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Loudness: Current Knowledge and Questions

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Loudness

Supraliminary sensation: how to measure it ?

Weber-Fechner law, 19th century

Weber: $\Delta\Phi/\Phi = \text{constant}$

Φ: stimulation

Fechner: $\Delta\Psi = k\ \Delta\Phi/\Phi$

Ψ: sensation

$\Psi = A \operatorname{Log}\Phi + B$

Stevens law: direct measurement, magnitude estimation

$\Psi = a\ \Phi^b$

Methods to measure Loudness

- Magnitude estimation: loudness **in sones**

  1 sone = loudness of a 1-kHz tone at 40 dB SPL

- Adjustement (loudness matches): loudness level **in phons**

  a loudness level of a sound of X phons means that the sound is as loud as a 1-kHz tone at X dB SPL

- Adaptive (2down–1up, 1down–2up): loudness level **in phons**

- Multitracking: loudness level **in phons**

- Categorical loudness scaling

Methods to measure Loudness
Adjustment

- **Test sound** (T): the sound that we want to know the loudness
- **Sound of comparison** (C): usually 1-kHz tone, variable level
- C after T (**1st test**) and T after C (**2nd test**)
- **Listener's task**: Adjust the C-level to have the same loudness as T
- **Random order**, different for each listener
- **Start level** was randomly X dB above or under T loudness level
- **Loudness level in phons** : mean of C-level obtained in the 2 tests for each sound

Methods to measure Loudness

- Magnitude estimation: loudness **in sones**

  1 sone = loudness of a 1-kHz tone at 40 dB SPL

- Adjustement (loudness matches): loudness level **in phons**

  a loudness level of a sound of X phons means that the sound is as loud as a 1-kHz tone at X dB SPL

- Adaptive (adown–bup, bdown–aup): loudness level **in phons**

- Multitracking: loudness level **in phons**

- Categorical loudness scaling

Methods to measure Loudness
adaptive methods

Presentation order : T & C or C & T, randomly
Listener's task : Which of these 2 sounds is louder

2down-1up (1st test) :

Start level above the T loudness level

++
-5 dB
++
-5 dB
-
1st reversal
+5 dB
++
2nd reversal
-2 dB
-

Mean of the last Y reversals

⟹ **+ JL**

Track finishes after X reversals

2up-1down (2nd test) :

--
+5 dB
--
+5 dB
+
1st reversal
-5 dB
--
2nd reversal
+2 dB
+

⟹ **- JS**

Loudness level in phons

Start level under the T loudness level

Methods to measure Loudness

- Magnitude estimation: loudness **in sones**

  1 sone = loudness of a 1-kHz tone at 40 dB SPL

- Adjustement (loudness matches): loudness level **in phons**

  a loudness level of a sound of X phons means that the sound is as loud as a 1-kHz tone at X dB SPL

- Adaptive (2down–1up, 1down–2up): loudness level **in phons**

- Multitracking: loudness level **in phons**

- Categorical loudness scaling

Methods to measure Loudness
Multitracking

- Principle similar to the adaptive method
- 4 or 5 simultaneous sequences
- Random choice of the sequence, different for each listener
- Loudness level in phons:

