Noise annoyance

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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 both on the **environment** (the expected sounds to be present) and on-going **activity**.

Environment

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

Activity

- 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**
- 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

Increment of morbidity

- Cardiovascular diseases
- Infections
- Psyche

Jauhiainen et al, (2007) Suomen ympäristö

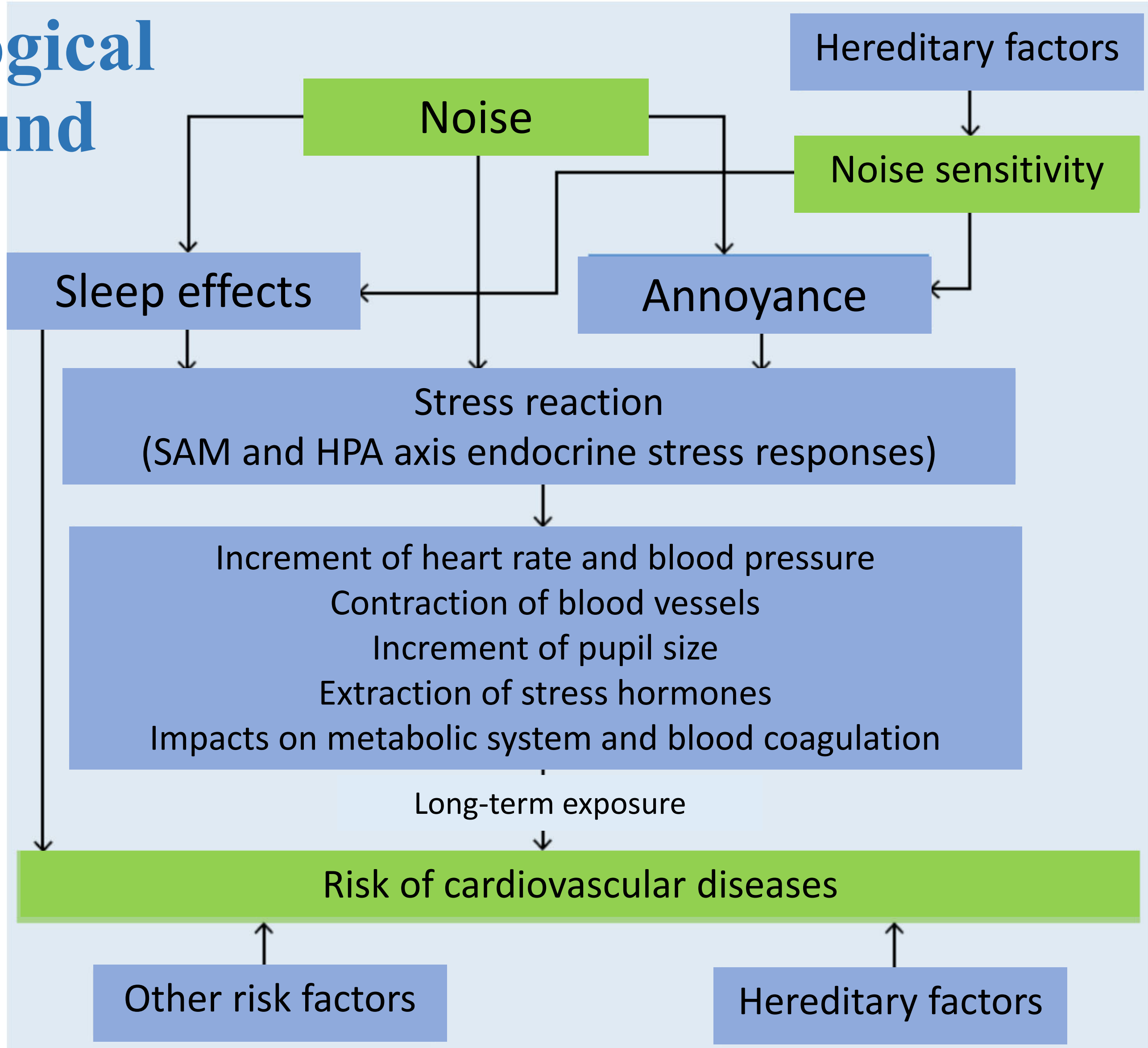
Noise annoyance

- 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, for instance, being **annoyed** is, in the light of the WHO definition, itself an adverse effect that should be avoided in order to retain well-being.

Pedersen, 2009

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 itself a risk factor



Heinonen-Guzejev (2012) Suomen lääkärilehti

Measurement of noise annoyance (ISO/TS 15666)

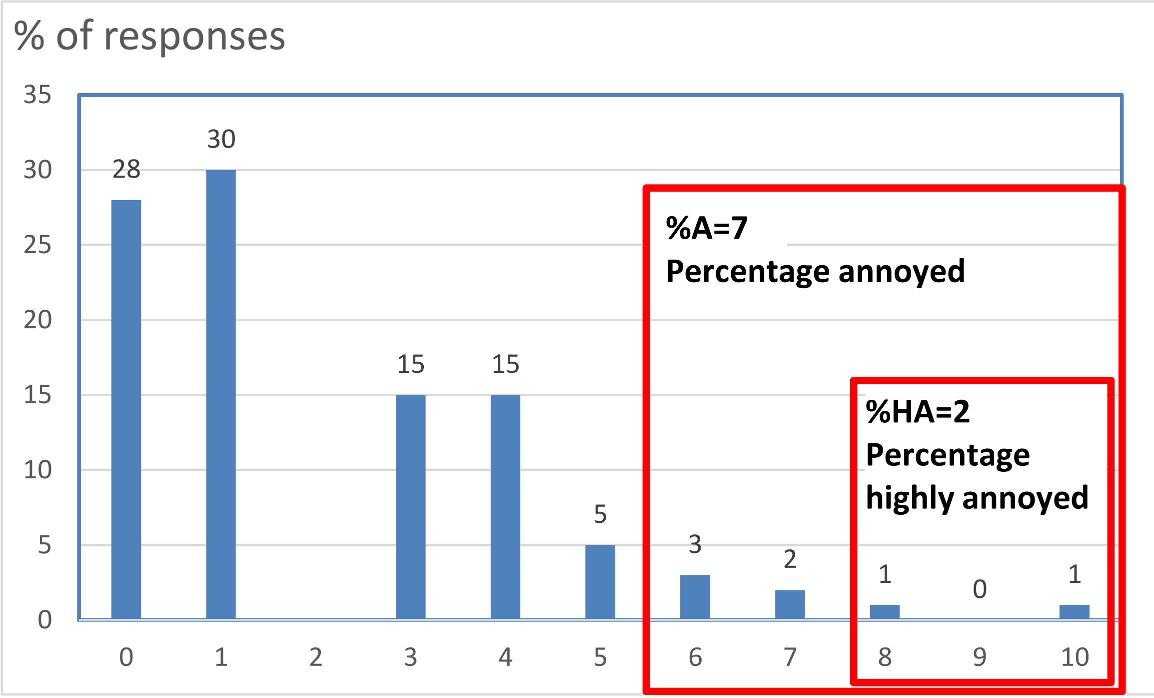
How much the noise of source X has bothered, disturbed or annoyed you?

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

- Annoyance is measured using an 11-step interval variable

Binary variable is created by giving 0 for those below a certain limit and 1 for those above a limit:

- **%A**: the share of those responding 6 or more
- **%HA**: the share of those responding 8 or more.



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.

Nilsson and Berglund 2006 *J Acoust Soc Am*

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*

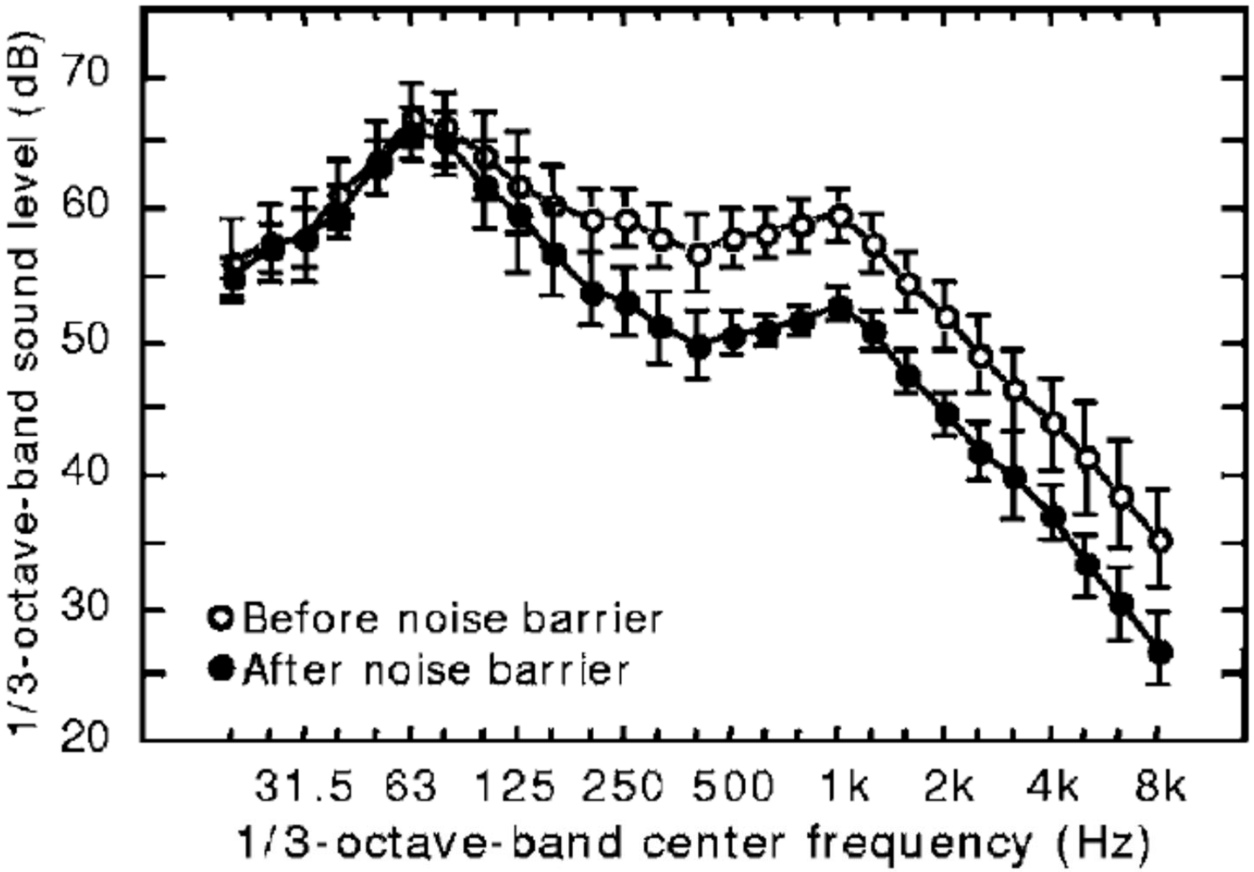


FIG. 2. Spectra for 45 min measurements conducted in eight gardens closest to the main road (23 m). Points show arithmetic averages of 1/3-octave-band sound levels ($L_{eq,45min}$) from eight measurements conducted before (open circles) and after the barrier (filled circles) was erected (error bars: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

