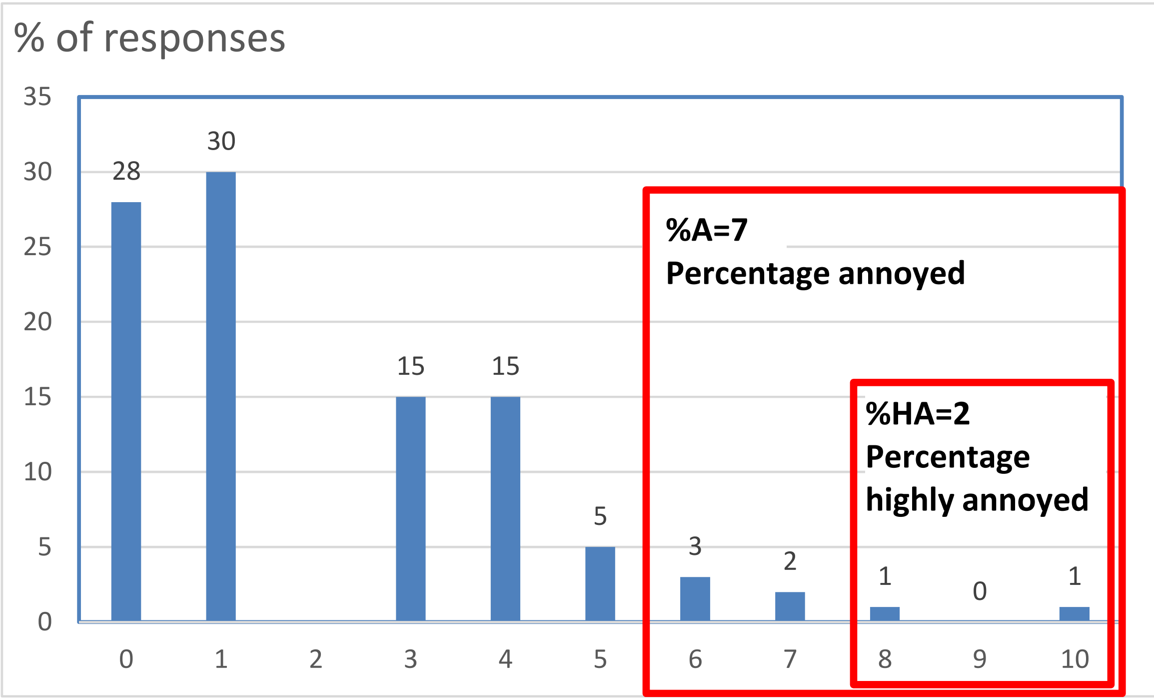
For logistig binary regression analyses, a binary variable is created:

- 0 for those below a limit and
- 1 for those above the limit:

Limits:

- **%A**: 1 when annoyance ≥ 6
- **%HA**: 1 when annoyance ≥ 8

Figure gives example data of 100 subjects exposed to 35-40 dB road traffic noise.



Noise annoyance and activity disturbance before and after the erection of a roadside noise barrier[a]

Mats E. Nilsson[b] and Birgitta Berglund
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(Received 4 September 2005; revised 5 January 2006; accepted 6 January 2006)

Questionnaire studies were conducted in a residential area before and after the erection of a 2.25 m high noise barrier of conventional type along a heavily traveled road (19 600 vehicles/24 h). The interval between studies was two years. Houses closest to the barrier received a sound-level reduction from ~70.0 to 62.5 dB L_{den} at the most exposed facade. The sound-level reduction decreased with distance to the road, and was negligible for houses at more than 100 m distance. Up to this distance, the noise barrier reduced residents' noise annoyance outdoors and indoors as well as improved speech communication outdoors. Indoors, speech communication and sleep disturbance were slightly but nonsignificantly improved. Predictions of the number of annoyed persons from published exposure-response curves (in L_{den}) agreed with the percentage of residents being annoyed when indoors, before and after the barrier. Conversely, the percentage of residents being annoyed when outdoors clearly exceeded the predictions. These results suggest that these exposure-response curves may be used in predicting indoor situations, but they should not be applied in situations where outdoor annoyance is at focus.

FIG. 1. Aerial photograph of studied residential areas taken before the noise barrier was erected. The white lines show location of the future barrier. The apartment buildings of the reference area are marked by arrows.

Nilsson and Berglund 2006 *J Acoust Soc Am*

TABLE I. Number of respondents and houses at various distances (m) to the center of the main road.

	Experimental area						Reference area
	<25 m	51–75 m	76–100 m	101–150 m	151–225 m	>225 m	55–220 m
No. of respondents	52	47	31	35	62	77	166
No. of houses	29	26	18	23	45	48	126[a]

[a]Apartments.

Nilsson and Berglund 2006 *J Acoust Soc Am*

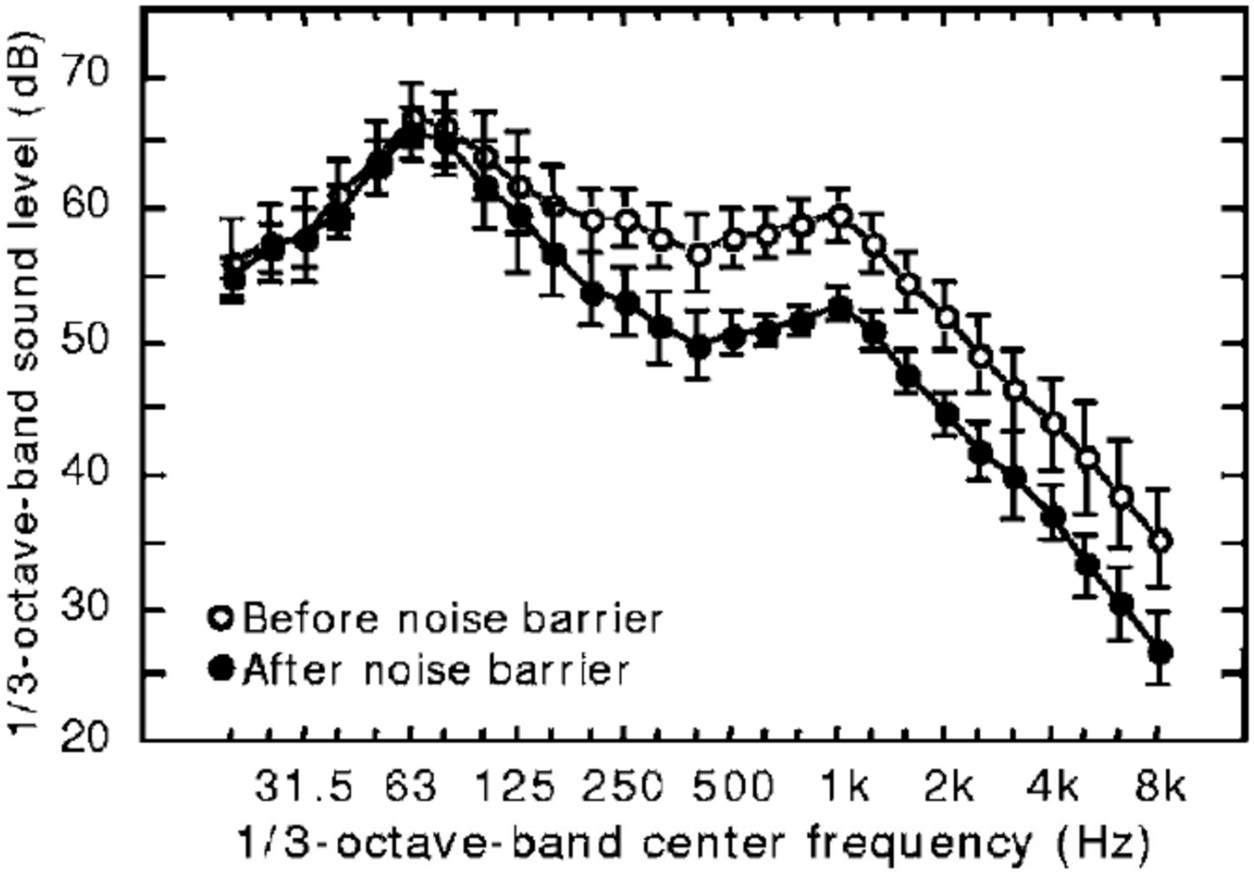


FIG. 2. Spectra for 45 min measurements conducted in eight gardens closest to the main road (23 m). Points show arithmetic averages of 1/3-octave-band sound levels ($L_{eq,45min}$) from eight measurements conducted before (open circles) and after the barrier (filled circles) was erected (error bars: ±1 standard deviation).

Nilsson and Berglund 2006 *J Acoust Soc Am*

TABLE II. Number of respondents in the experimental area according to noise contour (dB L_{den}), distance to center of main road (m), and study occasion (before and after the barrier was erected).

Contour dB L_{den}	<25 m		51–75 m		76–100 m		101–150 m		151–225 m		>225 m		*Total*	
	BS[a]	AS[b]	BS[a]	AS[b]	BS[a]	AS[b]	BS[a]	AS[b]	BS[a]	AS[b]	BS[a]	AS[b]	*BS*[a]	*AS*[b]
⩽45.0	0	0	0	0	0	0	0	2	20	34	60	71	*80*	*107*
>45.0–47.5	0	0	0	0	0	3	4	15	34	28	17	6	*55*	*52*
>47.5–50.0	0	0	0	0	3	17	23	18	6	0	0	0	*32*	*35*
>50.0–52.5	0	0	0	24	11	9	6	0	2	0	0	0	*19*	*33*
>52.5–55.0	0	0	0	23	15	2	2	0	0	0	0	0	*17*	*25*
>55.0–57.5	0	0	33	0	2	0	0	0	0	0	0	0	*35*	*0*
>57.5–60.0	0	0	14	0	0	0	0	0	0	0	0	0	*14*	*0*
>60.0–62.5	0	0	0	0	0	0	0	0	0	0	0	0	*0*	*0*
>62.5–65.0	0	52	0	0	0	0	0	0	0	0	0	0	*0*	*52*
>65.0–67.5	0	0	0	0	0	0	0	0	0	0	0	0	*0*	*0*
>67.5–70.0	0	0	0	0	0	0	0	0	0	0	0	0	*0*	*0*
>70.0–72.5	52	0	0	0	0	0	0	0	0	0	0	0	*52*	*0*

[a]BS= "Before-study," conducted before the barrier was erected.
[b]AS= "After-study," conducted after the barrier was erected.