mean of +JL and –JS for each sound

Methods to measure Loudness

- Magnitude estimation: loudness **in sones**

  1 sone = loudness of a 1-kHz tone at 40 dB SPL

- Adjustement (loudness matches): loudness level **in phons**

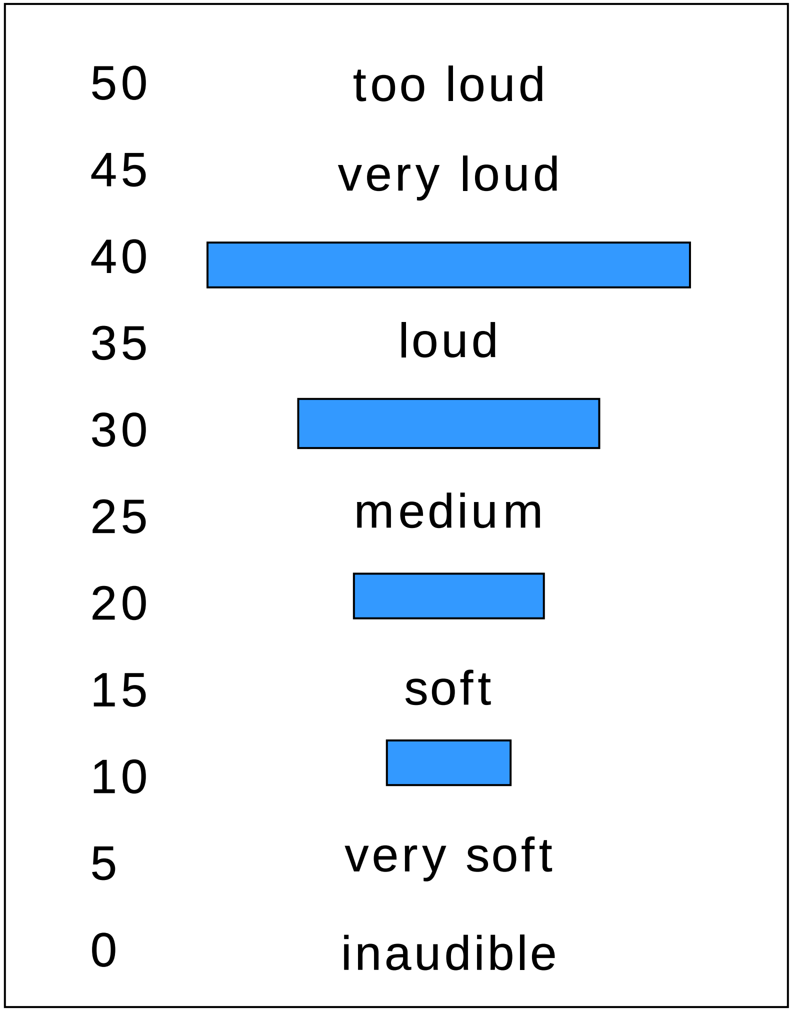
  a loudness level of a sound of X phons means that the sound is as loud as a 1-kHz tone at X dB SPL