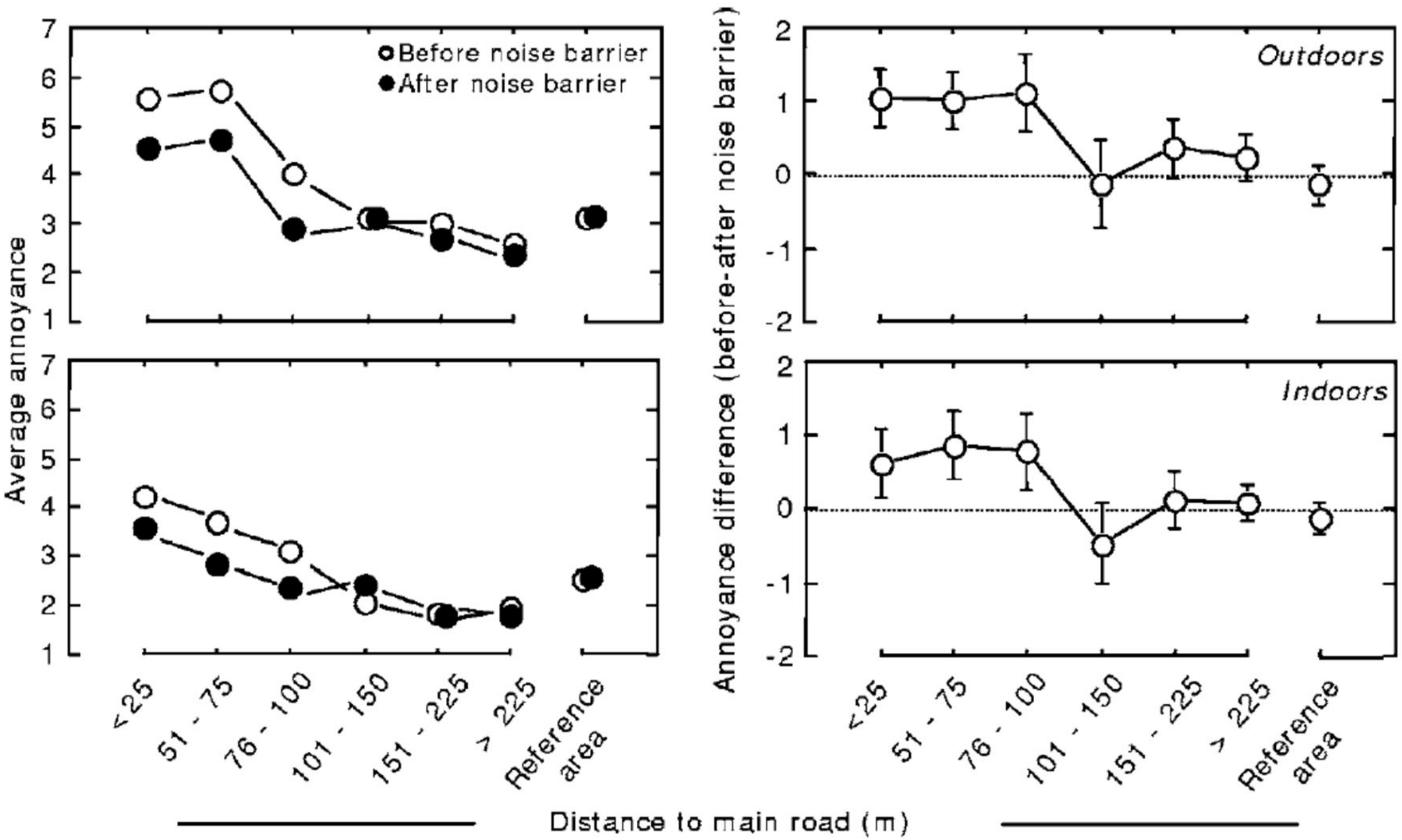


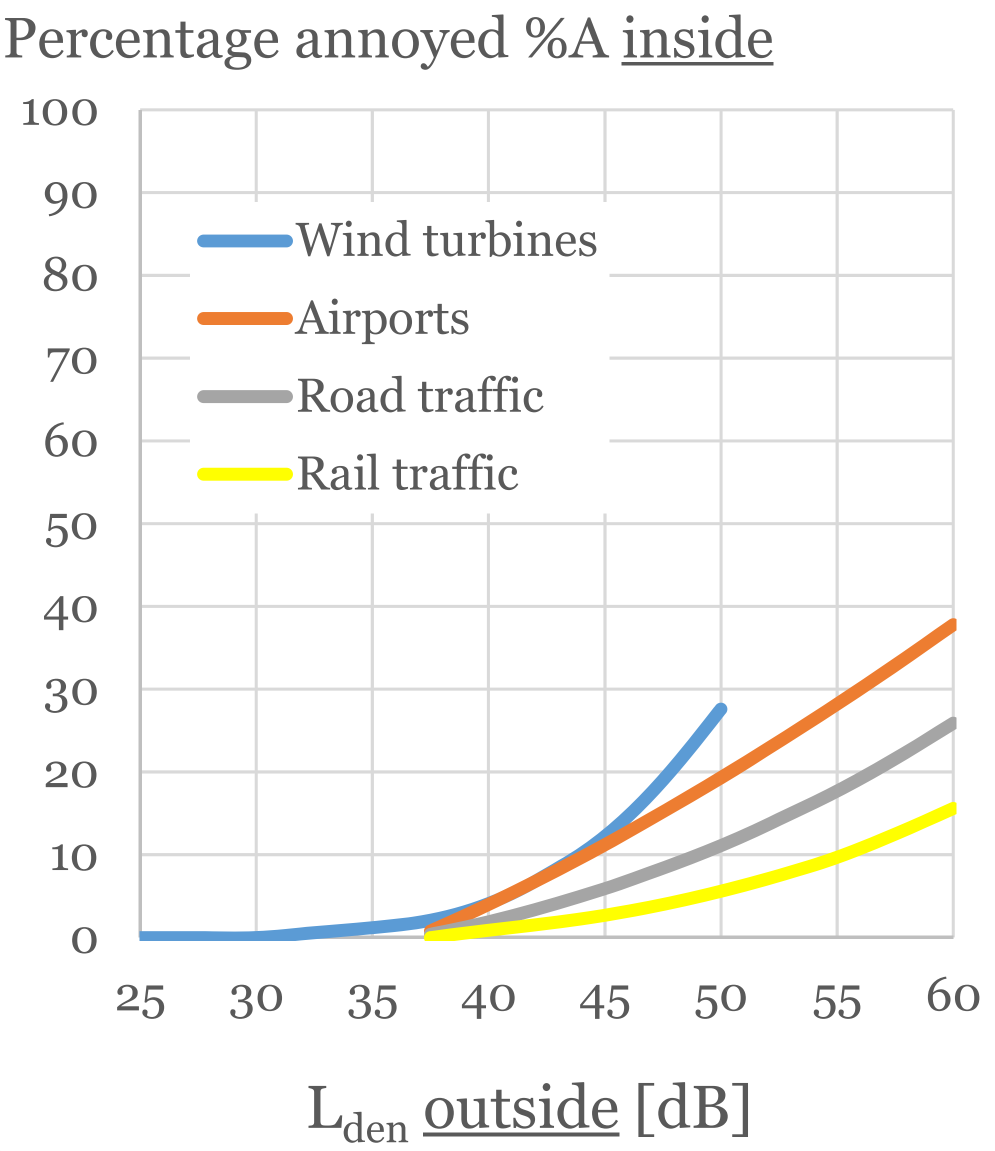
FIG. 3. Road-traffic noise annoyance (left panels) and annoyance difference between study waves (right panels), each plotted as a function of distance to the main road. Upper panels: outdoor annoyance. Lower panels: indoor annoyance. Left panels: Open symbols=before the barrier; filled symbols=after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

- Dose: Noise level
- Response: Annoyance
- DRR attempts to model the prevalence of annoyed people among the population.
- DRR describes the prevalence of a binary variable (%A or %HA) as a function of sound level
- Response is determined, e.g., within 5 dB steps using a prediction model
- DRR is source-specific.



Janssen et al. 2011 *J Acoust Soc Am*

$$L_{den} = 10*\log_{10}[(12/24)*10^{LD/10} + (4/24)*10^{(LE+5)/10} + (8/24)*10^{(LN+10)/10}]$$

where LD, LE, and LN are the A-weighted equivalent levels, L_{Aeq} [dB], for the day (07-19), evening (19-23), and night (22-07), respectively,

DRR depends on the study

- Schultz (1978) published the first %HA vs. L_{dn} curve regarding road traffic noise.
- The curve was based on 453 data points worldwide
- 74 dB L_{dn} yielded a mean value %HA=34.
- However, individual points varied between 5 and 100. Why?

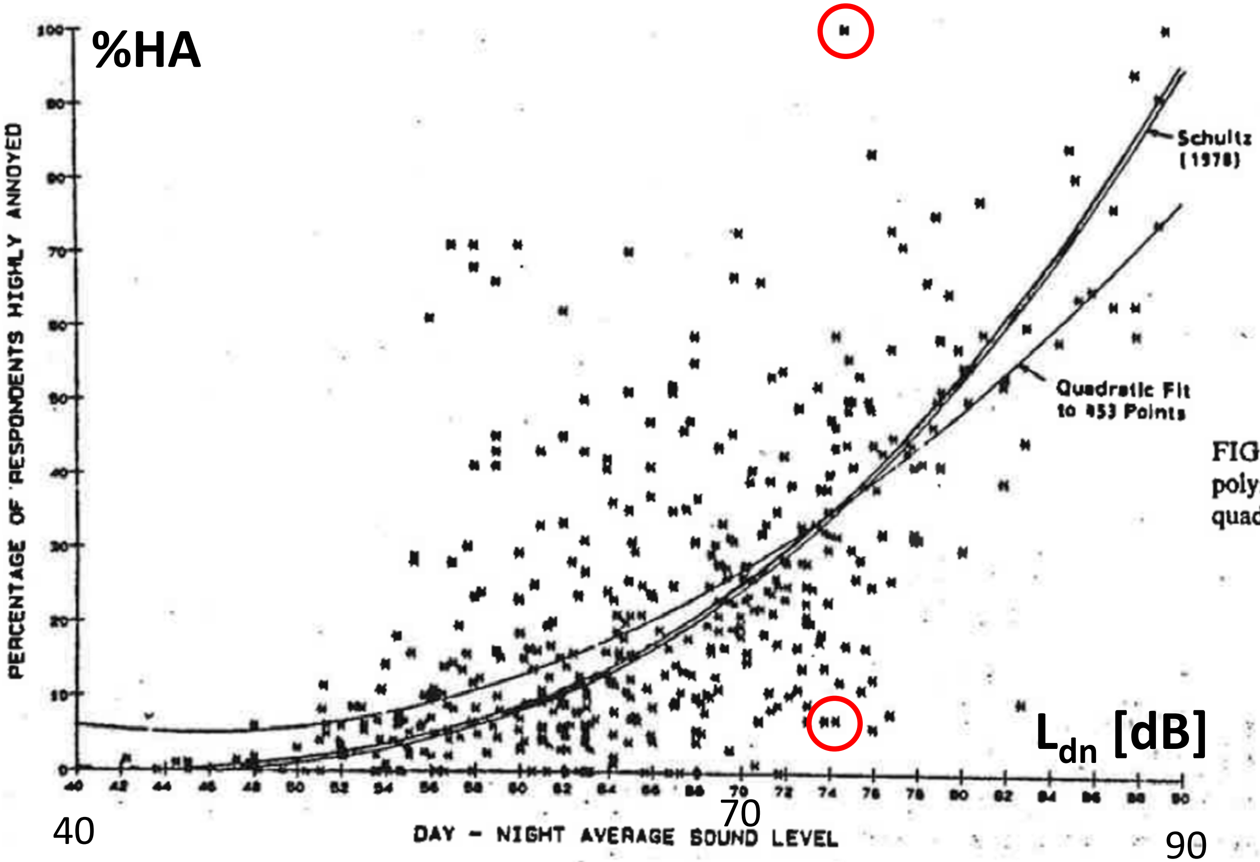


FIG. 14. Comparison of 1978 third-order polynomial fitting function with present quadratic fit to 453 data points.

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

Guski 1999 suggests:

- One-third of noise annoyance is explained by noise level.
- Another one-third is explained by non-acoustic factors.
- Remaining one-third by measurement errors

Important non-acoustic factors in residential context:

Individual (person)

- Noise sensitivity
- Neuroticm
- 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

- **Psychoacoustics** 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 (including noise, speech and music).
- Psychoacoustics is a branch of psychophysics.
- Psychoacoustics received its name from a field within psychology—i.e., recognition science—which deals with all kinds of human perceptions.
- Psychoacoustics is an interdisciplinary field of many areas, including psychology, acoustics, electronic engineering, physics, biology, physiology, and computer science.