Nilsson and Berglund 2006 *J Acoust Soc Am*

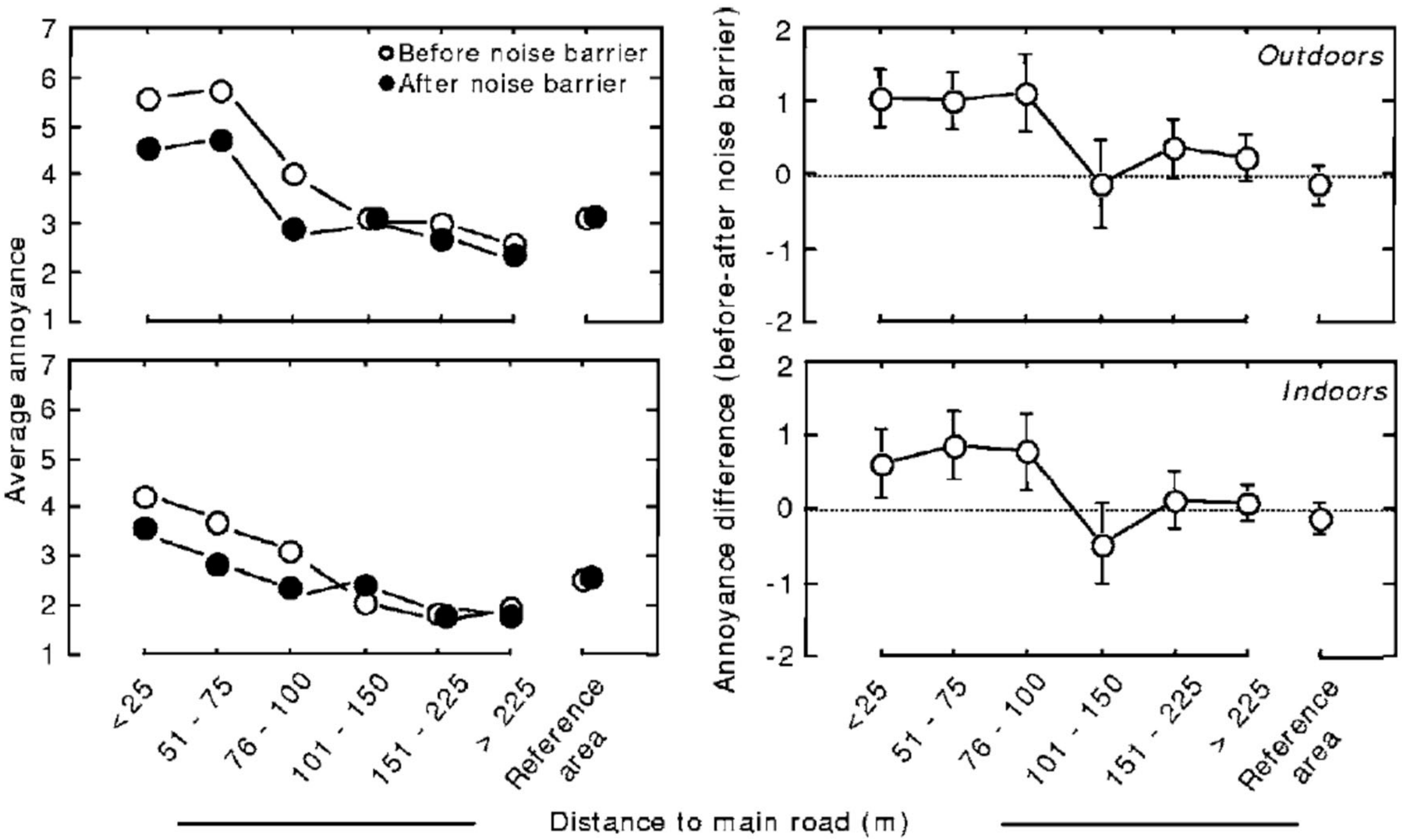


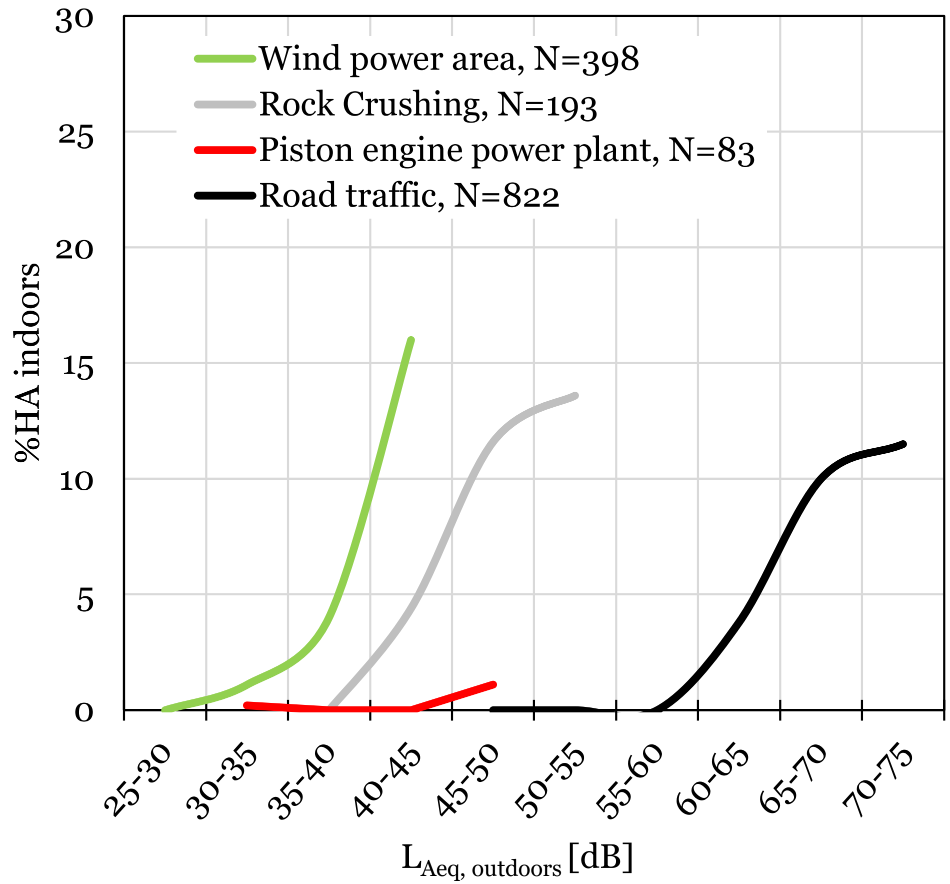
FIG. 3. Road-traffic noise annoyance (left panels) and annoyance difference between study waves (right panels), each plotted as a function of distance to the main road. Upper panels: outdoor annoyance. Lower panels: indoor annoyance. Left panels: Open symbols=before the barrier; filled symbols=after the barrier. Bars: 95% confidence intervals.

Annoyance response scale: 1 Not at all, 7 Very much

Nilsson and Berglund 2006 *J Acoust Soc Am*

Dose-response relationship (DRR)

- DRR tells the prevalence of highly annoyed (%HA) people among the population at different sound levels
- A.k.a. *exposure-effect relationship*
- We determined the DRR for four different environmental noise types in four independent surveys using exactly the same 5-step response scale.
- Significant differences were found.
- Why?



Meaning of $L_{Aeq,outdoors}$

Wind power: level during maximum energy production, which occurs only 10% of time on annual level.
Road traffic: daytime level $L_{Aeq,07-22}$. Nighttime level usually 7-10 dB lower
Rock crushing: Daytime level $L_{Aeq,07-19}$. Closed during evenings, nights, and weekends.
Piston engine power plant: Same level day & night.

How annoying do you find the sound?

1. Do not notice
2. Notice but not annoyed
3. Slightly annoyed
4. Rather annoyed
5. Very annoyed

There is no absolutely right DRR, since depends on the study

- Schultz (1978) published the first DRR of road traffic noise.
- It was based on 453 data points worldwide
- The data is extremely scattered
- Why?

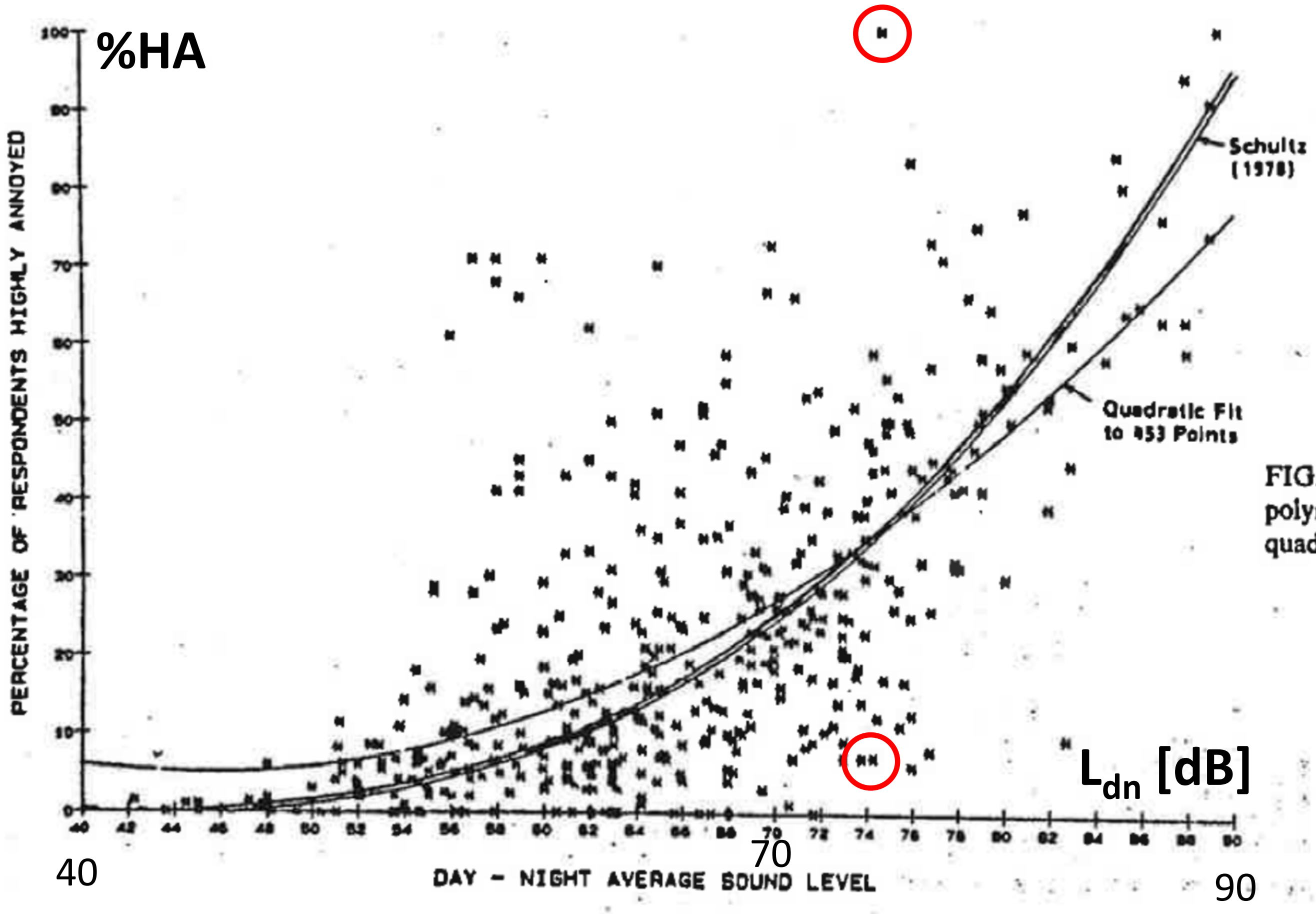


FIG. 14. Comparison of 1978 third-order polynomial fitting function with present quadratic fit to 453 data points.

230 J. Acoust. Soc. Am., Vol. 89, No. 1, January 1991 Fidell *et al.*: Noise dosage effects 230

Fidell et al. (1991)

Noise annoyance of environmental noise

- Noise annoyance in real living environment is not explained well only by noise level or sound quality.
- Non-acoustic factors usually explain annoyance better than sound level and/or sound quality.

Important non-acoustic factors in residential context:

Individual (person)

- Noise sensitivity
- Neurotism
- Extraversion
- Attitudes towards source
  - Fears
  - Benefiting from source
- Coping-ability
- Stimulus screening ability
- Home ownership
- Visibility of source

Social (area/group)

- Attitudes
- Trust towards authorities
- History of area
- Expectations
- Participation in land use design
- Benefiting of the society from the source

Flindell & Stallen 1999

Psychoacoustics (PA)

- **PA** is the scientific study of sound perception and audiology.
- More specifically, it is the branch of science studying the psychological and physiological responses associated with **sound itself**
  - Non-acoustic factors are ignored
- PA is a branch of psychophysics.
- PA is an interdisciplinary field of many areas, including psychology, acoustics, electronic engineering, physics, biology, physiology, and computer science.

Wikipedia, 18 May 2018

Basic facts of human sciences

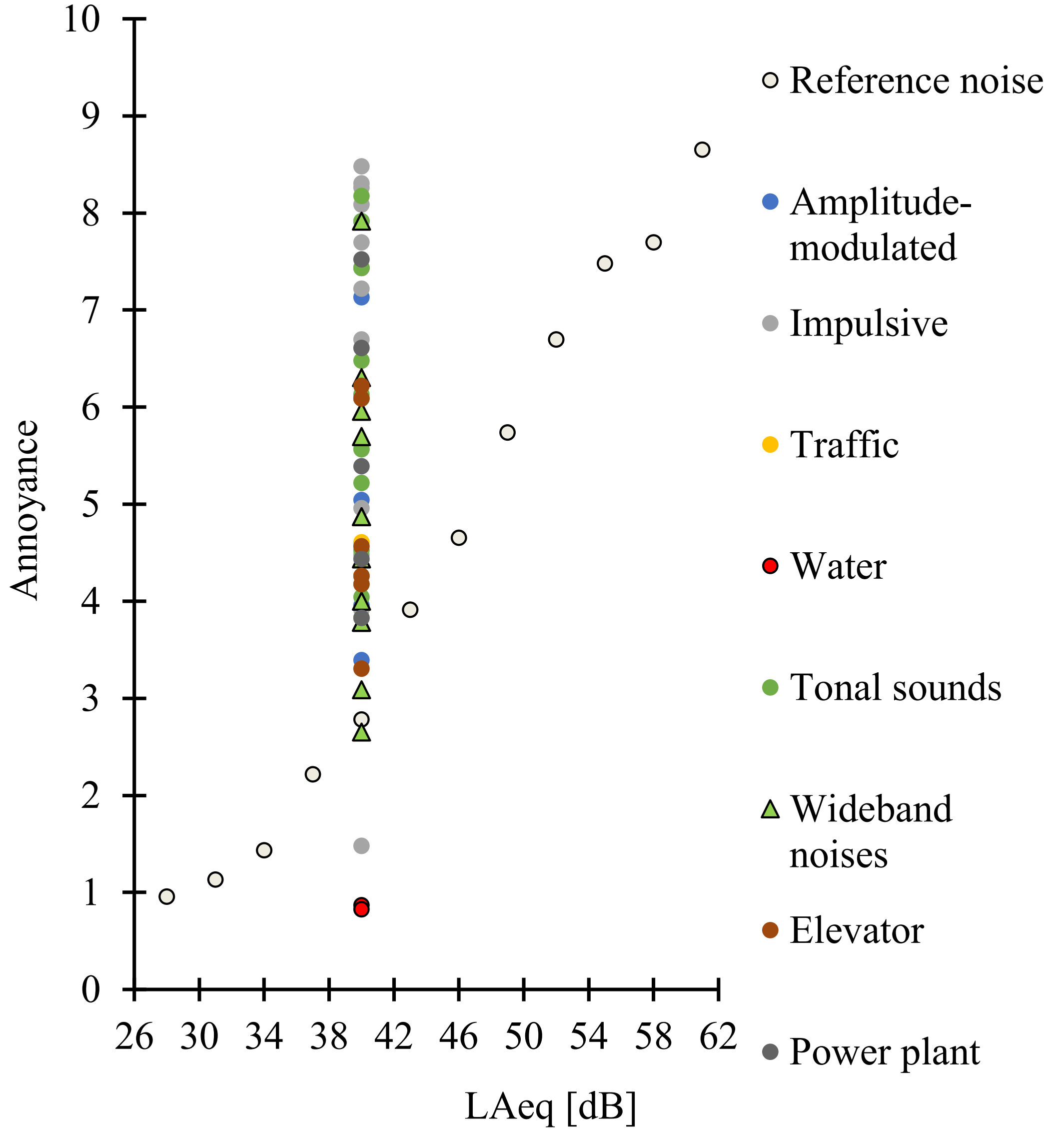
- PA shall be based on experimental evidence collected from humans.
- In a PA experiment, the results depend on all sounds that the participants have heard, since the participant evaluates the sounds in the pool of given sounds – all kinds of sounds cannot be studied in a single experiment!
- Therefore, a single PA experiment can provide a biased view.
- Empirical models can be created from solid experimental evidence, i.e. repeated similar evidence from independent studies.

Grand picture: the effect of sound type vs. annoyance

- 30 participants rated 60 real sounds presented at 40 dB L_{Aeq}, and 12 reference sounds presented at 28-61 dB L_{Aeq} with fixed spectrum (Brown noise) to determine the penalty of real sounds
- Annoyance was rated using scale 0-10
- 12 reference sounds' annoyance ranged logically from 0.8 (29 dB) to 8.7 (61 dB).
- Annoyance of real sounds ranged from 0.7 to 8.5 despite of constant A-weighted level

Conclusions

- A-weighted level explains well the annoyance caused by a specific sound quality (e.g., reference sounds in this study)
- A-weighted level does not explain annoyance between sounds having various sound qualities.