- Adaptive (2down–1up, 1down–2up): loudness level **in phons**

- Multitracking: loudness level **in phons**

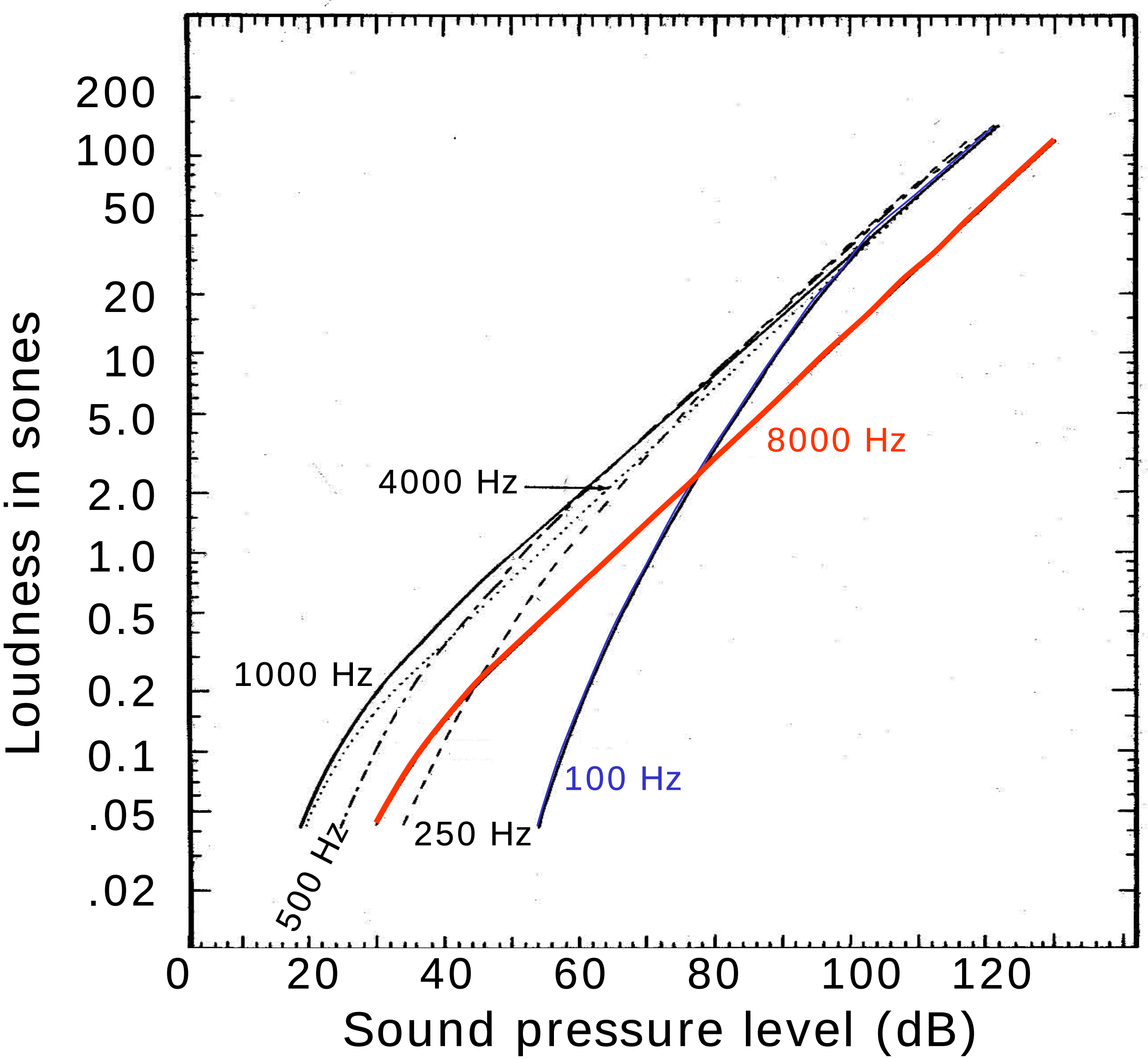
- Categorical loudness scaling

Methods to measure Loudness
Categorical loudness scaling



Loudness measured in Categorical Unit (CU)