Wikipedia, 18 May 2018

Effect of sound level on annoyance

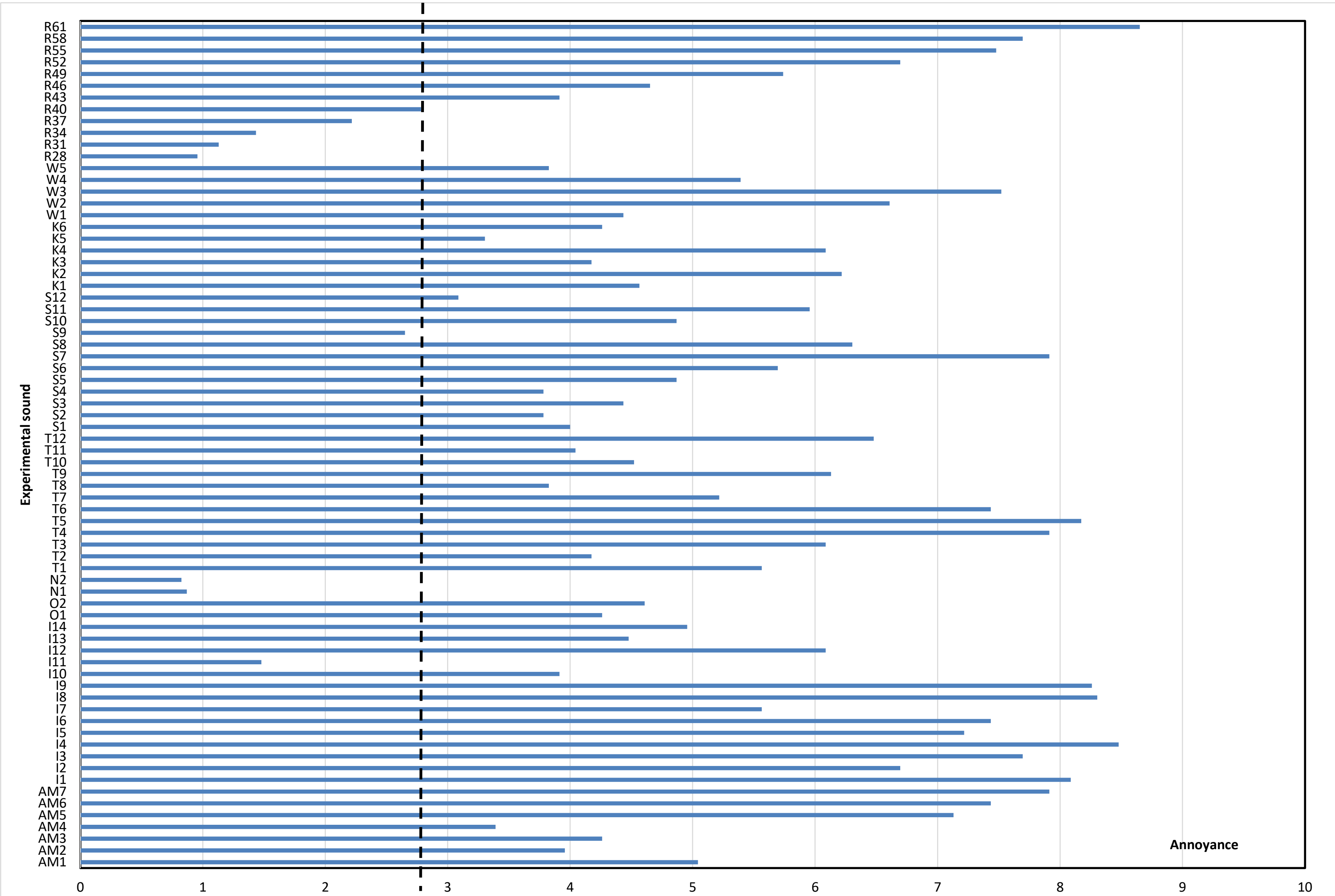
- An experiment was conducted where 60 different real sounds recorded in the living environment were presented at 40 dB L_{Aeq}.
- In addition, 12 broadband reference sounds was presented at 28-61 dB L_{Aeq}.
- 30 participants rated the annoyance using rating scale 0-10.
- 12 broadband sounds' annoyance ranged logically from 0.8 (29 dB) to 8.7 (61 dB).
- However, real sounds' annoyance ranged the same amount, from 0.7 to 8.5 although they had the same A-weighted level
- A-weighted level explains well the annoyance caused by a specific sound.
- However, A-weighted level does not explain annoyance differences between different sounds.

Effect of sound level on annoyance (scale: 0-10)

Name	Name	Type	LAeq [dB]	Annoyance
AM1	WTA recording 1	Amplitude-modulated soud	40.0	5.0
AM2	WTA recording 2	Amplitude-modulated soud	40.0	4.0
AM3	WTA recording 3	Amplitude-modulated soud	40.0	4.3
AM4	AM sound 0.25 Hz DL 16 dB	Amplitude-modulated soud	40.0	3.4
AM5	AM sound 1.0 Hz DL 16 dB	Amplitude-modulated soud	40.0	7.1
AM6	AM sound 4.0 Hz DL 16 dB	Amplitude-modulated soud	40.0	7.4
AM7	AM sound 16.0 Hz DL 16 dB	Amplitude-modulated soud	40.0	7.9
I1	Pile-driving 1	Impulsive sound	40.0	8.1
I2	Ron50DL20	Impulsive sound	40.0	6.7
I3	Ron50DL40	Impulsive sound	40.0	7.7
I4	Ron800DL40	Impulsive sound	40.0	8.5
I5	Shooting sound 1	Impulsive sound	40.0	7.2
I6	Shooting sound 1	Impulsive sound	40.0	7.4
I7	Firewood splitting with axe	Impulsive sound	40.0	5.6
I8	Nail hitting on wooden wall	Impulsive sound	40.0	8.3
I9	Carpet tamping	Impulsive sound	40.0	8.3
I10	Car exits from tunnel	Impulsive sound	40.0	3.9
I11	Catherdal bells	Impulsive sound	40.0	1.5
I12	Basket ball bouncing on the paying field	Impulsive sound	40.0	6.1
I13	Music from festival	Impulsive sound	40.0	4.5
I14	Construction noise	Impulsive sound	40.0	5.0
O1	Airplane takeoff	Traffic sound	40.0	4.3
O2	Train on a steel bridge	Traffic sound	40.0	4.6
N1	Water	Natural sound	40.0	0.9
N2	Ocean waves and birds	Natural sound	40.0	0.8
T1	Tone 50 Hz AT 25 dB	Tonal sound	40.0	5.6
T2	Tone 110 Hz AT 25 dB	Tonal sound	40.0	4.2
T3	Tone 290 Hz AT 25 dB	Tonal sound	40.0	6.1
T4	Tone 850 Hz AT 25 dB	Tonal sound	40.0	7.9
T5	Tone 2100 Hz AT 25 dB	Tonal sound	40.0	8.2
T6	Drill saw	Tonal sound	40.0	7.4
T7	Recorded source 1	Tonal sound	40.0	5.2
T8	Recorded source 2	Tonal sound	40.0	3.8
T9	Recorded source 3	Tonal sound	40.0	6.1
T10	Recorded source 4	Tonal sound	40.0	4.5
T11	Recorded source 5	Tonal sound	40.0	4.0
T12	Fan	Tonal sound	40.0	6.5

Name	Name	Type	LAeq [dB]	Annoyance
S1	m9dBperoct	Wide-band steady-state noise	40.0	4.0
S2	m6dBperoct	Wide-band steady-state noise	40.0	3.8
S3	m3dBperoct	Wide-band steady-state noise	40.0	4.4
S4	pink noise	Wide-band steady-state noise	40.0	3.8
S5	p3dBperoct	Wide-band steady-state noise	40.0	4.9
S6	p6dBperoct	Wide-band steady-state noise	40.0	5.7
S7	031Hz	Wide-band steady-state noise	40.0	7.9
S8	o63Hz	Wide-band steady-state noise	40.0	6.3
S9	o250Hz	Wide-band steady-state noise	40.0	2.7
S10	o1000Hz	Wide-band steady-state noise	40.0	4.9
S11	o4000Hz	Wide-band steady-state noise	40.0	6.0
S12	optimum masking	Wide-band steady-state noise	40.0	3.1
K1	Elevator 1 drive	Elevator sound	40.0	4.6
K2	Elevator 1 door clatter	Elevator sound	40.0	6.2
K3	Elevator 2 drive	Elevator sound	40.0	4.2
K4	Elevator 2 door clatter	Elevator sound	40.0	6.1
K5	Elevator 3 drive	Elevator sound	40.0	3.3
K6	Elevator 3 door clatter	Elevator sound	40.0	4.3
W1	Stack	Industrial sound	40.0	4.4
W2	Turbo 1	Industrial sound	40.0	6.6
W3	Turbo 2	Industrial sound	40.0	7.5
W4	Plant	Industrial sound	40.0	5.4
W5	Hill	Industrial sound	40.0	3.8
R28	Reference sound 28 dB	Steady-state wideband noise	28	1.0
R31	Reference sound 31 dB	Steady-state wideband noise	31	1.1
R34	Reference sound 34 dB	Steady-state wideband noise	34	1.4
R37	Reference sound 37 dB	Steady-state wideband noise	37	2.2
R40	Reference sound 40 dB	Steady-state wideband noise	40	2.8
R43	Reference sound 43 dB	Steady-state wideband noise	43	3.9
R46	Reference sound 46 dB	Steady-state wideband noise	46	4.7
R49	Reference sound 49 dB	Steady-state wideband noise	49	5.7
R52	Reference sound 52 dB	Steady-state wideband noise	52	6.7
R55	Reference sound 55 dB	Steady-state wideband noise	55	7.5
R58	Reference sound 58 dB	Steady-state wideband noise	58	7.7
R61	Reference sound 61 dB	Steady-state wideband noise	61	8.7

Effect of sound level on annoyance



Sound quality features and annoyance

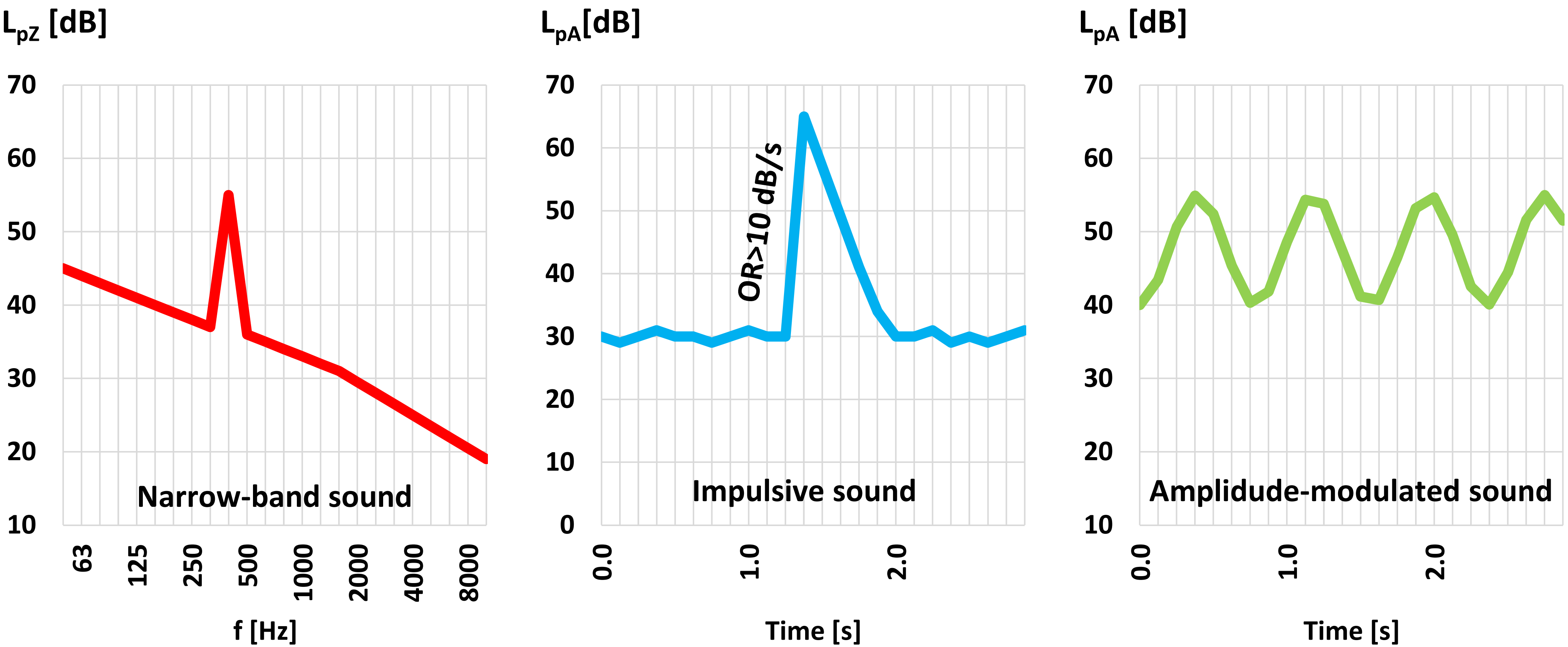
There is strong **psychoacoustic** evidence that certain special physical features in sound increase the annoyance compared to the annoyance caused by a neutral sound having the same overall level.