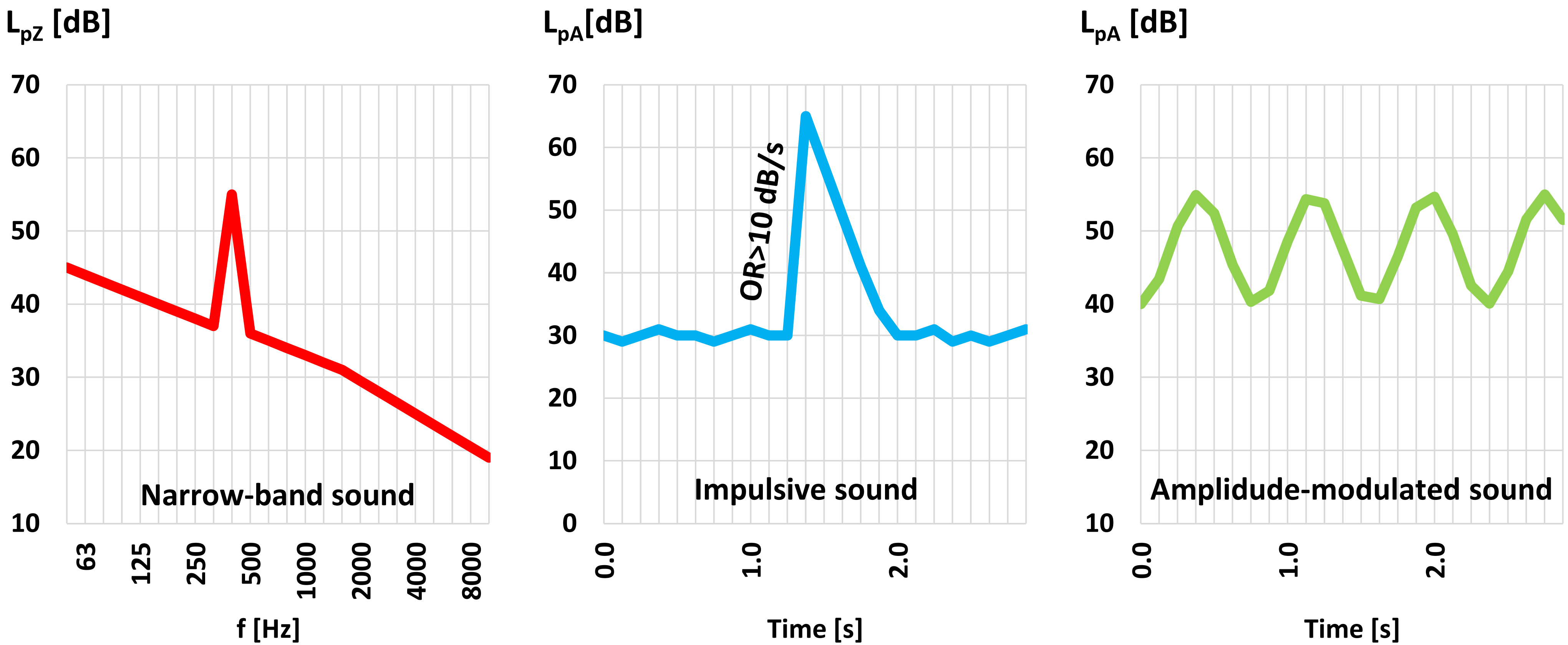
Sound quality features and annoyance

There is strong **psychoacoustic** evidence that certain special physical features in sound increase the annoyance compared to the annoyance caused by a neutral sound having the same overall level.

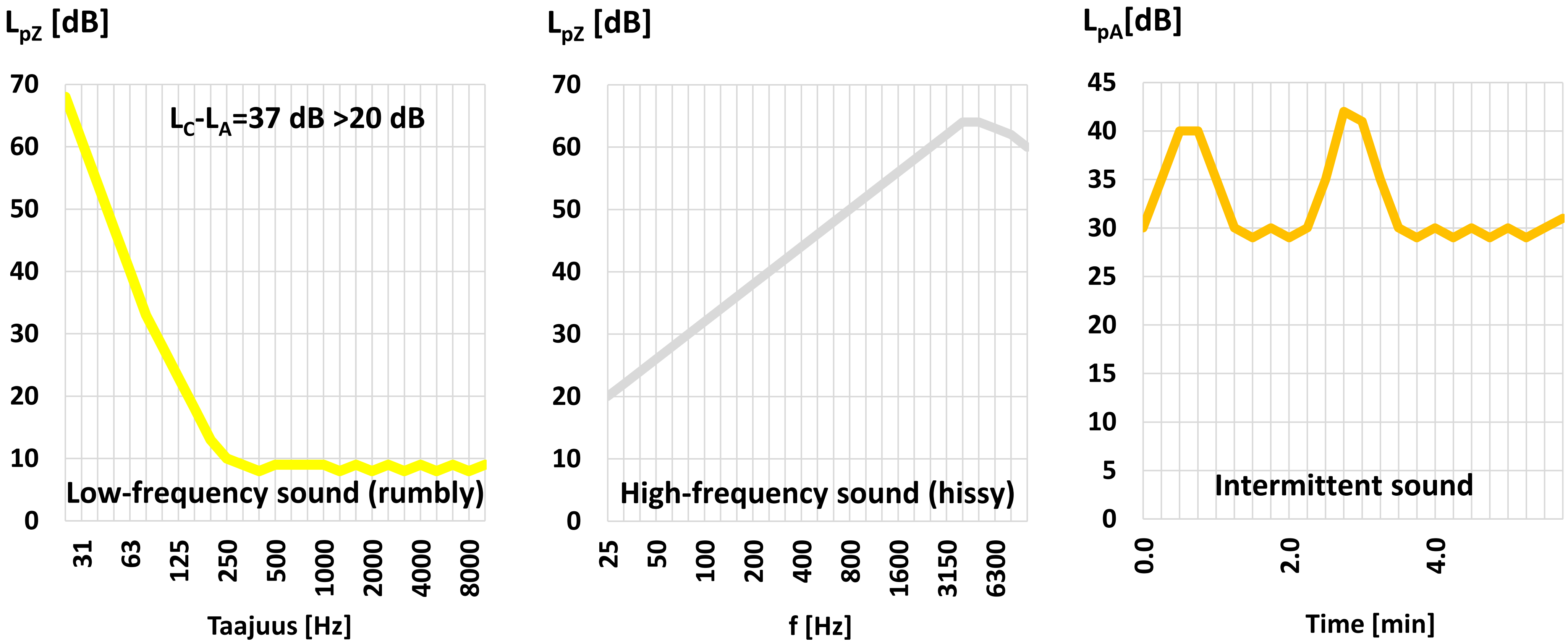
Such special features are:

- Narrow-band sound (tonal sound)
- Impulsive sound
- Spectrally special sounds (hissy, rumbly, roaring)
- Amplitude-modulated sound (periodically alternating)
- Intermittent (unpredictable) sound

Special sound quality features



Special sound quality features

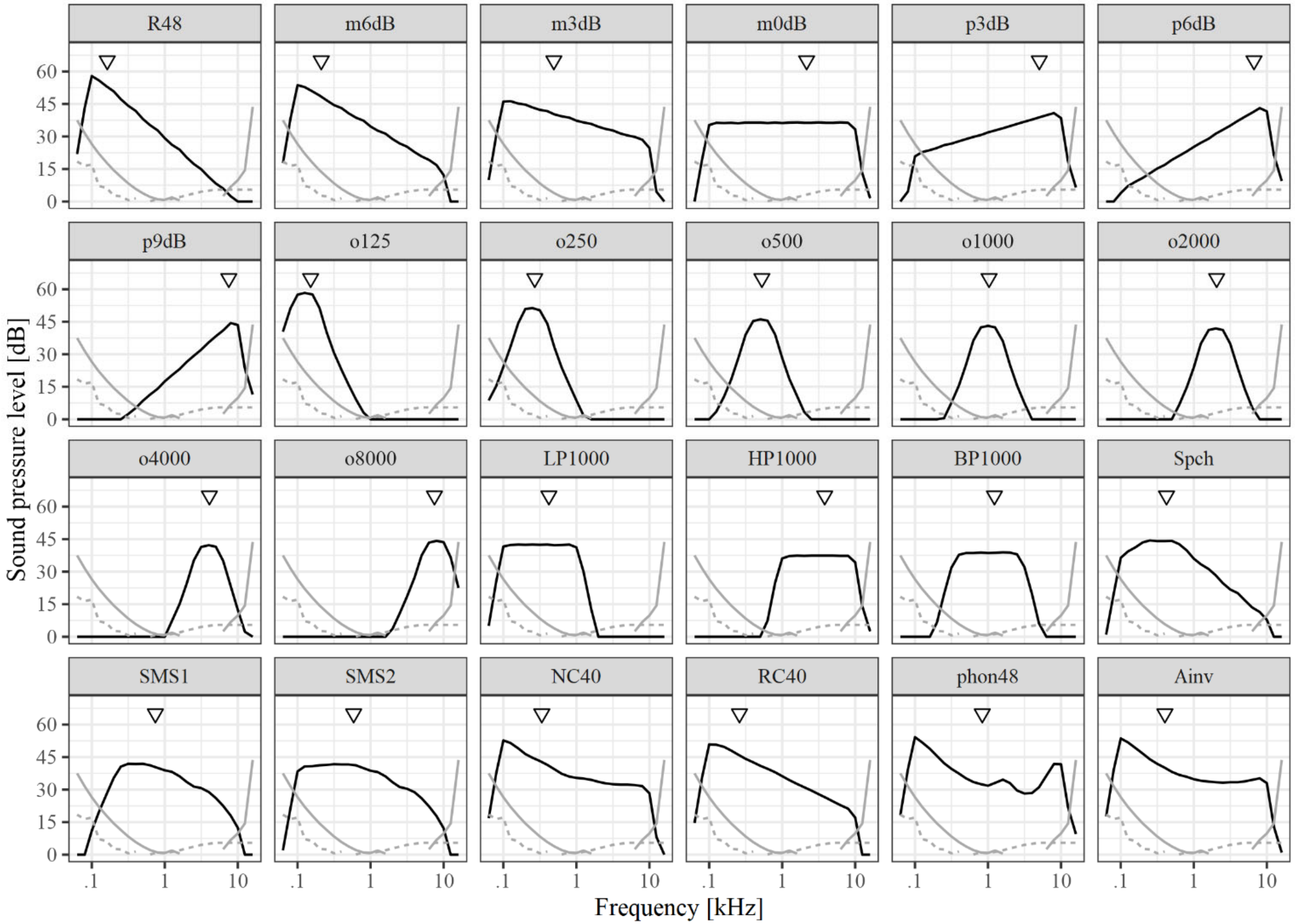


Experiment 1: The effect of spectrum on annoyance

Kuusinen & Hongisto 2023 Forum Acusticum, Turin, Italy

Spectrum study – Purpose and design

- We wanted to understand whether there should be a penalty (dB-adjustment to L_{Aeq}) due to annoying spectrum.
- 40 participants were recruited in laboratory experiment where the participants rated
  - 23 different spectra presented at three overall levels, 32, 40, and 48 dB L_{Aeq}.
  - nine reference sounds (a non-annoying spectrum) played within 28-60 dB in 3 dB steps.
- Altogether 78 sounds.



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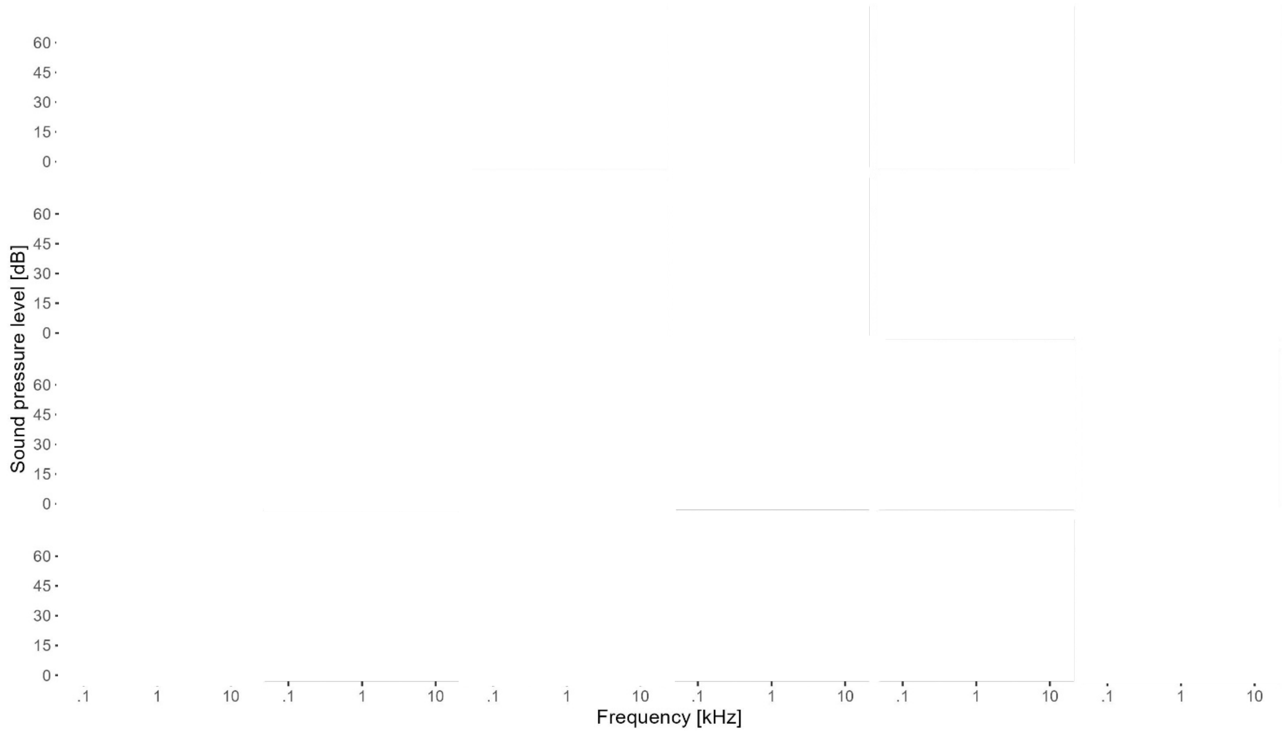
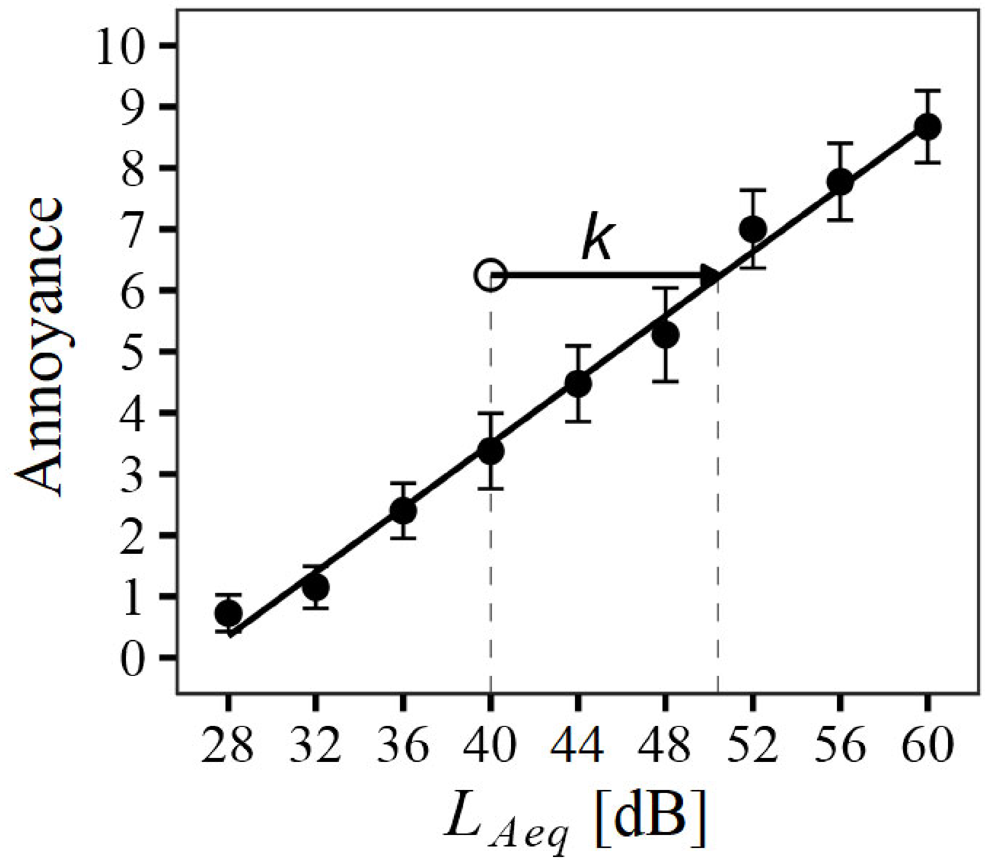
Spectrum study – the experimental sounds