Loudness as a function of SPL



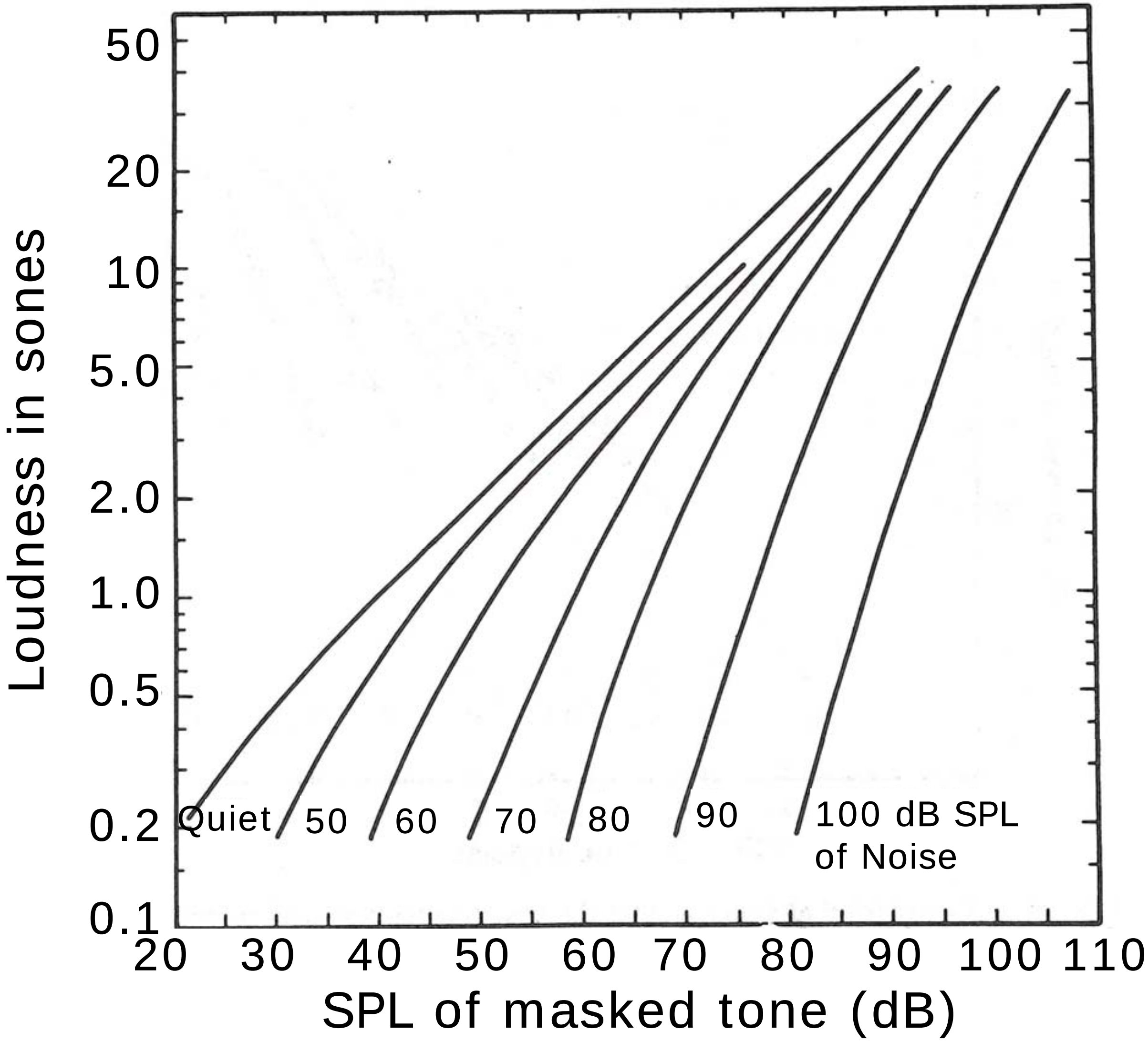
$N = k(P - P_0)^a$

at 1 kHz: a=0.6

N: loudness
P: pressure
P_0: constant

From Scharf (1978) in Handbook of perception, Carterette and Friedman

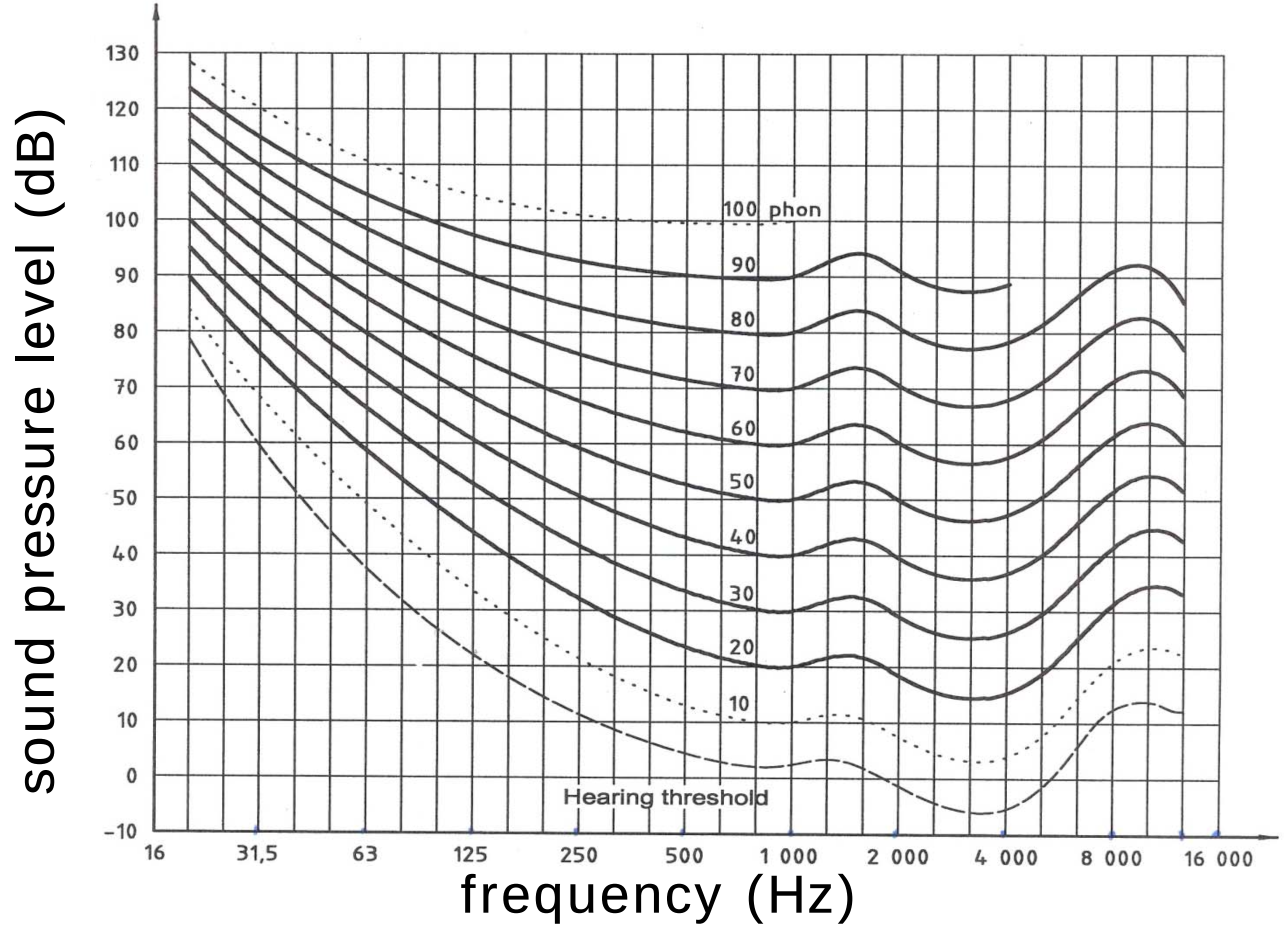
Loudness as a function of SPL
Partial loudness