Such special features are:

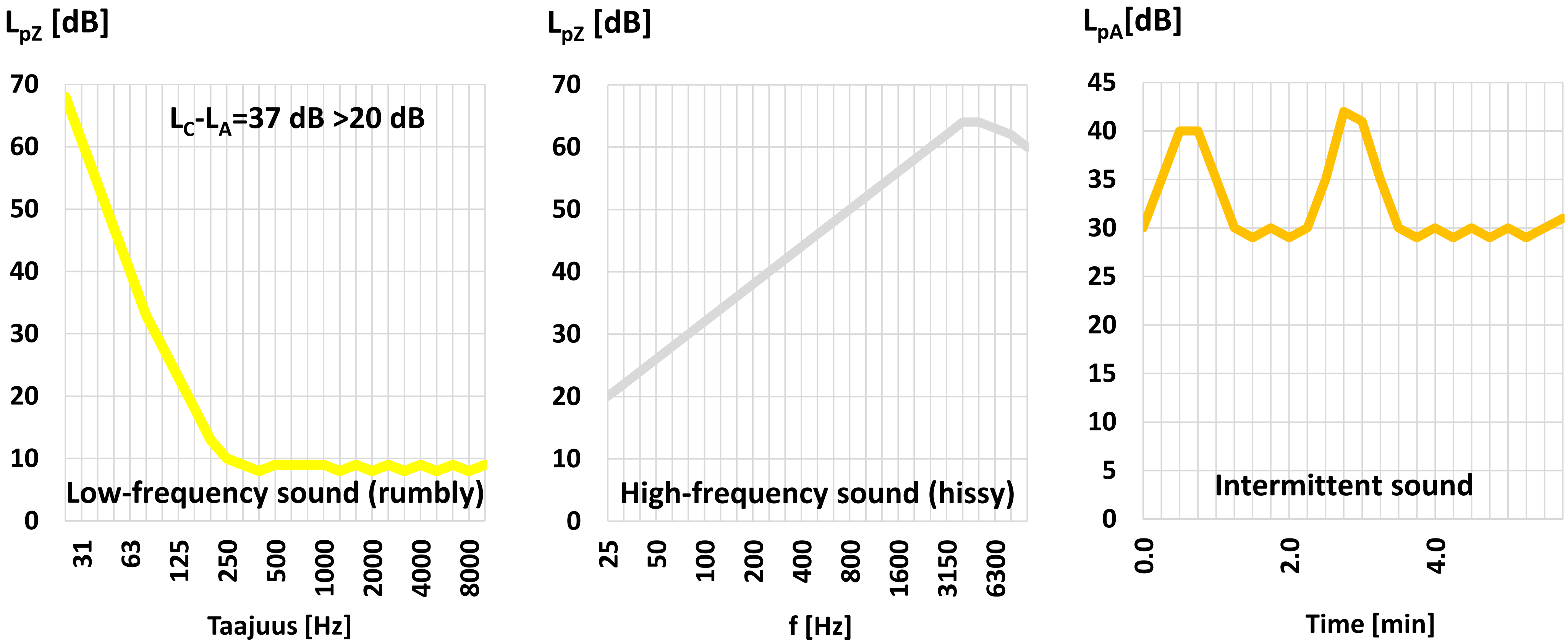
- Narrow-band sound (tonal sound)
- Impulsive sound
- Amplitude-modulated sound (periodically alternating)
- Spectrally special sounds (hissy, rumbly, roaring)
- Intermittent (unpredictable) sound

Psychoacoustics is not based on physical theories, like acoustic engineering. It is based on experimental evidence collected from humans because psychoacoustics deals with human perception. The laws of psychoacoustics must, therefore, be based on repeated evidence: a single experiment does not prove anything although it a well-designed experiment can tell the whole truth.

Special sound quality features



Special sound quality features

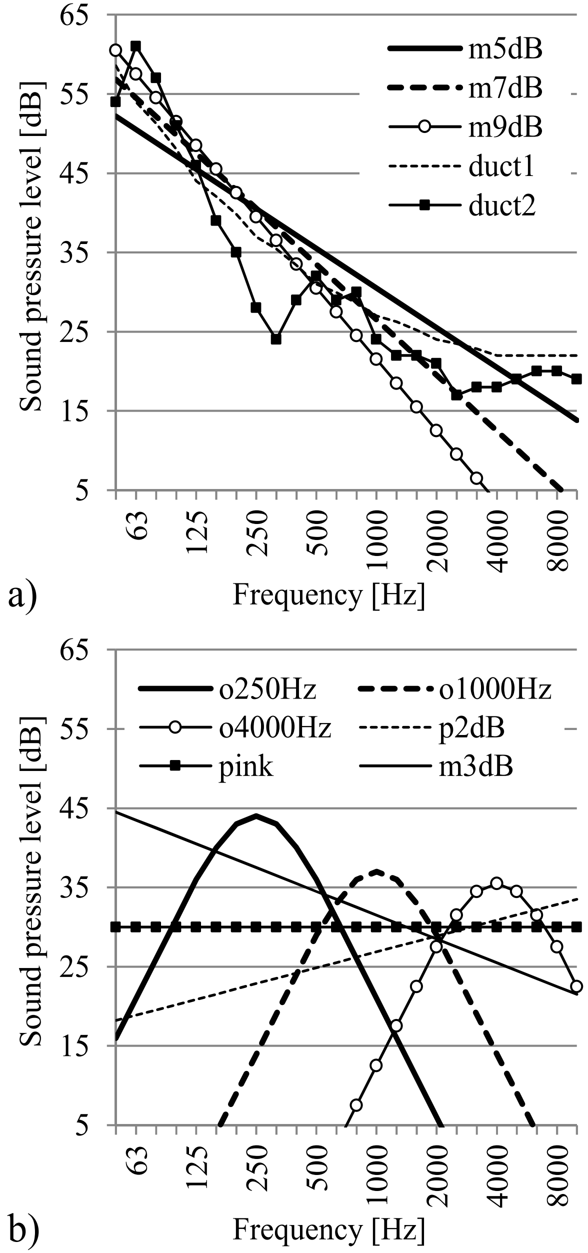


Experiment 1: The effect of spectrum on annoyance

Hongisto, V., Oliva, D., Rekola, L. (2015). Subjective and Objective Rating of Spectrally Different Pseudorandom Noises – Implications for Speech Masking Design, **The Journal of the Acoustical Society of America**, 137(3) 1344–1355.

Purpose and methods

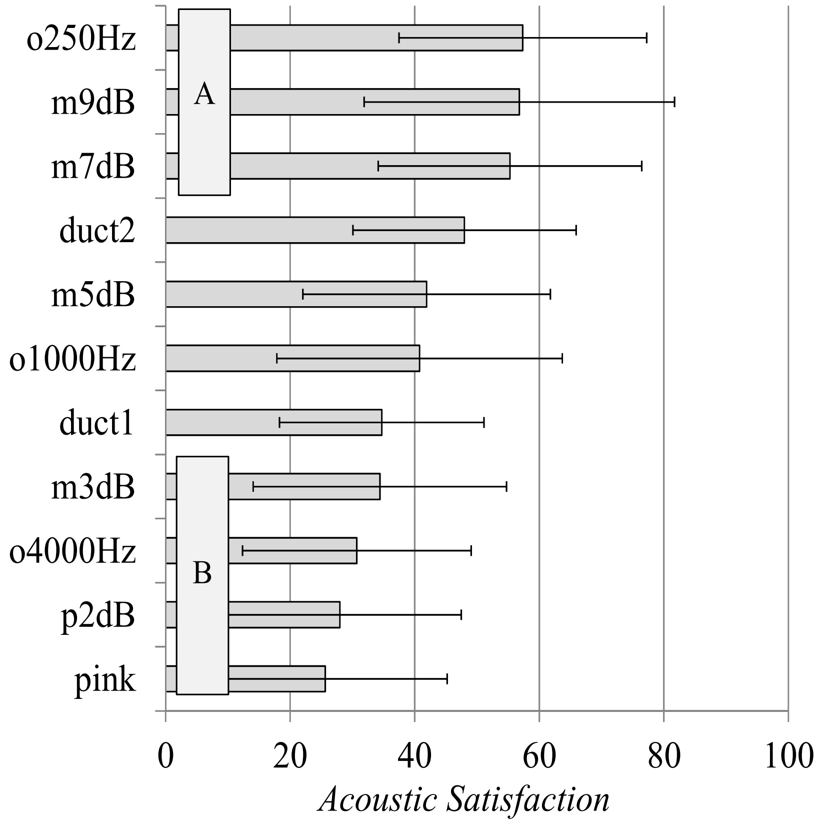
- The purpose was to identify which spectrum is preferred as a constant background in offices
- 23 subjects
- Subjective rating of 11 spectrally different pseudorandom *sounds*, all presented at 42 dB L_{Aeq}
- Rating was made to *Acoustic Satisfaction* (A.S.), which was a sum variable of three negative and three positive properties of the sound (loudness, disturbance, pleasantness, …)
- Exposure time 90 seconds
- Friedman's test was used to test the main effect of sound on A.S.
- Wilcoxon's test was used to determine the statistically significant differences between pairs of *sounds*.

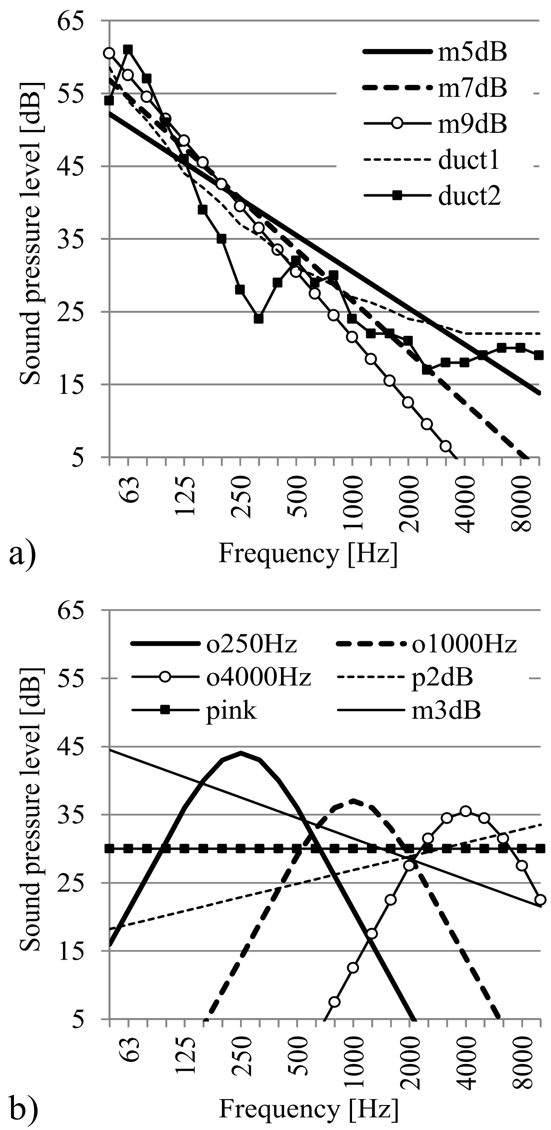


Hongisto et al. 2015 *J Acoust Soc Am*

Results

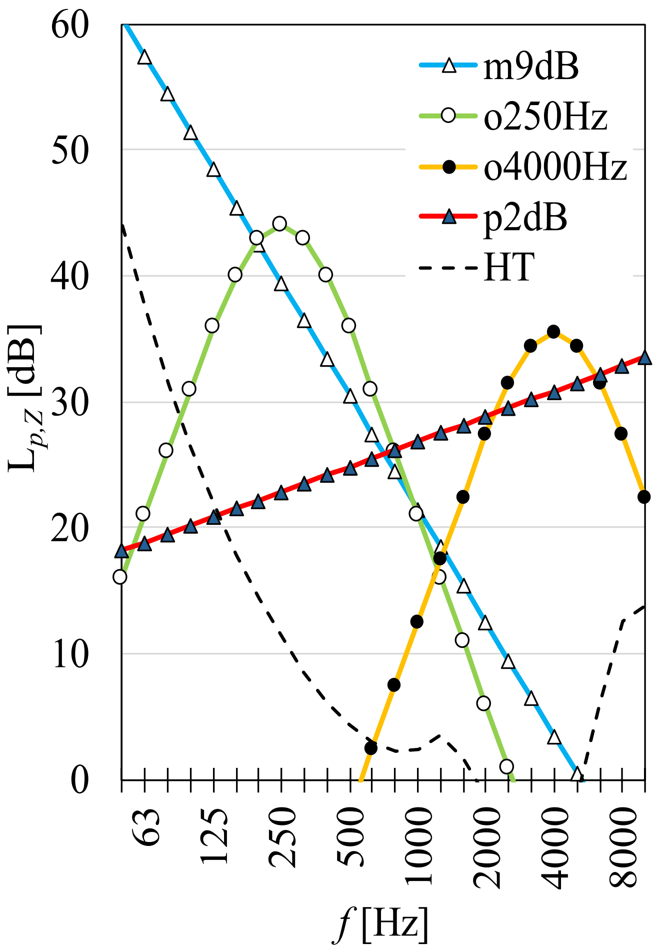
- Paired comparisons indicated groups of the most (A) and the least (B) satisfactory sounds
- Group A involved sounds having strong low frequency content
- Group B involved hissy sounds they were the most dissatisfactory sounds
- Speech masking efficiency was the largest for hissy sounds
- **Conclusion**: masking spectrum with a slope of -5–-7 dB per octave doubling is recommended for optimum balance between masking and annoyance.