Reference noises “m9dB”



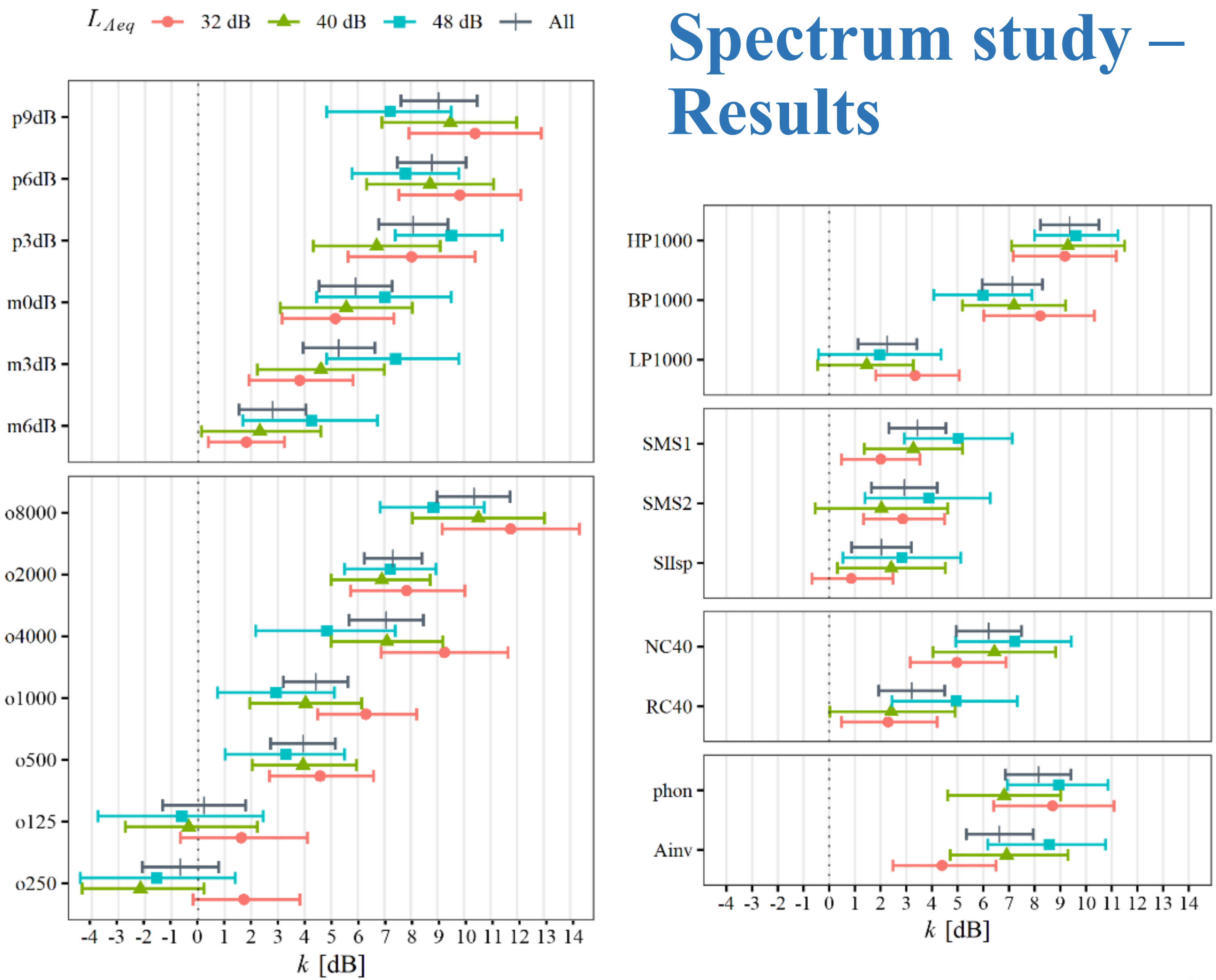
Spectrum study - Determination of penalty

- The mean annoyance ratings (closed circles) and 95% confidence intervals for the reference sounds is plotted as a function of L_{Aeq}. The linear regression line received a form $y = -7.0 + 0.26 \cdot x$.
- In addition, one spectrally modified sound presented at 40 dB L_{Aeq} is shown with hollow circle (o8000 at 40 dB L_{Aeq}). Its mean annoyance rating was 6.25. The penalty was calculated as the horizontal distance between the actual L_{Aeq} and the apparent L_{Aeq} levels of the reference sounds determined via the regression line. The penalty of o8000 was $k = 10.5$ dB.



Spectrum study – Results

- The penalty of spectrally modified sounds varied within **-2 … 12 dB**.
- Hissy sounds, i.e., sounds with strong high frequency content, were the most annoying.
- Since all sounds carry a spectrum, and spectrum is easy to measure, the spetrum should be penalized as well as tonality and impulsivity.



Experiment 2: Annoyance penalty of tonal sound

Oliva, D., Hongisto, V., Haapakangas, A. (2017). Annoyance of low-level tonal sounds - factors affecting the penalty. **Building and Environment** 123 404–414.
AND

Hongisto, V., Saarinen, P., Oliva, D. (2019). Annoyance of low-level tonal sounds – A penalty model. **Applied Acoustics** 145 358–361.

Background and purpose

- Regulations involve constant penalty k for tonal sounds to be added over the L_{Aeq}. Thus, the new value $L_{Aeq}+\underline{k}$ is expected to represent the annoyance better than L_{Aeq}alone.
  - VnP 993/92 [1], ***k* = 5 dB**
  - STM 545-2015 [2], ***k* = 3 / 6 dB**
- The avoidance of tonality indoors is of high importance regarding health
- Purpose: **determine the annoyance penalty** a function of tonal frequency and tonal audibility

How bothering, disturbing or annoying the sound is?

Not at all — Extremely

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

□ The sound is inaudible

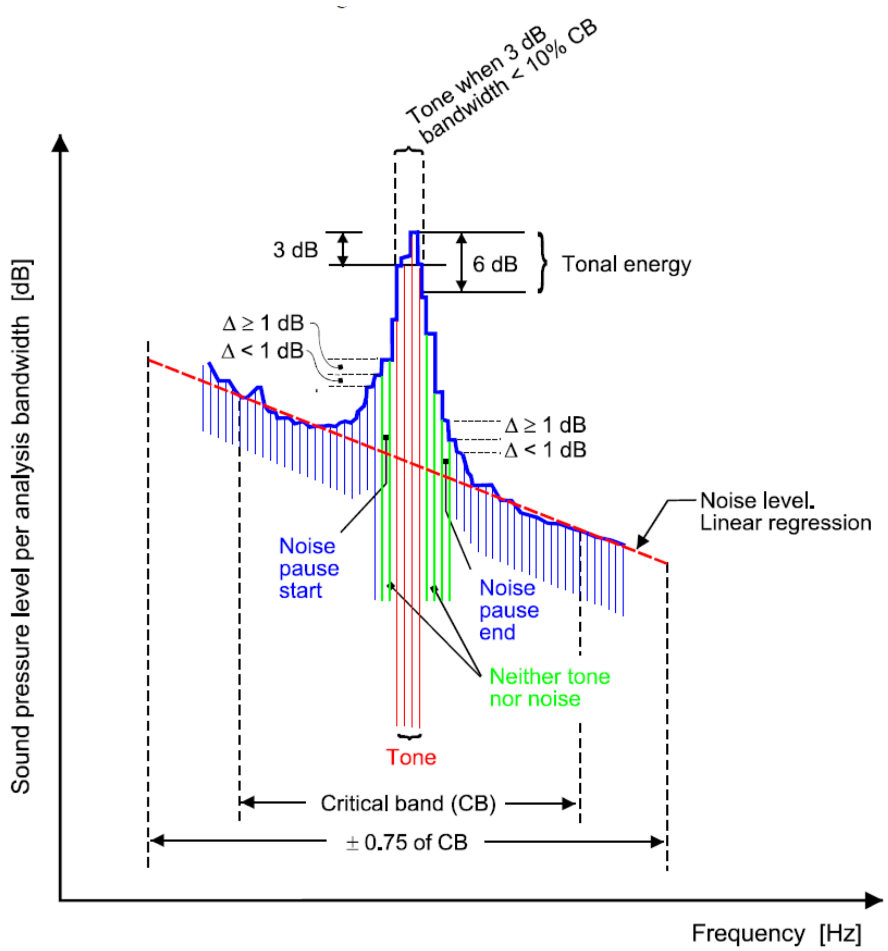


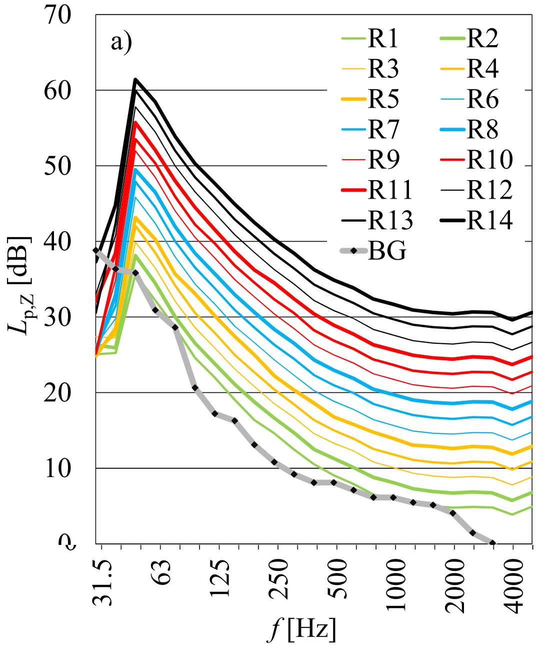
Figure 3
Definitions of tones, noise, and noise pause (neither tone nor noise).

$$\Delta L_t = L_{pt} - L_{pn} + 2 + log\left[1 + \left(\frac{f_c}{502}\right)^{2.5}\right]$$

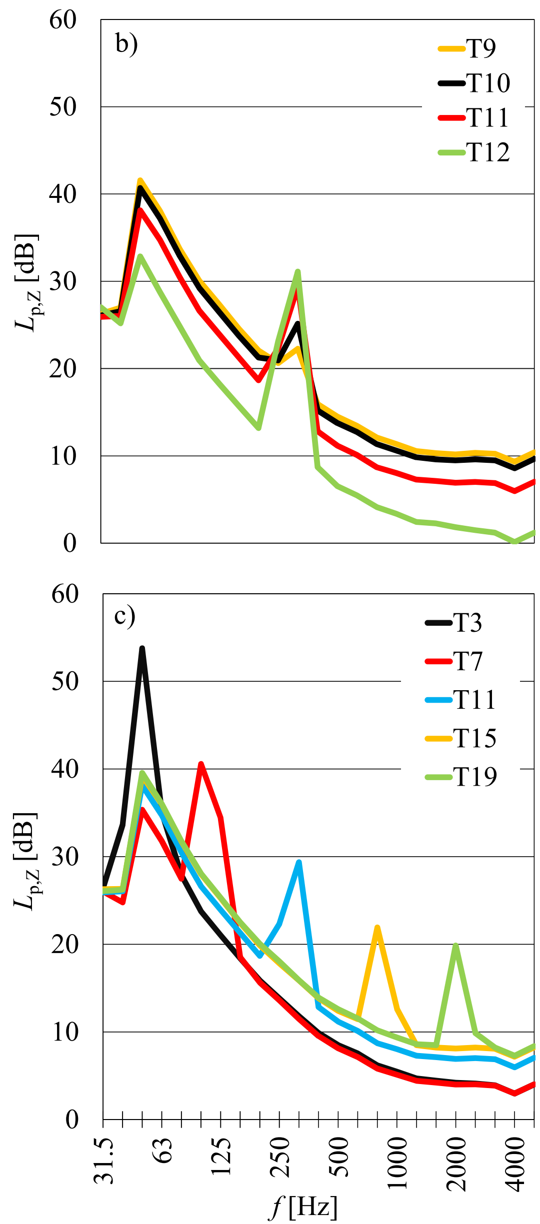
Oliva et al., 2017, Build. Environ.

Methods - Sounds

- 20 tonal sounds (T1-T20) were presented at 25 dB L_{Aeq}.
  - Four levels of tonal audibility, $\mathbf{A_T}$
  - Five tone frequencies, $\mathbf{f_T}$
- In addition, 14 wide-band reference sounds were used to determine the penalty (R1-R14)
- The background spectrum of both tonal sounds and reference sounds followed the inverse of A-weighting.