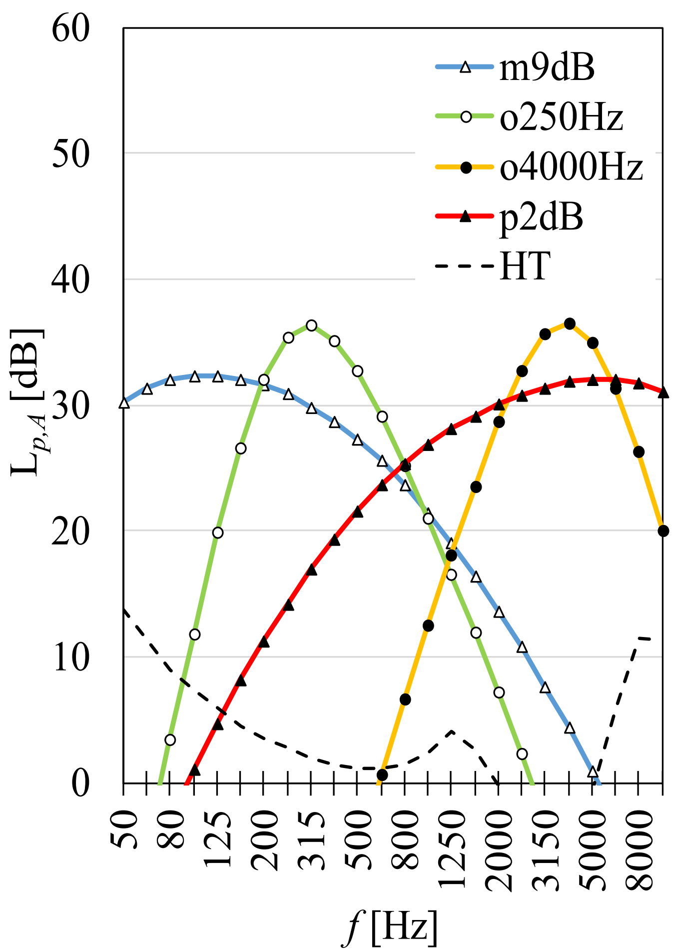


Hongisto et al. 2015 *J Acoust Soc Am*

Sound demos



60
50
40
30
20
10
0
$L_{p,Z}$ [dB]
m9dB
o250Hz
o4000Hz
p2dB
HT
63
125
250
500
1000
2000
4000
8000
f [Hz]



60
50
40
30
20
10
0
$L_{p,A}$ [dB]
m9dB
o250Hz
o4000Hz
p2dB
HT
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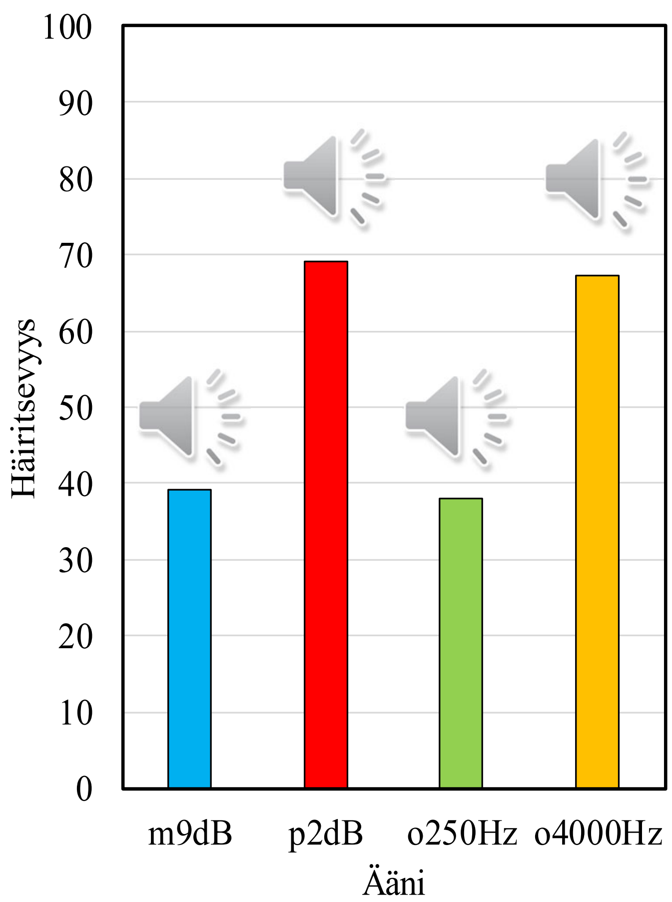
80
125
200
315
500
800
1250
2000
3150
5000
8000
f [Hz]



100
90
80
70
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50
40
30
20
10
0
Häiritsevyys
m9dB
p2dB
o250Hz
o4000Hz
Ääni

Experiment 2: Annoyance penalty of tonal sound

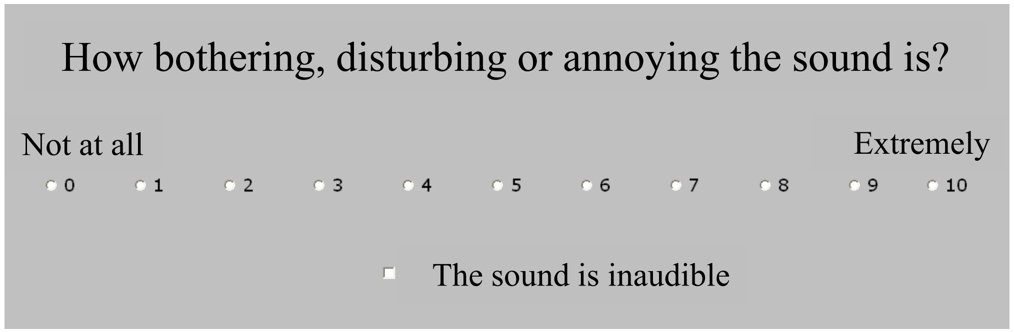
Oliva, D., Hongisto, V., Haapakangas, A. (2017). Annoyance of low-level tonal sounds - factors affecting the penalty. **Building and Environment** 123 404–414.

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

Oliva et al. (2017)

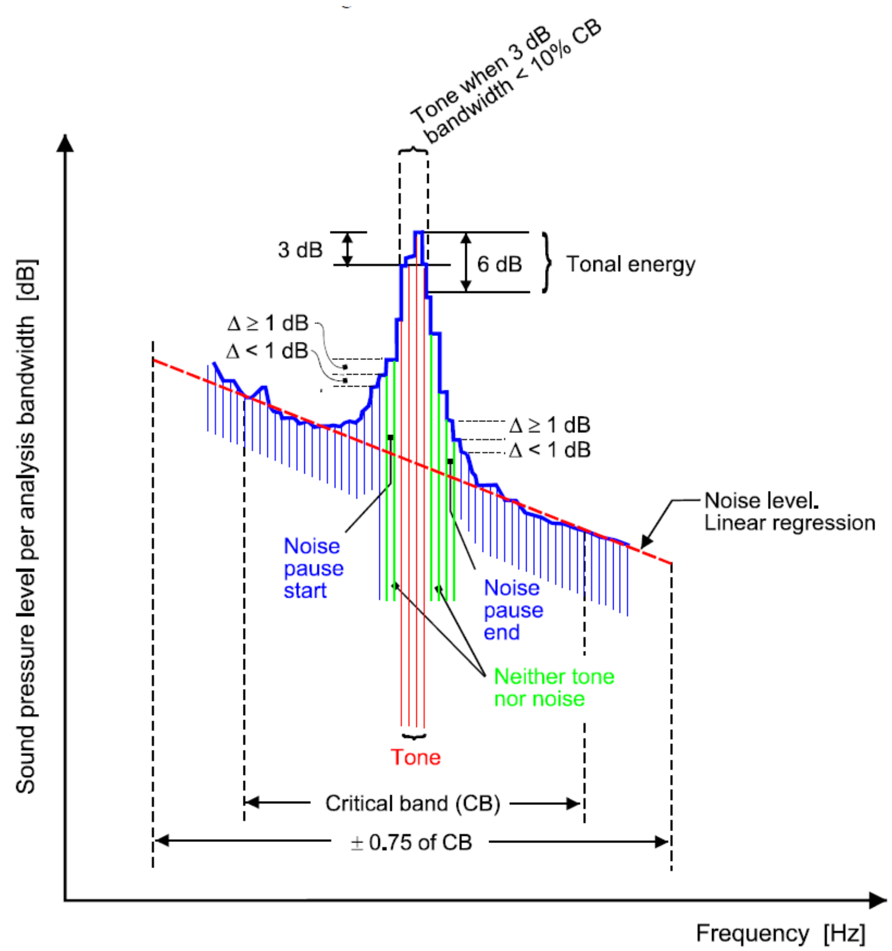
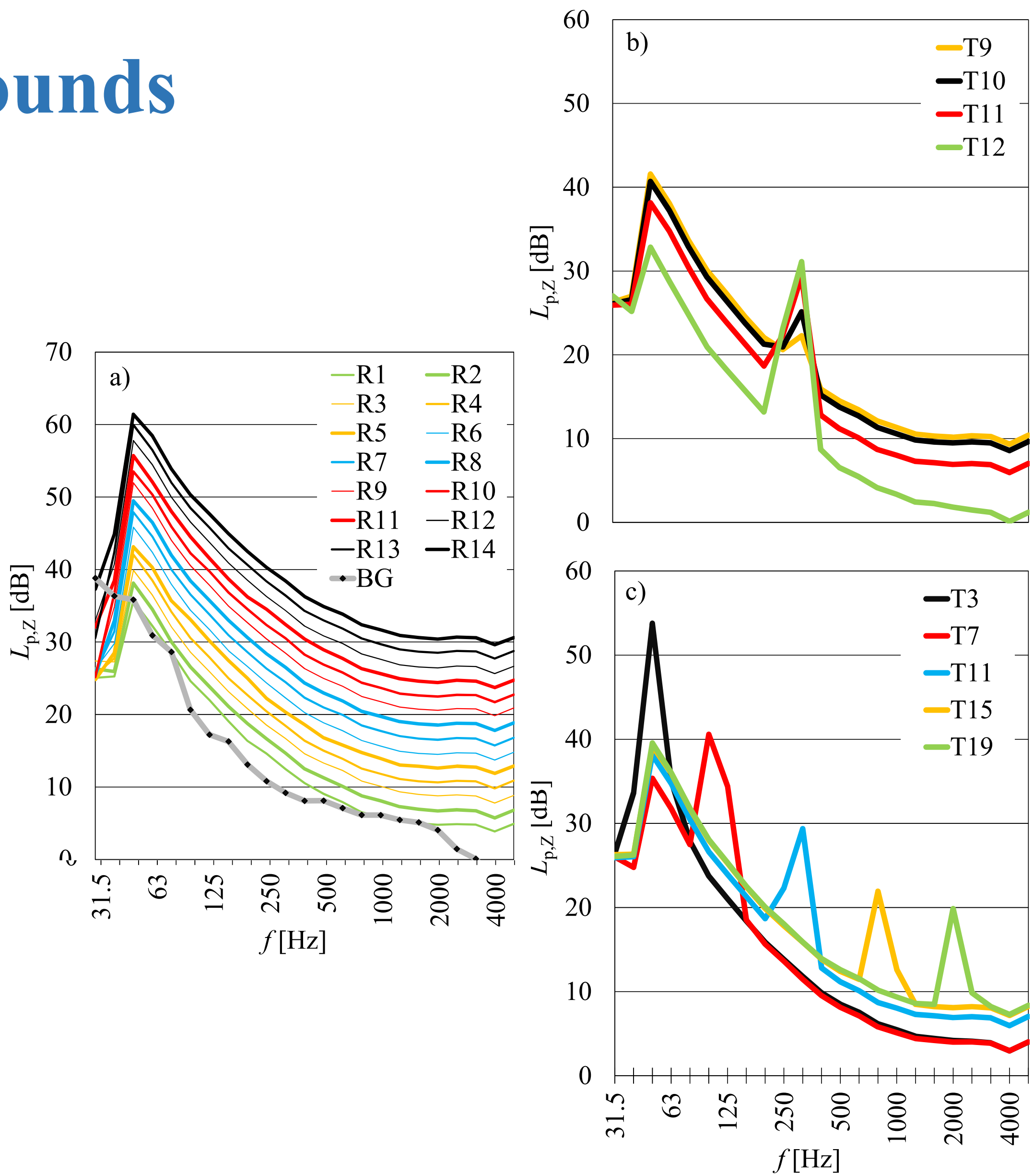


Figure 3
Definitions of tones, noise, and noise pause (neither tone nor noise).

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

Methods - Sounds

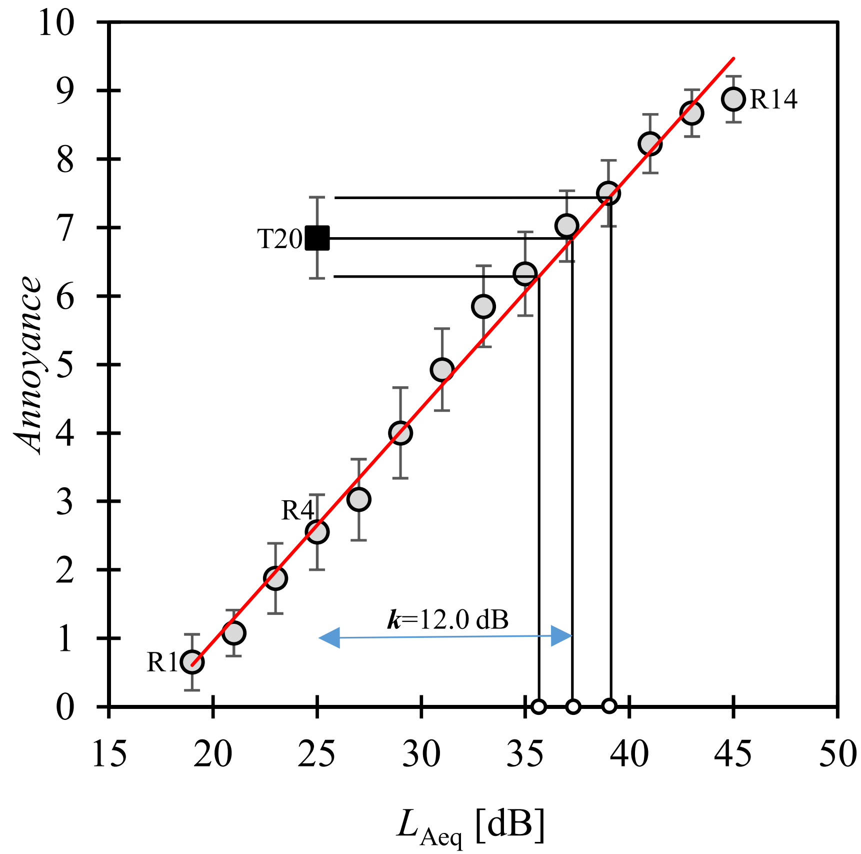
- 20 tonal sounds were presented at 25 dB L_{Aeq}.
  - Four levels of tonal audibility
  - Five different tonal frequencies
- 14 reference sounds were used to determine the penalty
- The background spectrum of both tonal sounds and reference sounds followed the inverse of A-weighting.



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

Methods - Penalty *k*

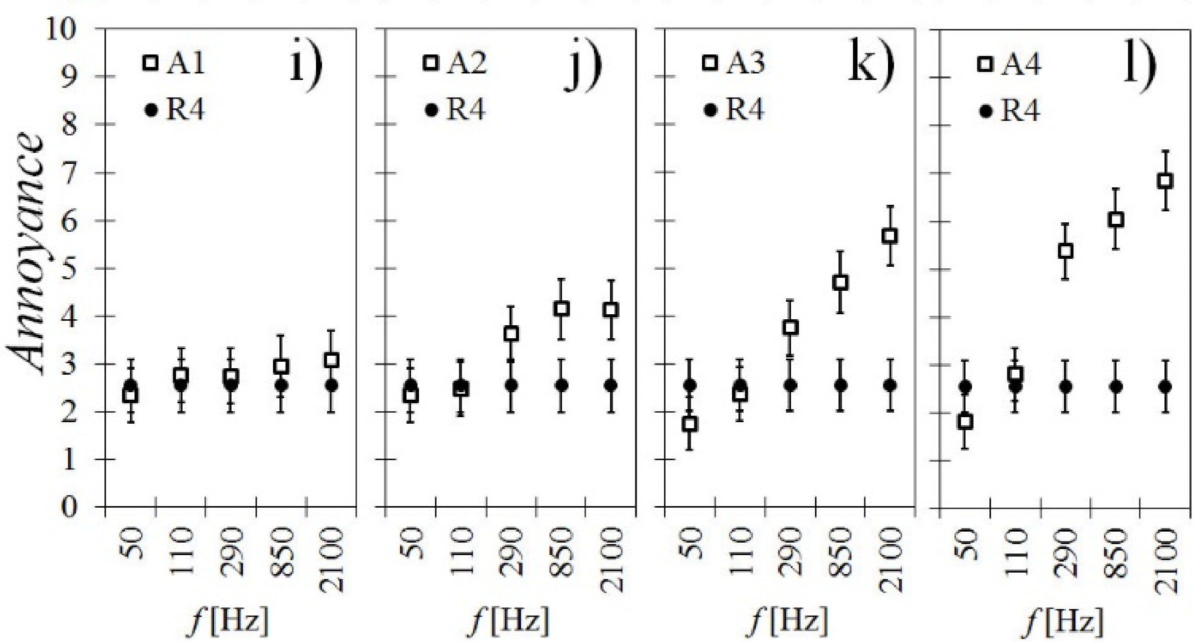
- Reference sounds were presented within 25–45 dB L_{Aeq} to be able to determine the penalty
- Example of the determination of penalty value *k* for *experimental sound* T35 (black square).
- The 95% confidence interval is shown by whiskers.
- Linear interpolation over the mean of the reference sounds 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)

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 f_T and tonal audibility A_T.



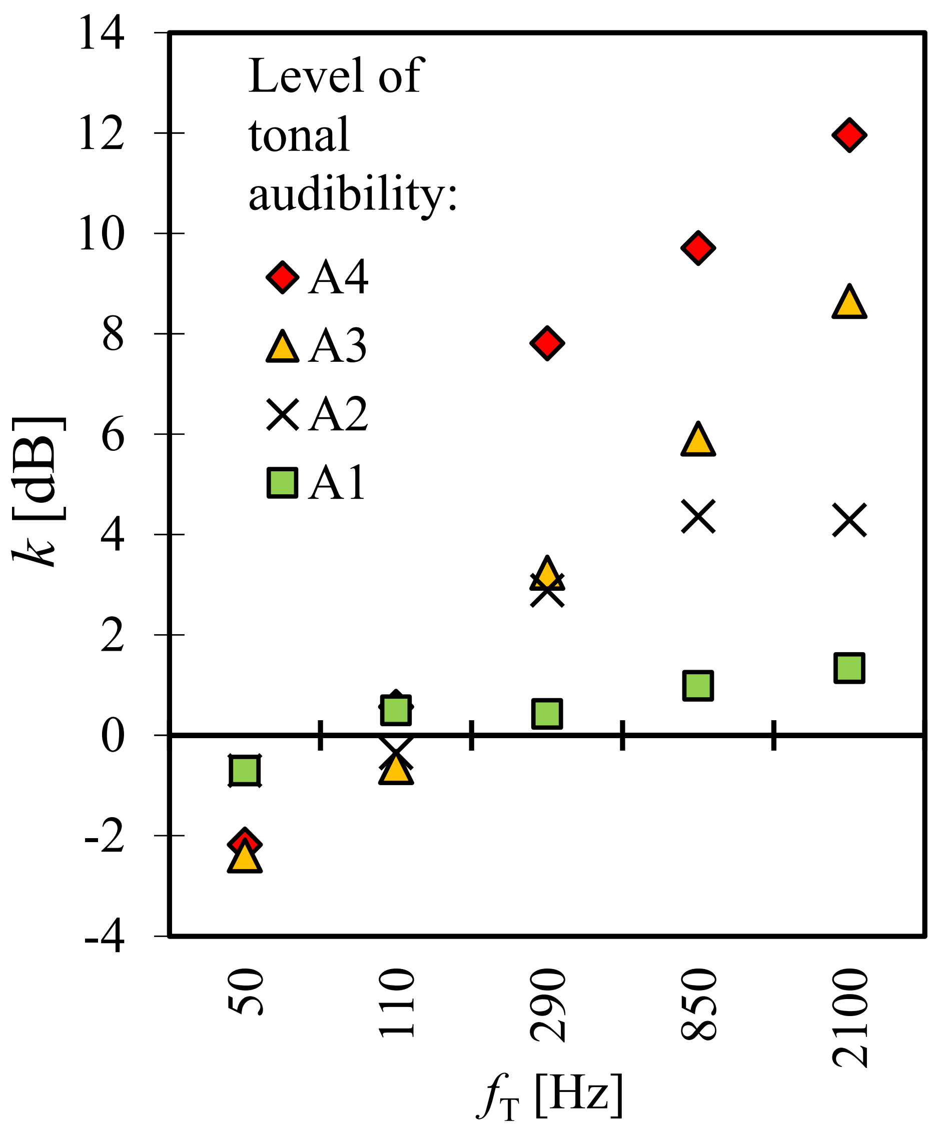
Oliva et al. (2017)

Sound	f_T [Hz]	A_T Level	A_T [dB]	L_{Aeq} [dB]	*Annoyance* M	*Annoyance* SE
R1	-	-	0	19	0.68	0.20
R2	-	-	0	21	1.08	0.17
R3	-	-	0	23	1.88	0.26
R4	-	-	0	25	2.55	0.28
R5	-	-	0	27	3.03	0.30
R6	-	-	0	29	4.00	0.34
R7	-	-	0	31	4.93	0.30
R8	-	-	0	33	5.85	0.30
R9	-	-	0	35	6.33	0.31
R10	-	-	0	37	7.03	0.26
R11	-	-	0	39	7.50	0.24
R12	-	-	0	41	8.23	0.22
R13	-	-	0	43	8.68	0.17
R14	-	-	0	45	8.88	0.17
T1	50	A1	5	25	2.35	0.29
T2	50	A2	10	25	2.35	0.29
T3	50	A3	18	25	1.78	0.32
T4	50	A4	25	25	1.93	0.38
T5	110	A1	5	25	2.78	0.29
T6	110	A2	10	25	2.48	0.29
T7	110	A3	17	25	2.38	0.30
T8	110	A4	24	25	2.83	0.37
T9	290	A1	5	25	2.75	0.30
T10	290	A2	10	25	3.63	0.37
T11	290	A3	17	25	3.75	0.39
T12	290	A4	25	25	5.38	0.35
T13	850	A1	5	25	2.95	0.32
T14	850	A2	10	25	4.15	0.34
T15	850	A3	18	25	4.70	0.36
T16	850	A4	25	25	6.05	0.39
T17	2100	A1	5	25	3.08	0.31
T18	2100	A2	10	25	4.13	0.38
T19	2100	A3	18	25	5.68	0.39
T20	2100	A4	25	25	6.85	0.30

Results - Annoyance penalty

- The penalty increased with increasing f_T and A_T [dB].
- 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