- 40 participants
- headphones

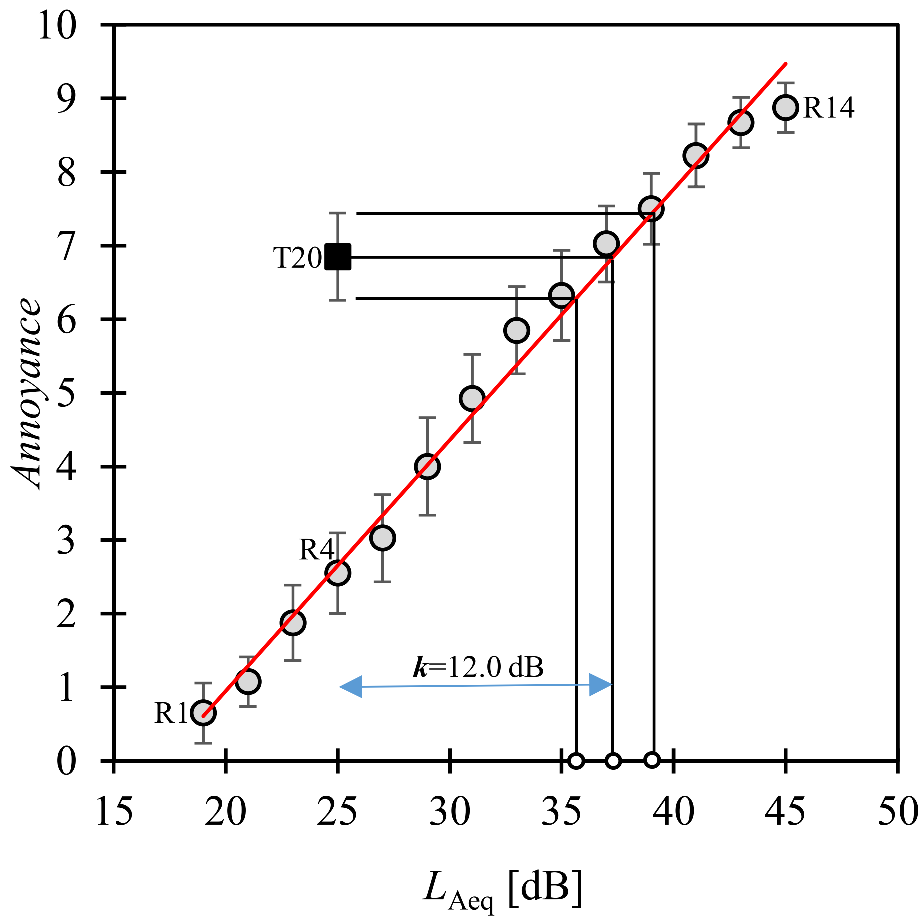


Sound	f_T [Hz]	A_T Level	[dB]	L_{Aeq} [dB]
R1	-	-	0	19
R2	-	-	0	21
R3	-	-	0	23
R4	-	-	0	25
R5	-	-	0	27
R6	-	-	0	29
R7	-	-	0	31
R8	-	-	0	33
R9	-	-	0	35
R10	-	-	0	37
R11	-	-	0	39
R12	-	-	0	41
R13	-	-	0	43
R14	-	-	0	45
T1	50	A1	5	25
T2	50	A2	10	25
T3	50	A3	18	25
T4	50	A4	25	25
T5	110	A1	5	25
T6	110	A2	10	25
T7	110	A3	17	25
T8	110	A4	24	25
T9	290	A1	5	25
T10	290	A2	10	25
T11	290	A3	17	25
T12	290	A4	25	25
T13	850	A1	5	25
T14	850	A2	10	25
T15	850	A3	18	25
T16	850	A4	25	25
T17	2100	A1	5	25
T18	2100	A2	10	25
T19	2100	A3	18	25
T20	2100	A4	25	25

Oliva et al., 2017, Build. Environ.

Methods - Determination of penalty *k*

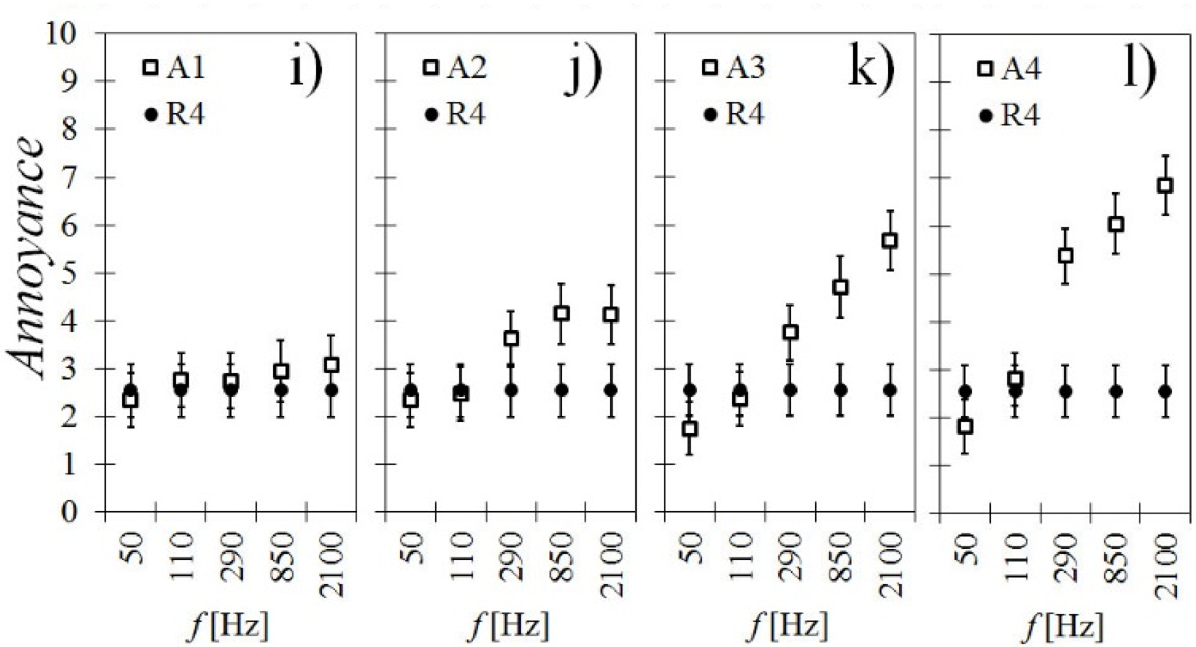
- Reference sounds were presented within 25–45 dB L_{Aeq} to be able to determine the penalty
- Example of the determination of penalty value *k* for *experimental sound* T35 (black square).
- The 95% confidence interval is shown by whiskers.
- Linear interpolation over the mean of the reference sounds R1-R14 (circles) is indicated by a line.
- The penalty (line with arrow) and its uncertainty (dashed lines with arrow) was determined by finding the apparent level of the equally annoying reference sound using the fitted line.
- In this case, *k* = 5.3 dB. The confidence interval was 4.2 … 6.4 dB.



Oliva et al., 2017, Build. Environ.

Results - annoyance

- *Annoyance* of *sounds* varied significantly between sounds:
  - Tonal sounds: 1.8–6.8
  - Reference sounds: 0.7–8.9
- *Annoyance* of tonal sounds increased with increasing tonal frequency $\mathbf{f_T}$ and tonal audibility $\mathbf{A_T}$.



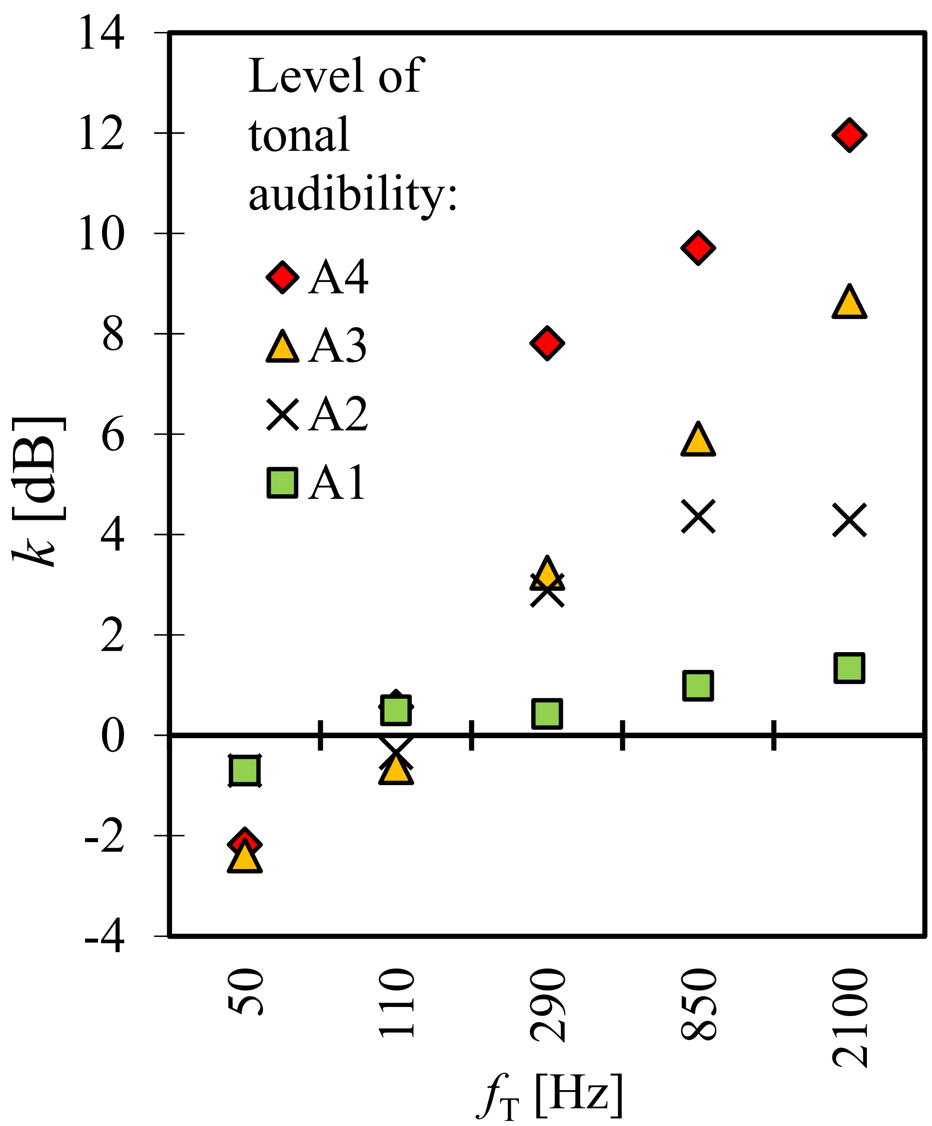
Oliva et al., 2017, Build. Environ.

Sound	f_T [Hz]	A_T Level	[dB]	L_{Aeq} [dB]	*Annoyance* M
R1	-	-	0	19	0.68
R2	-	-	0	21	1.08
R3	-	-	0	23	1.88
R4	-	-	0	25	2.55
R5	-	-	0	27	3.03
R6	-	-	0	29	4.00
R7	-	-	0	31	4.93
R8	-	-	0	33	5.85
R9	-	-	0	35	6.33
R10	-	-	0	37	7.03
R11	-	-	0	39	7.50
R12	-	-	0	41	8.23
R13	-	-	0	43	8.68
R14	-	-	0	45	8.88
T1	50	A1	5	25	2.35
T2	50	A2	10	25	2.35
T3	50	A3	18	25	1.78
T4	50	A4	25	25	1.93
T5	110	A1	5	25	2.78
T6	110	A2	10	25	2.48
T7	110	A3	17	25	2.38
T8	110	A4	24	25	2.83
T9	290	A1	5	25	2.75
T10	290	A2	10	25	3.63
T11	290	A3	17	25	3.75
T12	290	A4	25	25	5.38
T13	850	A1	5	25	2.95
T14	850	A2	10	25	4.15
T15	850	A3	18	25	4.70
T16	850	A4	25	25	6.05
T17	2100	A1	5	25	3.08
T18	2100	A2	10	25	4.13
T19	2100	A3	18	25	5.68
T20	2100	A4	25	25	6.85

Results - Annoyance penalty

- The penalty increased with increasing f_T and A_T [dB].
- Constant penalty models in many legislations was not supported.
- Bolded values deviate statistically significantly from zero.

Sound	f_T [Hz]	A_T Level	[dB]	k [dB]	*95% C.I.* [dB]
T1	50	A1	5	-0.7	-2.3 – 0.9
T2	50	A2	10	-0.7	-2.3 – 0.9
T3	50	A3	18	**-2.4**	-4.2 – -0.6
T4	50	A4	25	**-2.2**	-4.3 – 0.0
T5	110	A1	5	0.5	-1.1 – 2.1
T6	110	A2	10	-0.4	-1.9 – 1.2
T7	110	A3	17	-0.6	-2.3 – 1.0
T8	110	A4	24	0.6	-1.5 – 2.6
T9	290	A1	5	0.4	-1.2 – 2.1
T10	290	A2	10	**2.9**	0.8 – 4.9
T11	290	A3	17	**3.2**	1.1 – 5.4
T12	290	A4	25	**7.8**	5.9 – 9.7
T13	850	A1	5	1.0	-0.8 – 2.8
T14	850	A2	10	**4.4**	2.5 – 6.2
T15	850	A3	18	**5.9**	3.9 – 7.9
T16	850	A4	25	**9.7**	7.6 – 11.8
T17	2100	A1	5	1.3	-0.4 – 3.1
T18	2100	A2	10	**4.3**	2.2 – 6.4
T19	2100	A3	18	**8.7**	6.5 – 10.8
T20	2100	A4	25	**12.0**	10.3 – 13.6

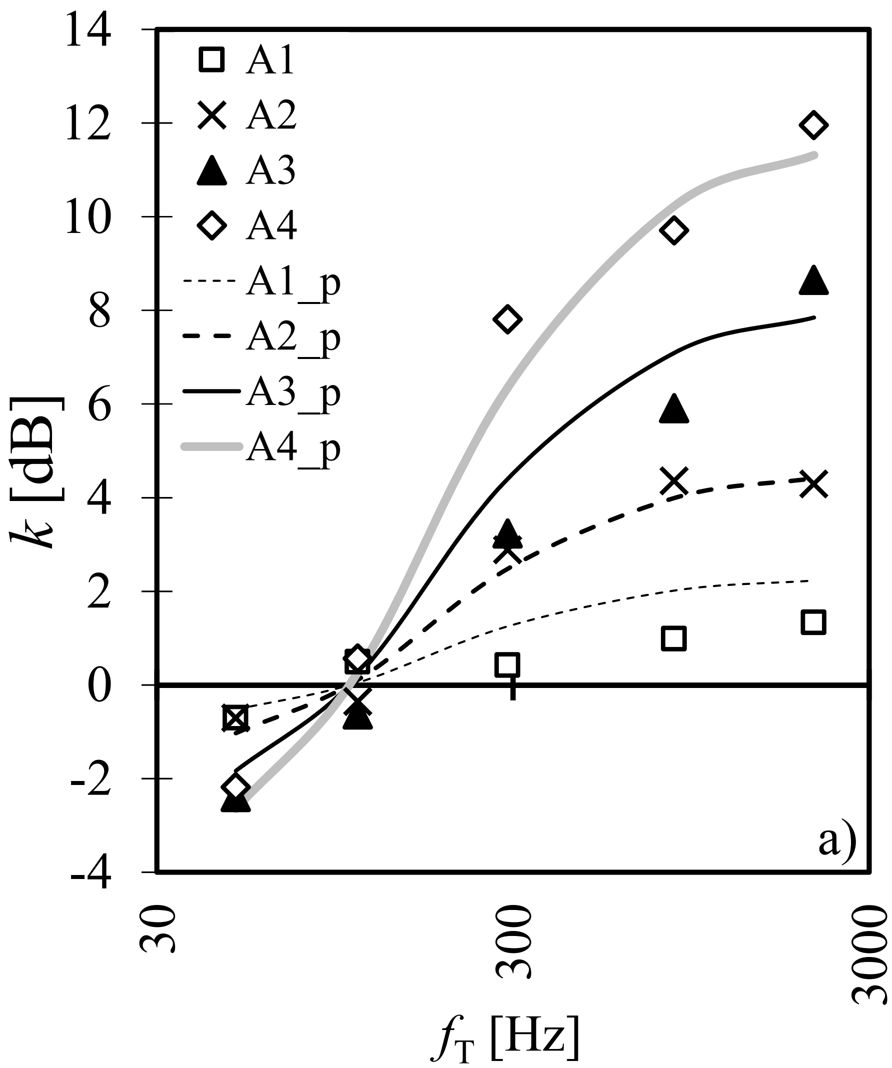


Oliva et al., 2017, Build. Environ.