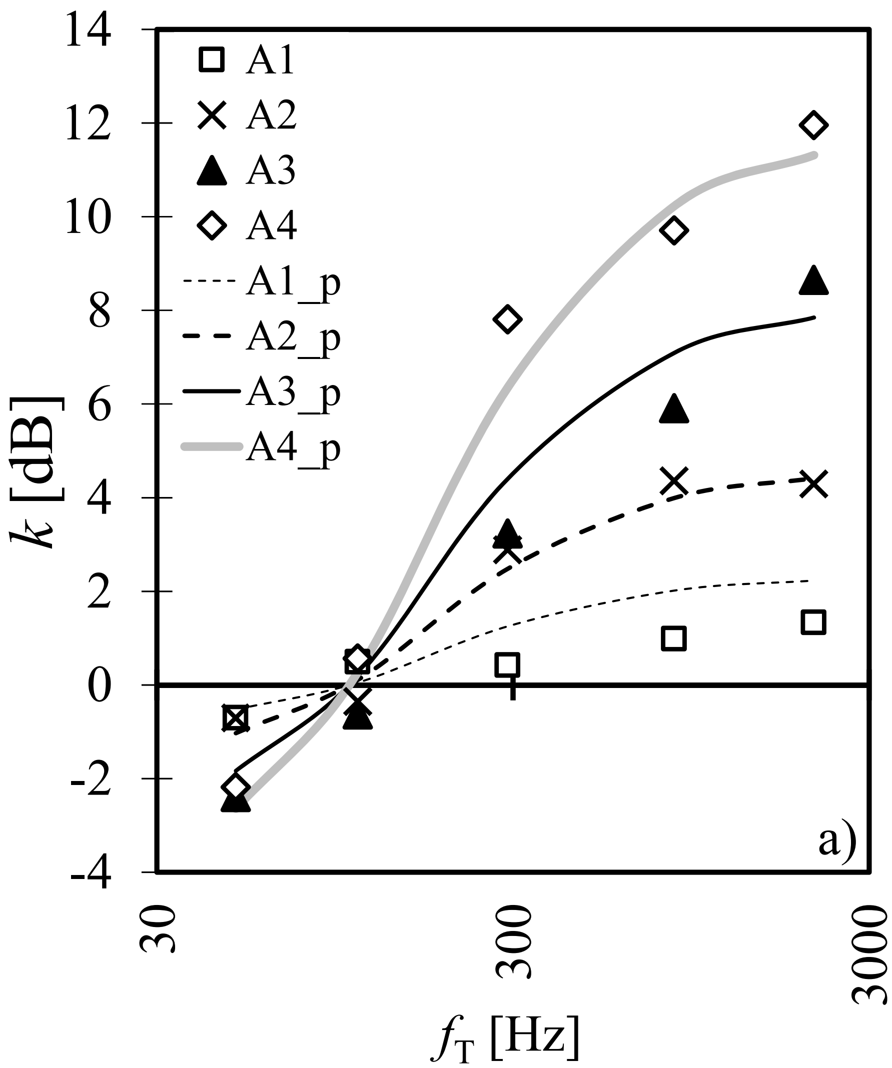


Oliva et al. (2017)

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

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



Hongisto et al. (2018)

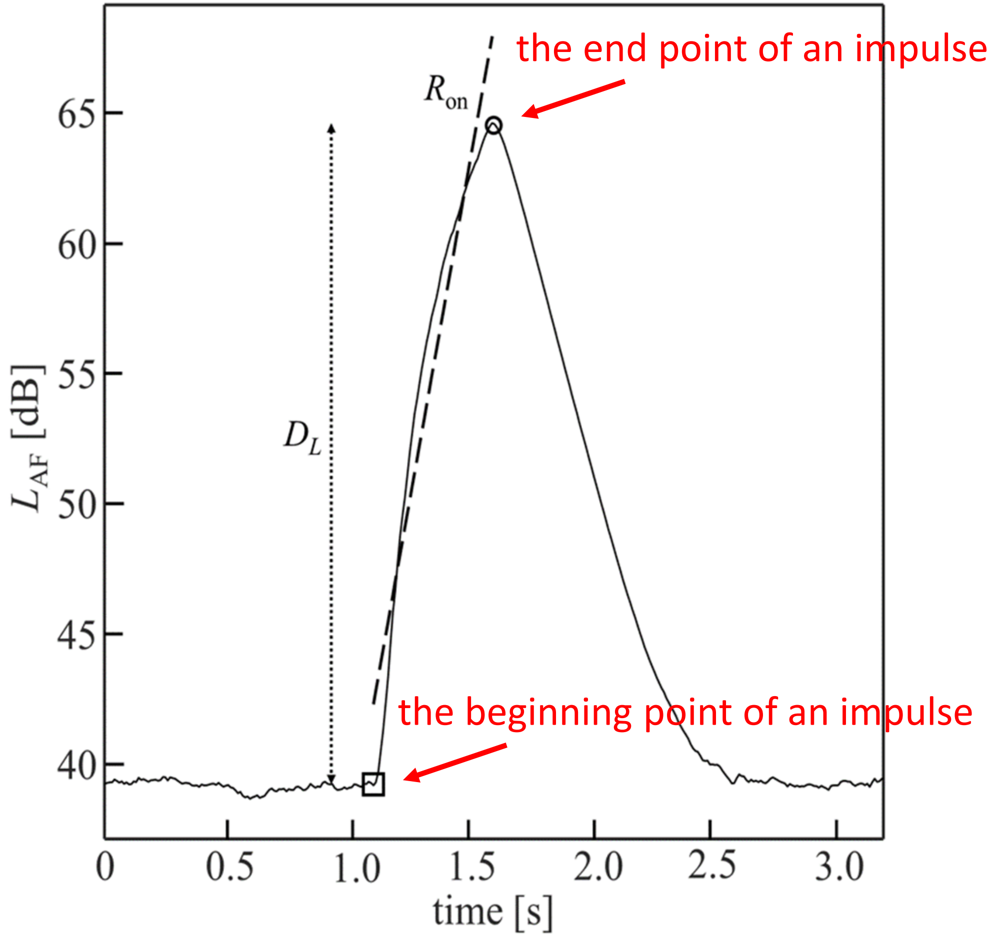
Experiment 3 - Annoyance penalty of impulsive sound

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)

Sound demos

Impulsive sounds

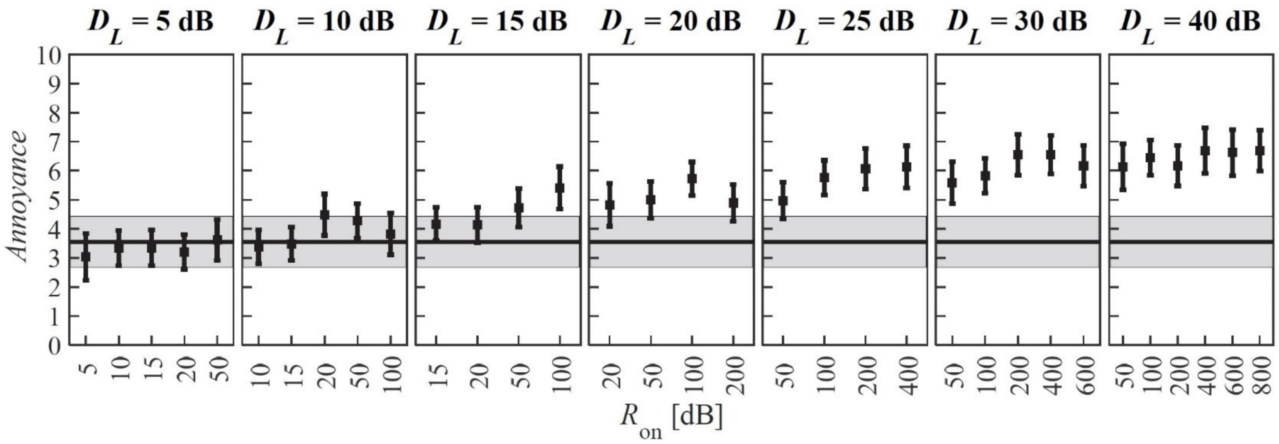
D_L [dB]	R_{on} [dB/s]									
	5	10	15	20	50	100	200	400	600	800
5	x	x	x	x	x					
10		x	x	x	x	x				
15			x	x	x	x				
20				x	x	x	x			
25					x	x	x	x		
30					x	x	x	x	x	
40					x	x	x	x	x	x

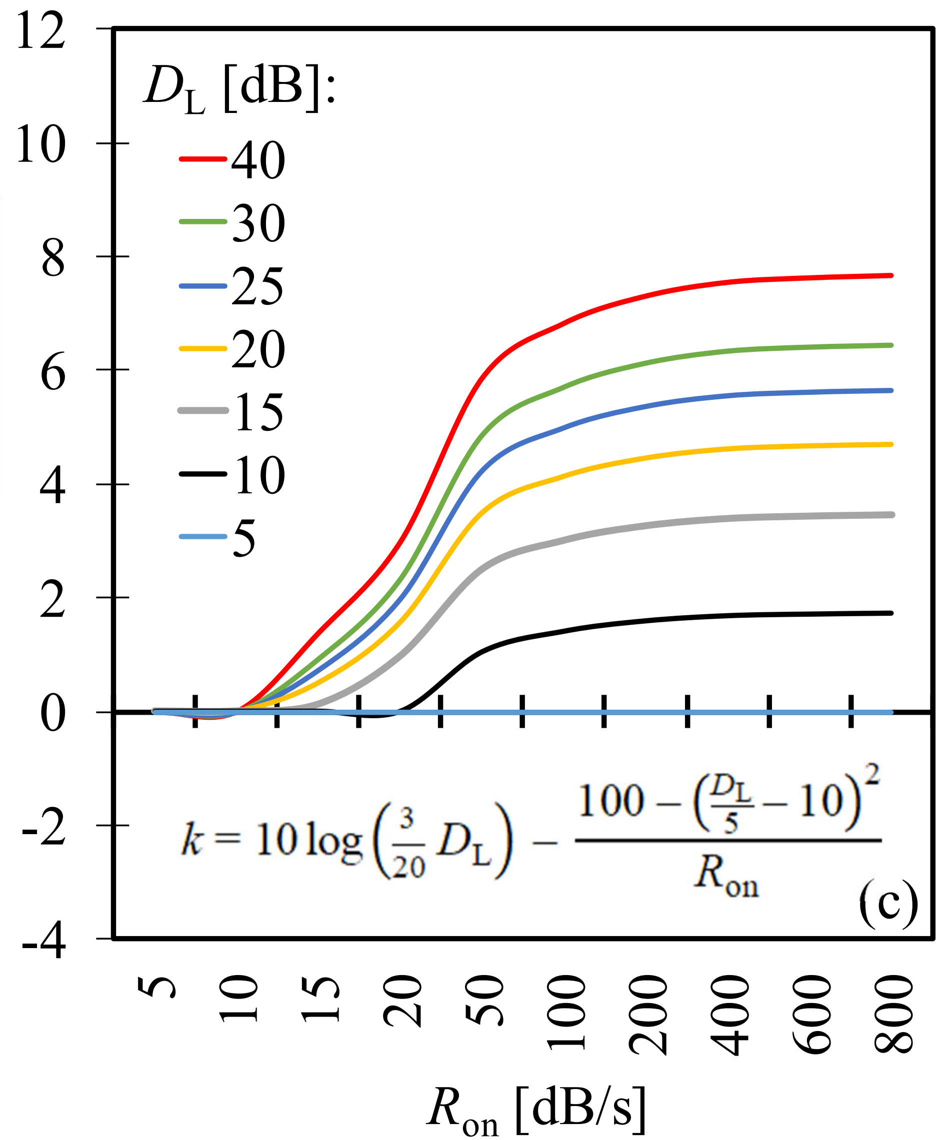
Reference sounds

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 for impulsive sounds compared to a reference sound at 55 dB L_{Aeq}
- 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
- Annoyance penalty depends strongly on R_{on} and D_L.
- R_{on} <20 dB/s and D_L<15 dB deserve no penalty since since 95% confidence interval is ± 2 dB
- Constant impulse model is not supported.