Results - Prediction model for penalty

- The following equation predicted the penalty k better than the standardized models.
  - r_P=0.984, p=6.6·10^{-15}, 2-tailed

$$k = -0.036A_T + 0.326\,A_T \tan^{-1}\left(6\left(\frac{f_T}{1000\text{ Hz}} - 0.0858\right)\right)$$



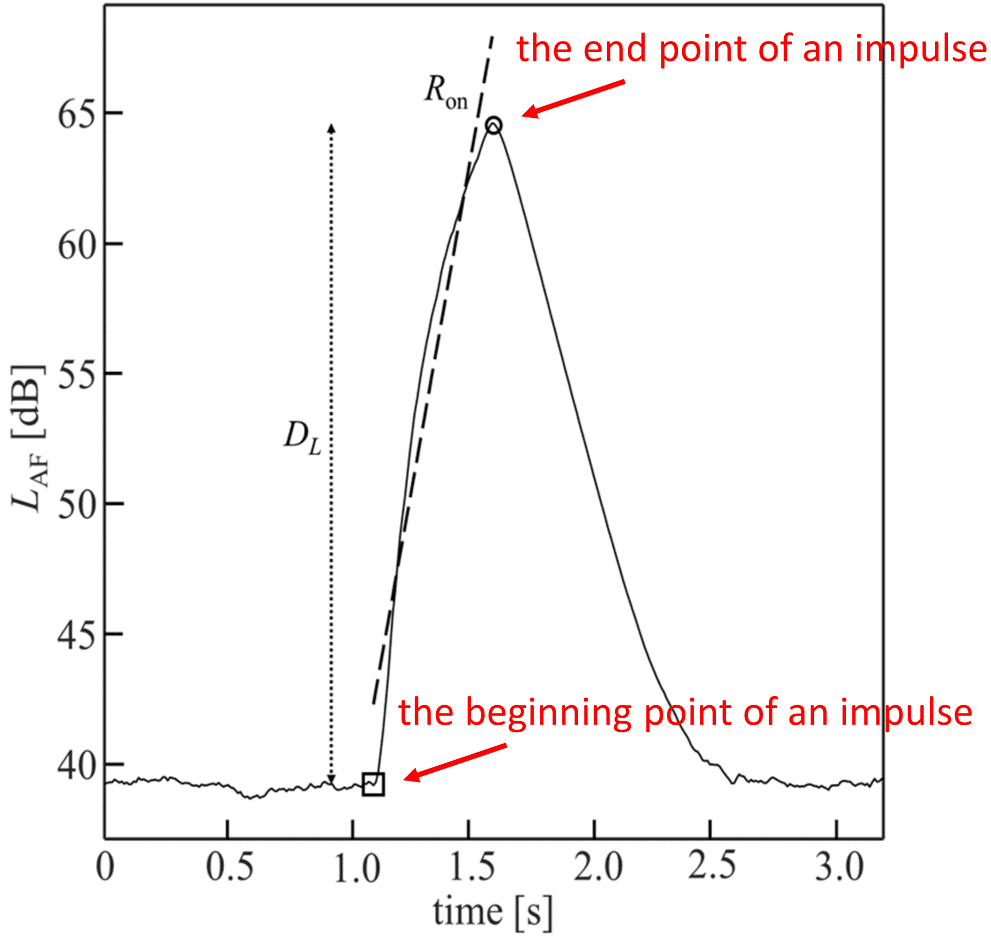
Experiment 3 - Annoyance penalty of impulsive sound

Rajala, V., Hongisto, V. (2020). Annoyance penalty of impulsive noise – the effect of impulse onset. **Building and Environment** 168, 106539.

Purpose and method

- Nordtest method NT ACOU 112 defines two measures for impulse:
  - Onset rate, R_{on} [dB/s]
  - Level difference, D_L [dB]
- Our aim was to determine the annoyance penalty as a function of R_{on} and D_L
- 74 synthetic sounds: 66 impulsive sounds and 6 reference sounds (steady noise)
- Impulses were created from random noise
- L_{Aeq}= 55 dB for all impulsive sounds

		R_{on} [dB/s]									
		5	10	15	20	50	100	200	400	600	800
D_L [dB]	5	x	x	x	x	x					
	10		x	x	x	x	x				
	15			x	x	x	x				
	20				x	x	x	x			
	25					x	x	x	x		
	30					x	x	x	x	x	
	40					x	x	x	x	x	x



Rajala & Hongisto, 2019, Build. Environ.

Sound demos

Impulsive sounds

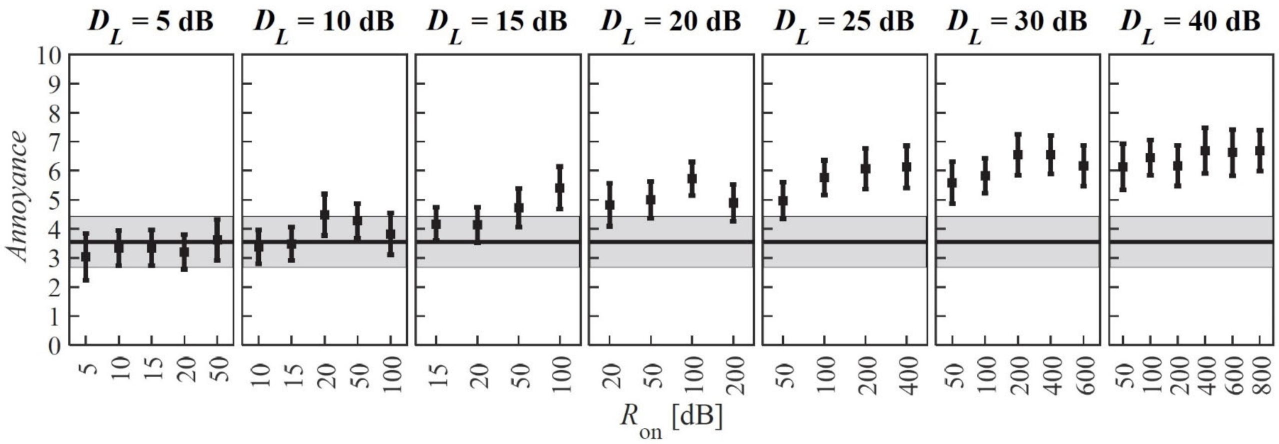
D_L [dB] \ R_{on} [dB/s]	5	10	15	20	50	100	200	400	600	800
5	x	x	x	x	x					
10		x	x	x	x	x				
15			x	x	x	x				
20				x	x	x	x			
25					x	x	x	x		
30					x	x	x	x	x	
40					x	x	x	x	x	x

Reference sounds

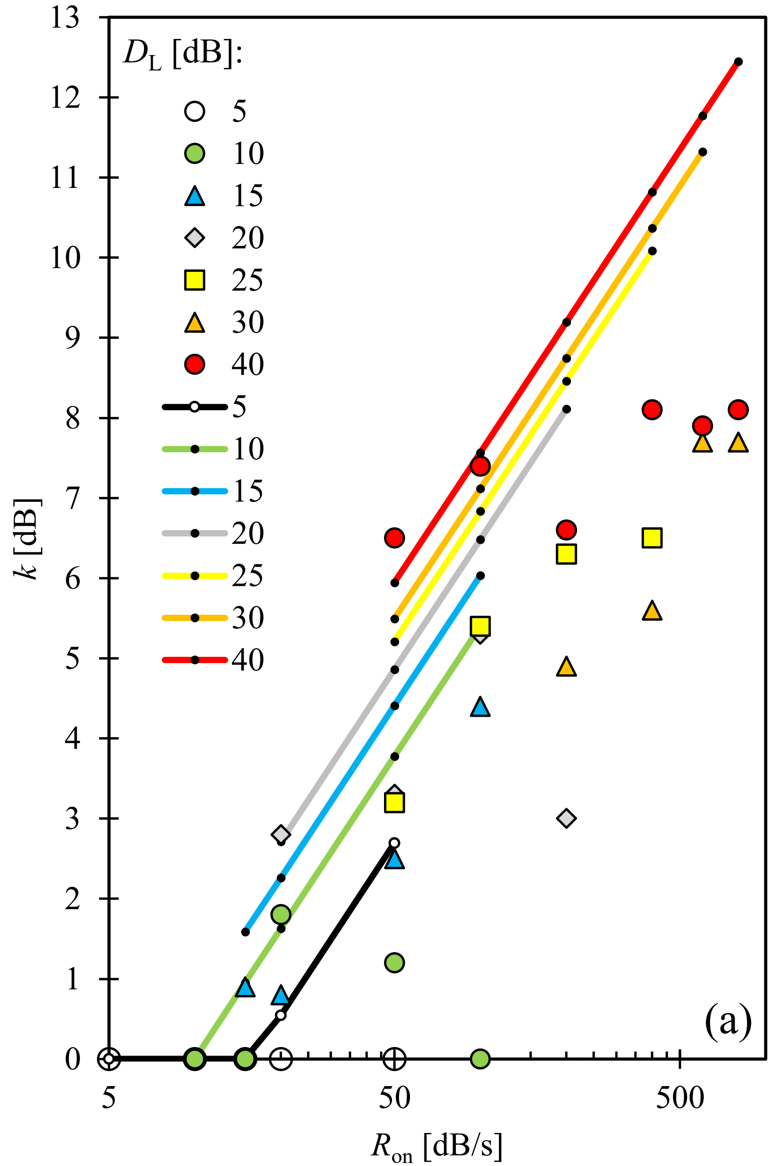
L_{Aeq} [dB]							
49	52	55	58	61	64	67	70

Rajala & Hongisto 2020 **Build Environ**

Results



- Figure on top shows the mean annoyance and 95% CI's for impulsive sounds compared to a reference sound at 55 dB L_{Aeq} (horizontal line)
- Although all impulsive sounds were played at 55 dB, some of them are much more annoying than the reference sound
- Figure on right gives the penalty of our data and NT ACOU 112
- Annoyance penalty depends strongly on R_{on} and D_L.
- R_{on} <20 dB/s and D_L<15 dB deserve no penalty
- Constant penalty used in many legislations is not supported.



Rajala & Hongisto, 2019, Build. Environ.

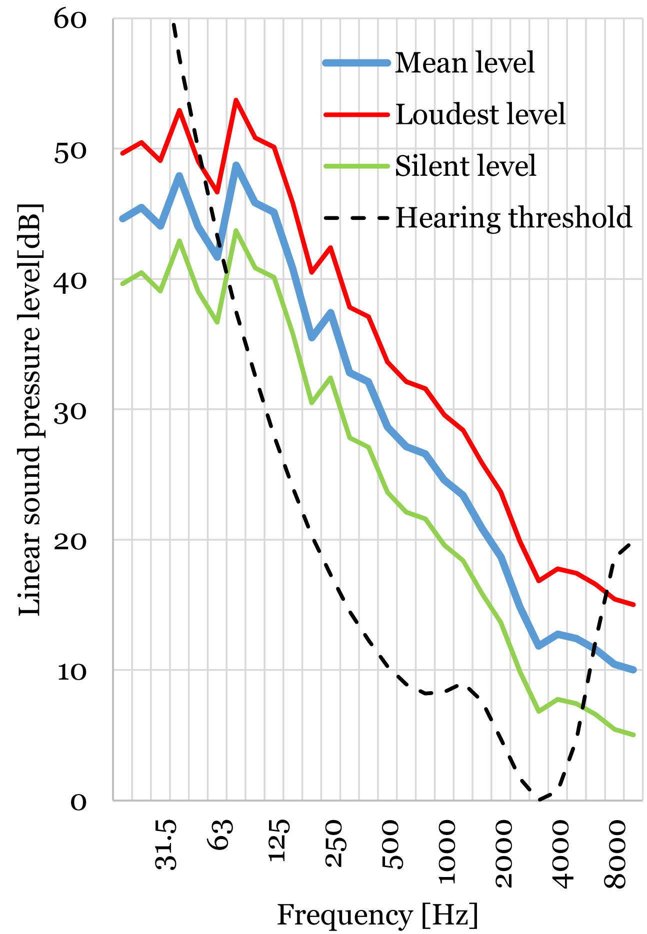
Experiment 4 – Annoyance penalty of amplitude-modulated sound

Virjonen, P., Hongisto, V., Radun, J. (2019). Annoyance penalty of periodically amplitude-modulated wide-band sound. **The Journal of the Acoustical Society of America**, 146(6) 4159–4170**.**

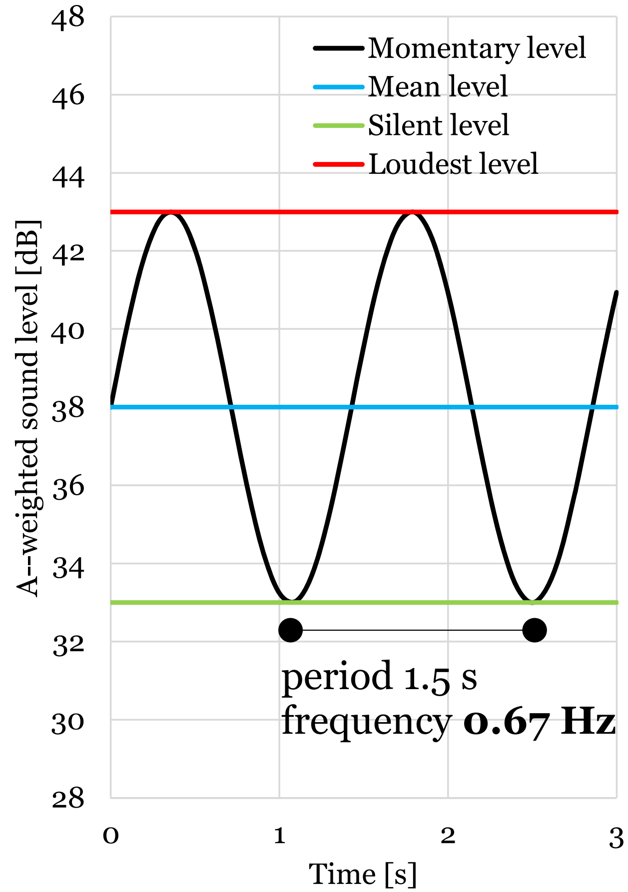
Amplitude modulation

- Amplitude modulation means that the SPL varies periodically
- For wind turbines, the strongest AM depth has been 10 dB but usually it is under 4 dB
- Does it need penalty?
- What about road traffic noise, which fluctuates as well?
  - due to the rhythm of traffic lights,
  - Single pass by vehicles

Spectrum of sound



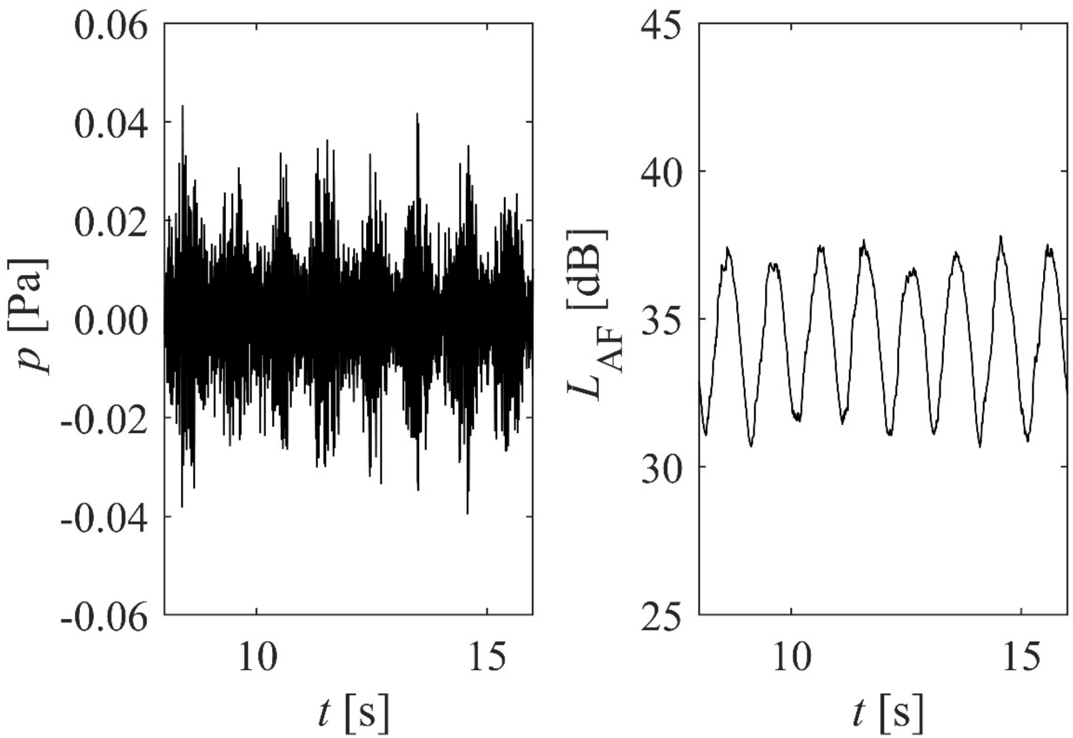
Level as a function of time



Virjonen et al., J Acoust Soc Am 2019

Purpose

- **AM**: amplidude modulation: the amplitude of a carrier sound varies with time.
  - modulation frequency $\mathbf{f_m}$ [Hz]
  - modulation depth $\mathbf{D_m}$ [dB].
- **Our purpose** was to determine the *annoyance* penalty of AM sound as a function $\mathbf{f_m}$ and $\mathbf{D_m}$.
- 40 participants.



- Amplitude of carrier wave was varied sinusoidally with modulation index *m*:
- The carrier wave was multiplied by Q:
- Time was discretized (f_s = 44.1 kHz):

$$m = \frac{10^{D_m/20} - 1}{10^{D_m/20} + 1}$$

$$Q = 1 + m \cdot \sin(2\pi f_m t)$$

$$t = (0, 1, 2, \dots, n_s - 1)\frac{1}{f_s},$$

Virjonen et al., J Acoust Soc Am 2019

Sounds

- The studied sounds involved
  - 35 amplitude-modulated sounds (A101-A135)
  - 11 reference sounds (R101-R111)
- The AM sounds were created as combinations of two variables:
  - modulation depth (**D_m**, 5 levels),
  - modulation frequency (**f_m**, 7 levels)
- AM sounds were presented at 35 dB L_{Aeq}.
- Carrier wave was wide-band pseudo-random noise, whose spectrum was set to urban road traffic noise (S1). It was not modulated.
- Reference sounds were unmodulated carrier wave. They were used to determine the penalty. They were presented at 29 to 49 dB L_{Aeq} in 2 dB steps.

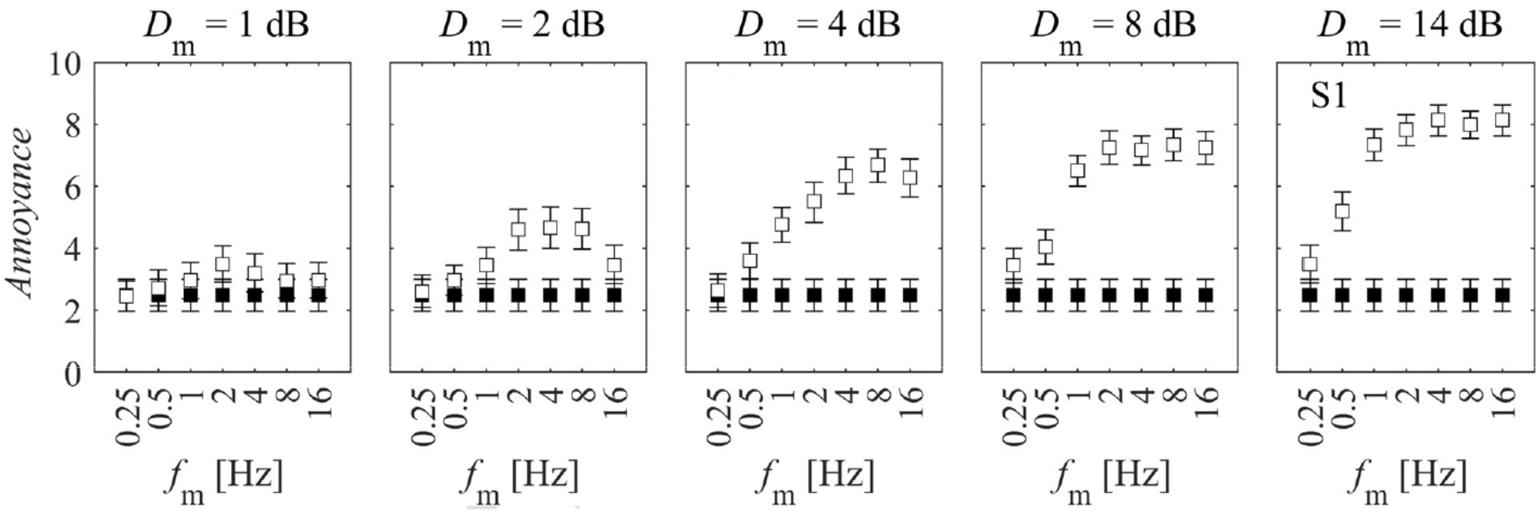
Experimental sound	Spectrum	D_m [dB]	f_m [Hz]	L_{Aeq} [dB]
R101[a]	S1	-	-	29
R102	S1	-	-	31
R103	S1	-	-	33
R104	S1	-	-	35
R105	S1	-	-	37
R106[a]	S1	-	-	39
R107	S1	-	-	10
R108	S1	-	-	43
R109	S1	-	-	45
R110	S1	-	-	47
R111[a]	S1	-	-	49

Experimental sound	Spectrum	D_m [dB]	f_m [Hz]	L_{Aeq} [dB]
A101	S1	1	0.25	35
A102	S1	2	0.25	35
A103	S1	4	0.25	35
A104	S1	8	0.25	35
A105	S1	14	0.25	35
A106	S1	1	0.5	35
A107	S1	2	0.5	35
A108[a]	S1	4	0.5	35
A109	S1	8	0.5	35
A110[a]	S1	14	0.5	35
A111	S1	1	1	35
A112	S1	2	1	35
A113	S1	4	1	35
A114	S1	8	1	35
A115	S1	14	1	35
A116	S1	1	2	35
A117	S1	2	2	35
A118	S1	4	2	35
A119	S1	8	2	35
A120	S1	14	2	35
A121	S1	1	4	35
A122	S1	2	4	35
A123	S1	4	4	35
A124	S1	8	4	35
A125	S1	14	4	35
A126	S1	1	8	35
A127	S1	2	8	35
A128	S1	4	8	35
A129	S1	8	8	35
A130	S1	14	8	35
A131	S1	1	16	35
A132	S1	2	16	35
A133[a]	S1	4	16	35
A134	S1	8	16	35
A135[a]	S1	14	16	35

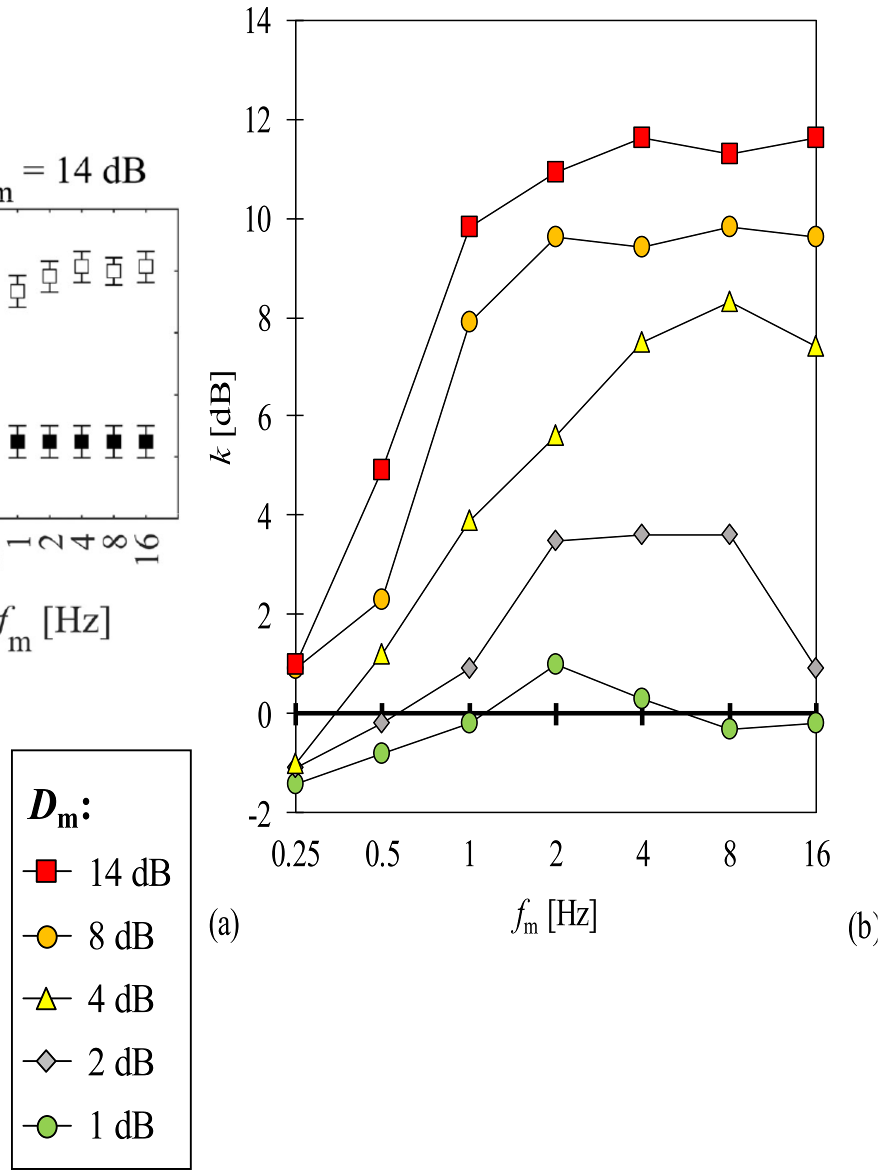
[a]The *so*

Virjonen et al., J Acoust Soc Am 2019

Results



- Figure above shows the mean annoyance and 95% Cis for AM sounds compared to a reference sound at 35 dB L_{Aeq} (black square)
- Although all AM sounds were played at 35 dB, most sounds were more annoying than the reference sound
- The larger the modulation frequency $\mathbf{f_m}$ and/or the modulation depth $\mathbf{D_m}$, the larger the penalty.
- Values exceeding k=1.5 were statistically significant.



Virjonen et al., J Acoust Soc Am 2019

Perception of infrasound

Rajala, V., Hakala, J., Alakoivu, R., Koskela, V., Hongisto, V. (2022). Hearing threshold, loudness, and annoyance of infrasonic versus non-infrasonic frequencies. **Applied Acoustics** 198 108981 13+6 pp.
Open access at:
https://doi.org/10.1016/j.apacoust.2022.108981.

Purpose

- We are teached in school and wikipedia that infrasound
  - has frequency below 20 Hz
  - is below our hearing range
- Based on this, infrasound is inaudible. However, several laboratory researches have shown the opposite.
- Spaceflight research in 60's showed that infrasound inside spaceship causes a serious health risk.
- However, the health risk occurred only during very loud infrasound (>140 dB), which is audible and also loud.
- Despite of this, there is a general belief among many concerned citizens that whenever there is an infrasound source nearby, it poses a health risk. This misunderstanding is fed by the erroneous definition of infrasound.

- **Purpose of our study** was to determine infrasonic
  - hearing threshold,
  - constant loudness contours, and
  - constant annoyance contours.