Rajala & Hongisto (2019)

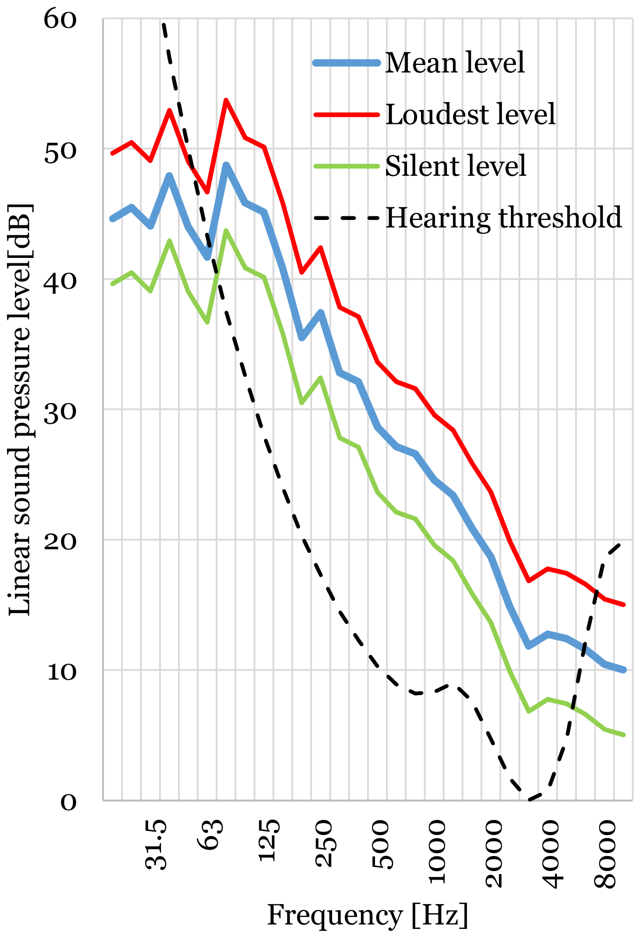
Experiment 4 – Annoyance penalty of amplitude-modulated sound

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**.**

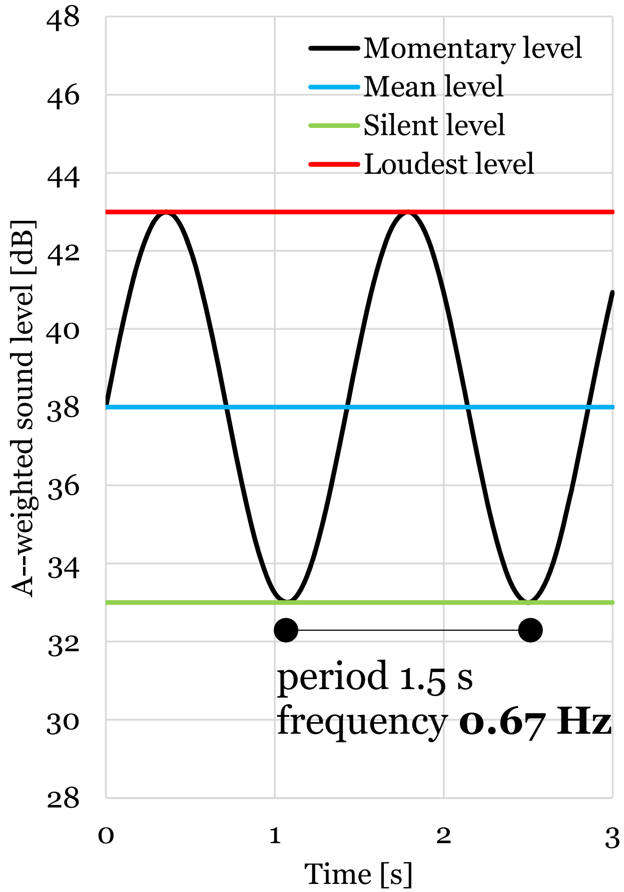
Amplitude modulation

- Amplitude modulation means that the SPL varies periodically
- In practice, the variation of SPL is random due to the turbulence of air

Spectrum of sound



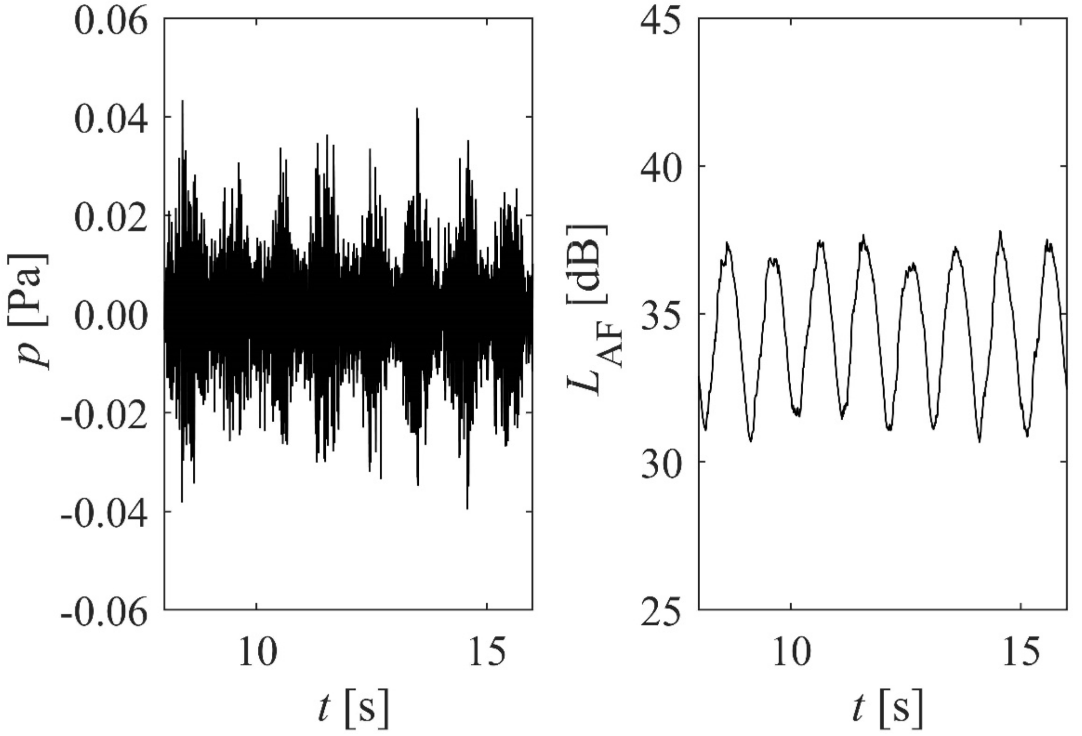
Level as a function of time



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):

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

$$m = \frac{10^{D_m/20} - 1}{10^{D_m/20} + 1} \quad t = (0, 1, 2, \dots, n_s - 1)\frac{1}{f_s},$$

Virjonen et al., J Acoust Soc Am 2019

Sounds

- The sounds involved AM and reference sounds.
- The AM sounds were created as combinations of two variables:
  - modulation depth (D_m, 5 levels),
  - modulation frequency (f_m, 7 levels), and
- Altogether 35 AM sounds, at 35 dB L_{Aeq}.
- Sound were created by modulating wide-band noise
- Reference sounds were steady-state sounds. They were used to determine the penalty. They were presented at 29 to 49 dB L_{Aeq} in 2 dB steps.

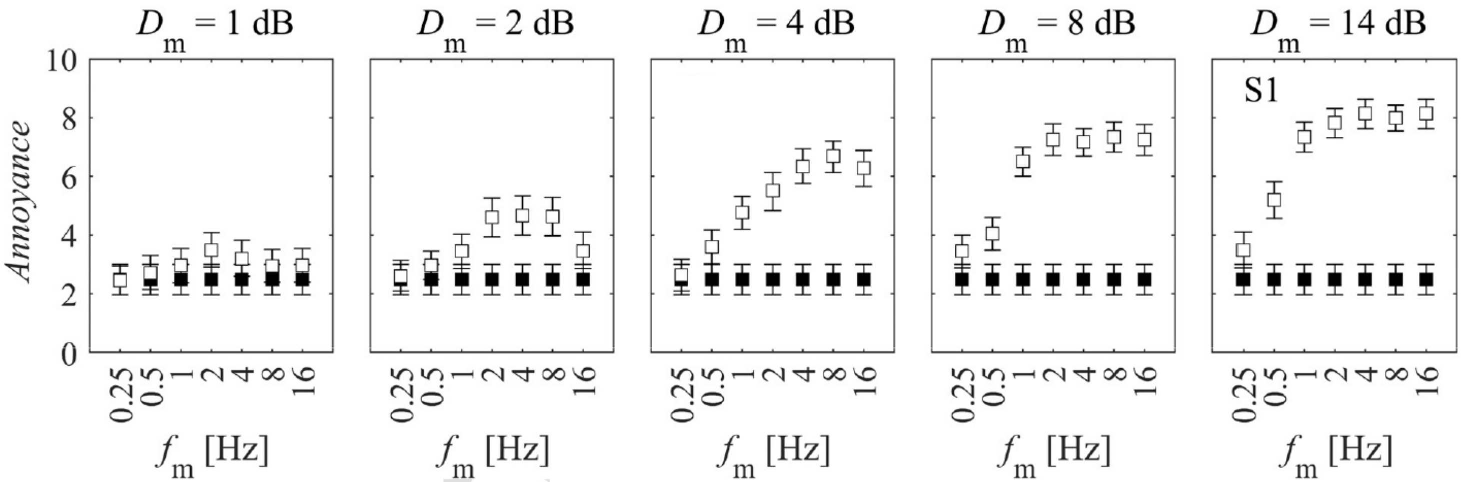
Experimental sound	Spectrum	D_m [dB]	f_m [Hz]	L_{Aeq} [dB]
R101[a]	S1	-	-	29
R102	S1	-	-	31
R103	S1	-	-	33
R104	S1	-	-	35
R105	S1	-	-	37
R106[a]	S1	-	-	39
R107	S1	-	-	10
R108	S1	-	-	43
R109	S1	-	-	45
R110	S1	-	-	47
R111[a]	S1	-	-	49
R201[a]	S2	-	-	29
R202	S2	-	-	31
R203	S2	-	-	33
R204	S2	-	-	35
R205	S2	-	-	37
R206[a]	S2	-	-	39
R207	S2	-	-	10
R208	S2	-	-	43
R209	S2	-	-	45
R210	S2	-	-	47
R211[a]	S2	-	-	49

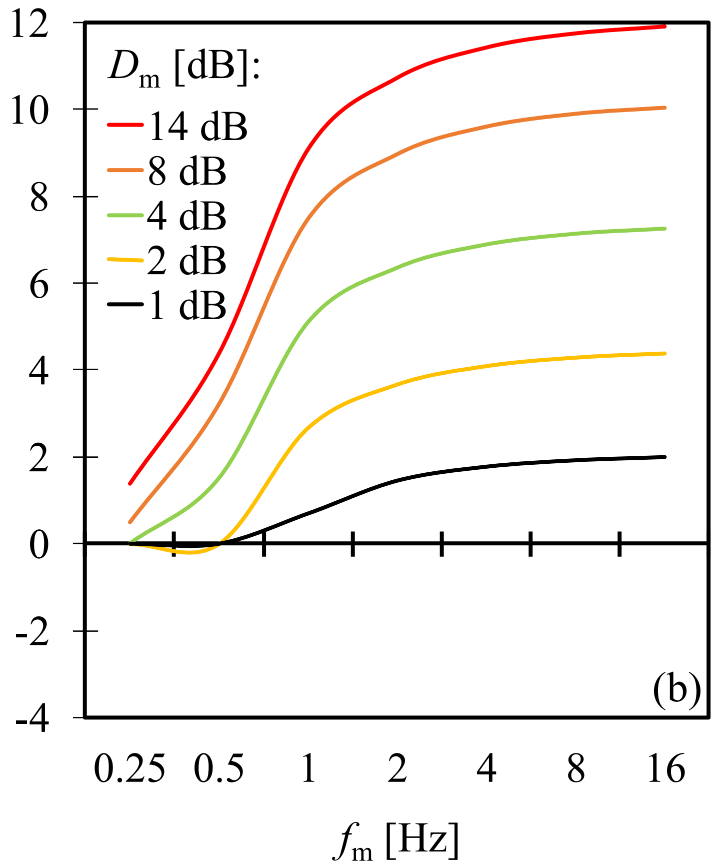
Experimental sound	Spectrum	D_m [dB]	f_m [Hz]	L_{Aeq} [dB]
A101	S1	1	0.25	35
A102	S1	2	0.25	35
A103	S1	4	0.25	35
A104	S1	8	0.25	35
A105	S1	14	0.25	35
A106	S1	1	0.5	35
A107	S1	2	0.5	35
A108[a]	S1	4	0.5	35
A109	S1	8	0.5	35
A110[a]	S1	14	0.5	35
A111	S1	1	1	35
A112	S1	2	1	35
A113	S1	4	1	35
A114	S1	8	1	35
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 *soı*

Virjonen et al., J Acoust Soc Am 2019

Results





- Figure on top shows the mean annoyance and 95% CI for AM sounds compared to a reference sound at 35 dB L_{Aeq}
- 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.

$$\begin{cases} a = A_1 \sqrt{\frac{D_m}{D_m + A_2}} \\ d = D_1 \sqrt{\frac{D_m}{D_m + D_2}} \\ A_1 = 25.23 \text{ dB} \\ A_2 = 5.557 \\ D_1 = 9.46 \text{ dB} \\ D_2 = 0.477 \end{cases}$$

$$k = max\left\{0,\ \frac{a\,(f_m - b)^2}{(f_m - c)^2} - d\right\}$$

$$\begin{cases} b = 0.2734 \text{ Hz} \\ c = 0.2169 \text{ Hz} \end{cases}$$

Virjonen et al., J Acoust Soc Am 2019