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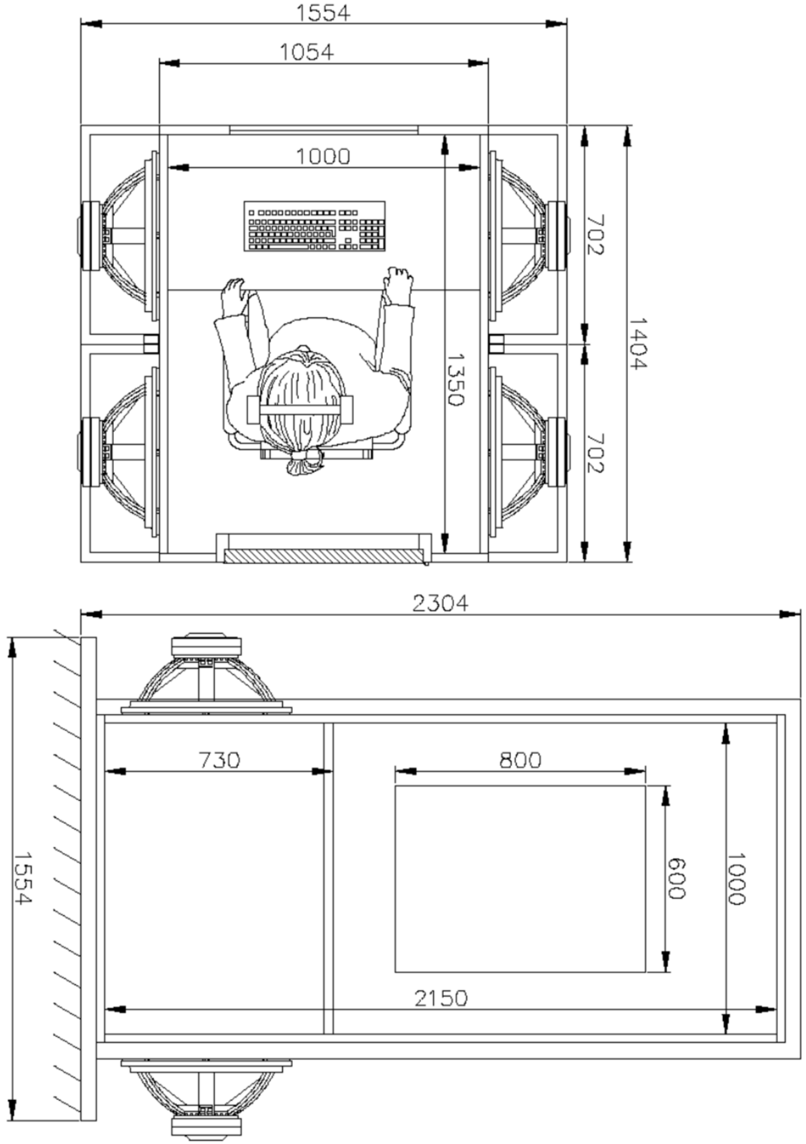
Methods

- 19 subjects
- 2.5 h experimental duration

Phase	Duration [min]	Description
1	5	Information consent form
2	10	Loudness rehearsal
3	30	Loudness test, part 1
4	5	Break
5	30	Loudness test, part 2
6	5	Break
7	30	Hearing threshold test
8	5	Break
9	5	Annoyance rehearsal
10	17	Annoyance test
11	10	Reporting other sensations
12	5	Feedback and gift token



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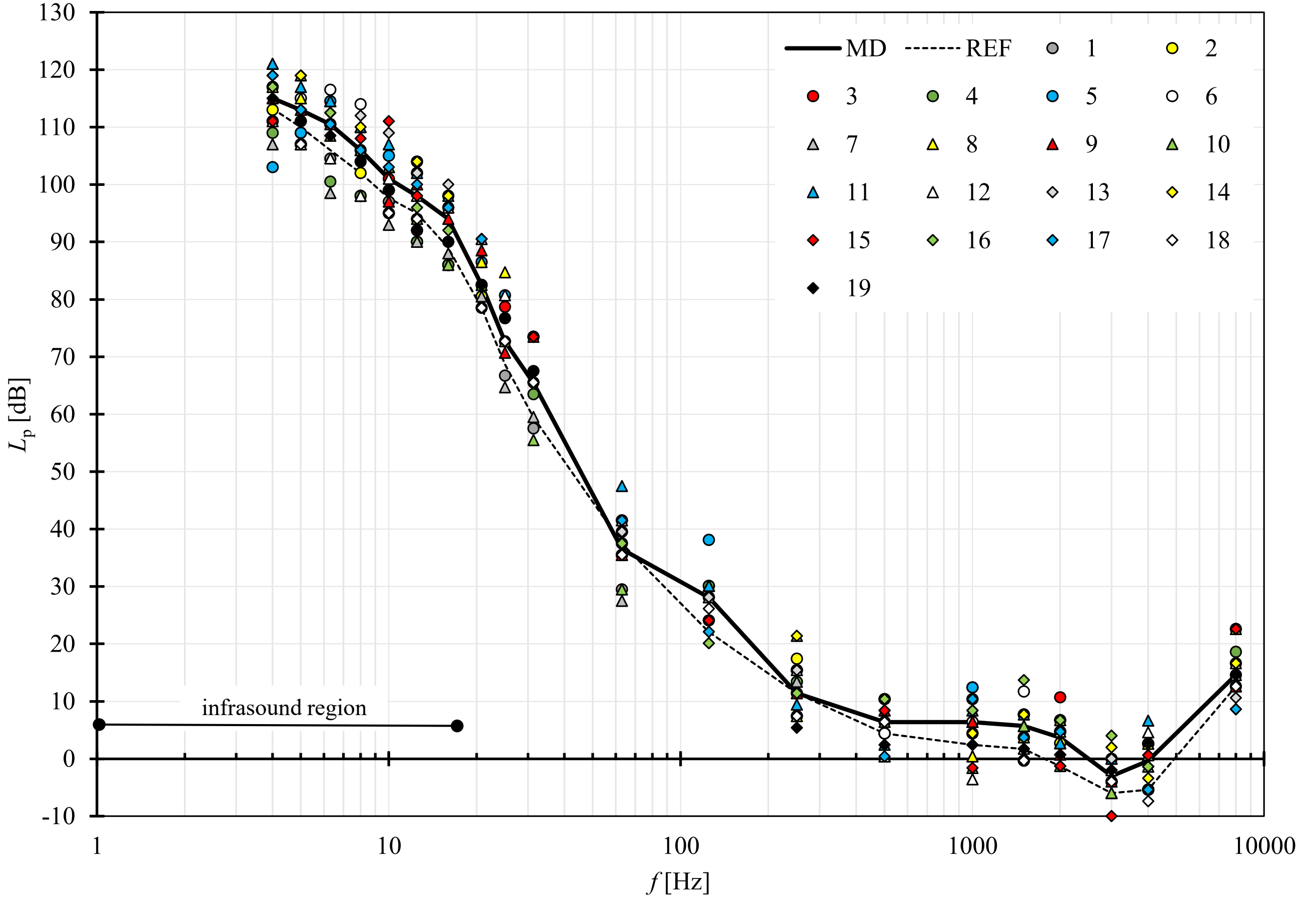
Results - Hearing threshold level

- Results within 20-10000 Hz agreed well with previous data (REF).
- Infrasound is audible below 20 Hz, which confirms earlier findings.
- It was recommended that the HTL of infrasonic frequencies should also be standardized to reduce misinformation related to infrasound.
- Standardization of HTL of infrasound would change the situation, since the definition could be changed, and environmental medicine could give better diagnoses for people who have been exposed to infrasound, since the SPL must be known before any diagnose can be given.



REF is a combination of the standardized HT of ISO 226 (**ISO, 2003a**) within 20–8000 Hz and the proposal of infrasonic HT presented by **Møller and Pedersen (2004)** within 4–16 Hz.

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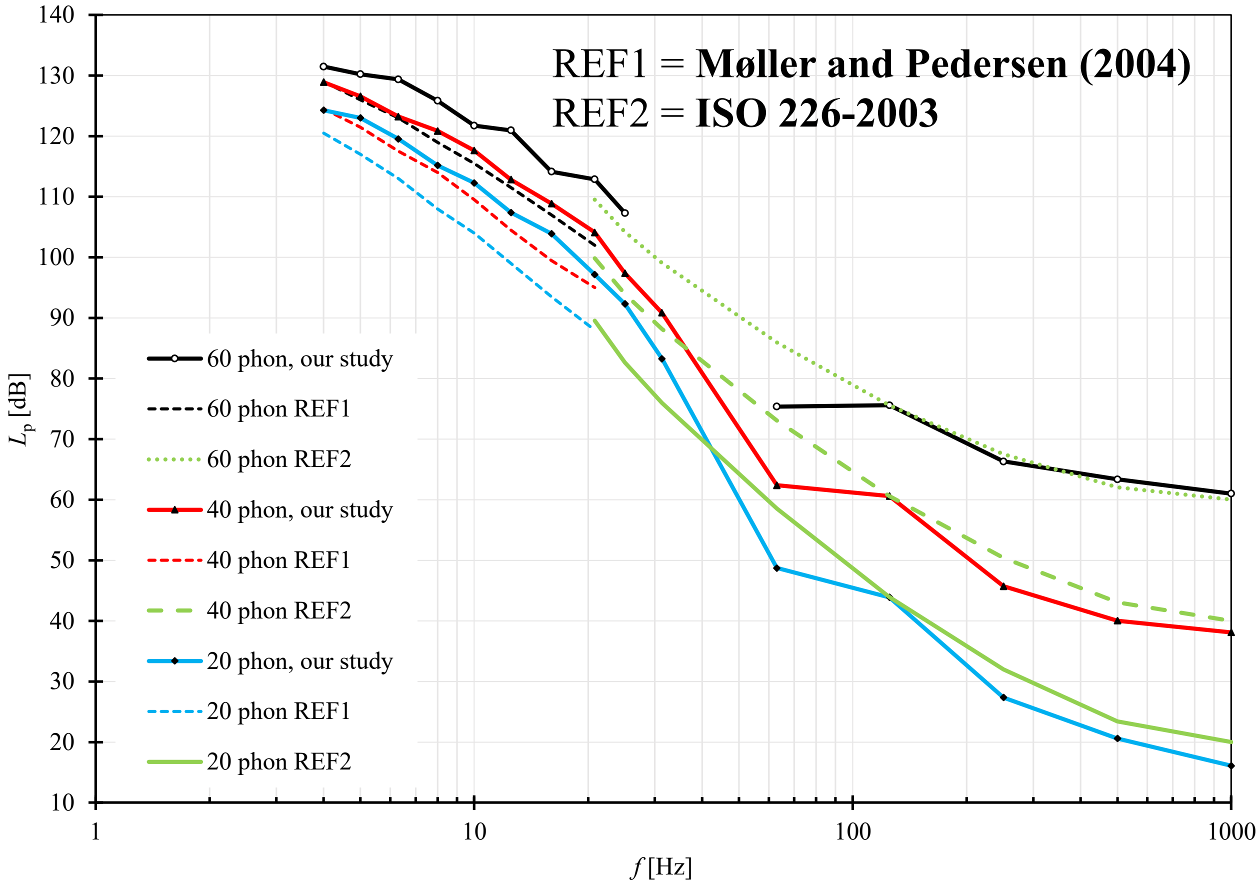
Results – Equal loudness contours

- Equal loudness contour; ELC, indicates the SPLs that sound equally loud.
  - 20 phon ELC curve means that the curve crosses 20 dB at 1 kHz.
  - 40 phon ELC crosses 40 dB at 1 kHz, etc.
- Our results agreed well with REF within 20-1000 Hz except at 63 Hz.
- Our results are significantly above REF1 at 4-20 Hz.
- Therefore, more research is needed about the ELCs below 20 Hz and they should not yet be standardized.
- Most important: the three ELCs are only separated by 3 dB at 4 Hz while they are separated by 20 dB at 1 kHz.
- Hearing organ is not a linear system like a microphone.



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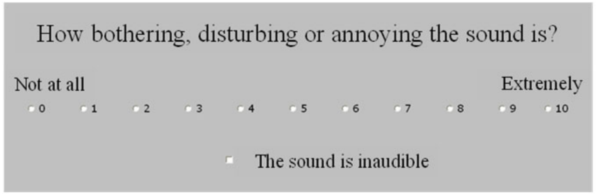
Results – Infrasound annoyance

- We determined the annoyance responses to the ELC 20 phon, 40 phon and 60 phon levels using 11-point response scale

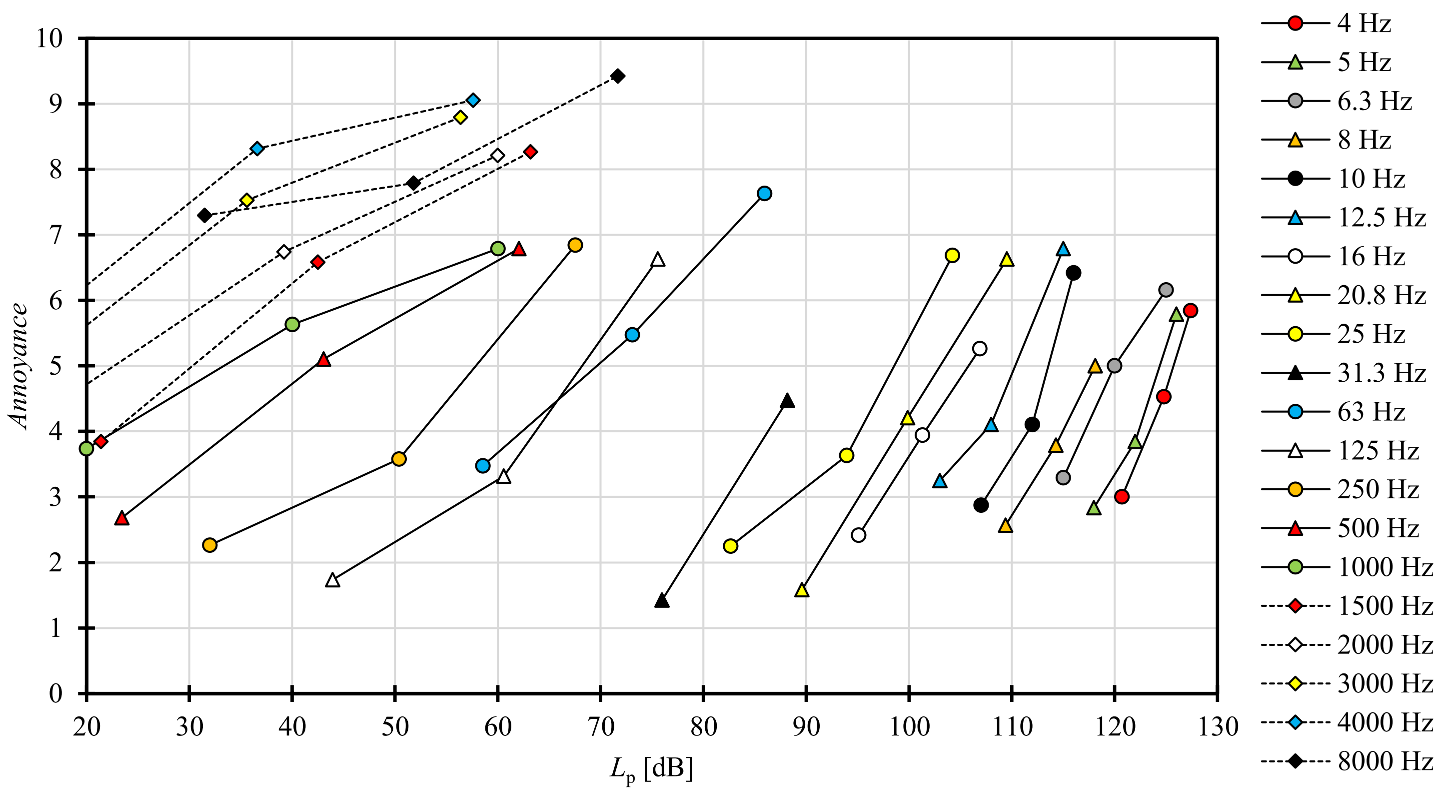

How bothering, disturbing or annoying the sound is?

Not at all — Extremely

0 1 2 3 4 5 6 7 8 9 10

The sound is inaudible

- Annoyance was significantly higher for high frequency tones than for infrasound tones at the same ELC level. That is, infrasound is not especially annoying.
- On the other hand, the gradient of annoyance vs. SPL is larger for infrasound: even a small SPL increment leads to large increment in annoyance.



The mean *annoyance* as a function of unweighted SPL, L_p, for the 20 studied frequencies from 4 to 8000 Hz. For each frequency, the three SPLs conformed with the ELC 20 phon (lowest point), 40 phon (middle point), and 60 phon (highest point) indicated in **Table 1**.

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