From Scharf (1978) in Handbook of perception, Carterette and Friedman

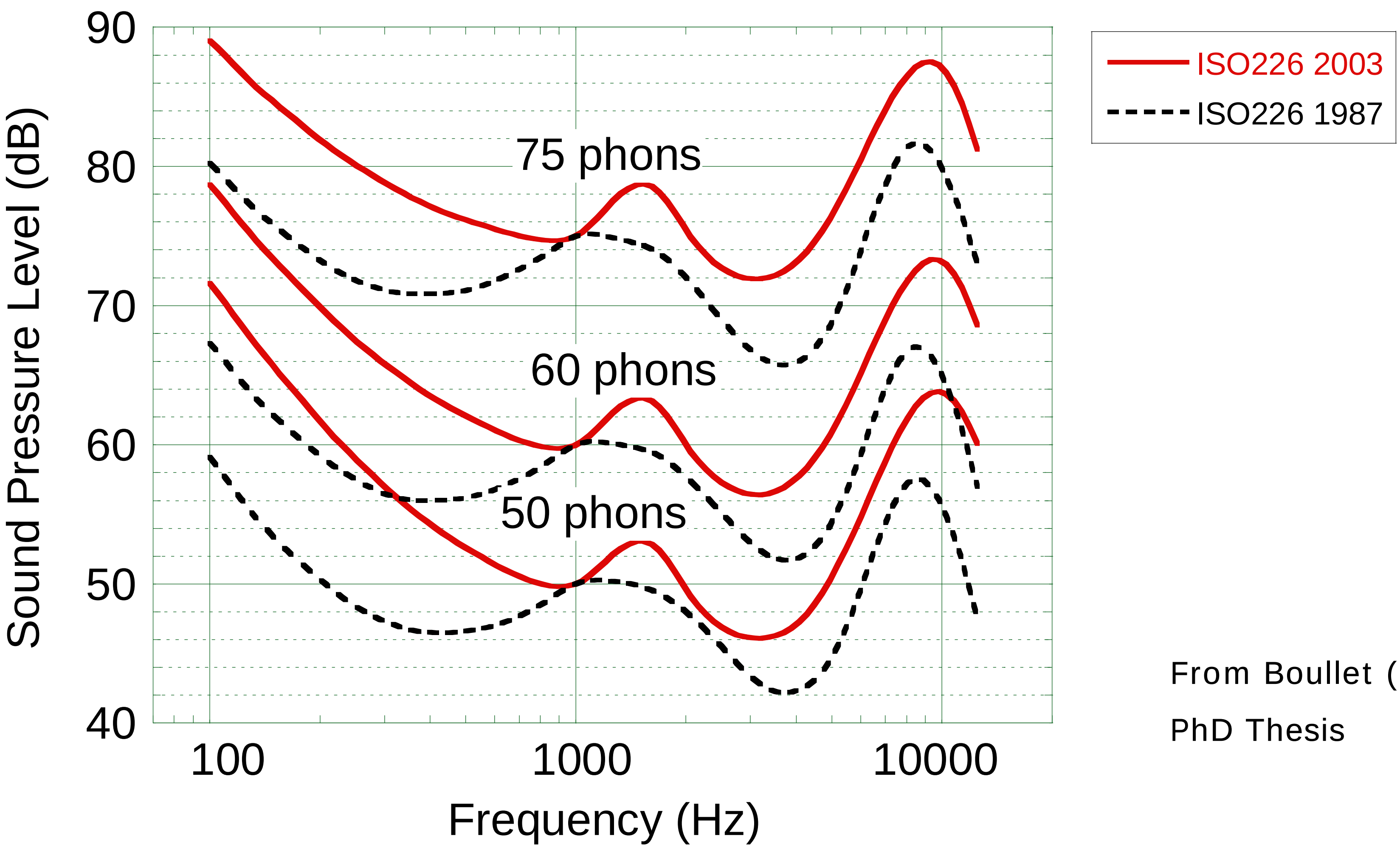
Loudness as a function of frequency

Equal loudness contours
Standard: ISO 226, 2003



Loudness as a function of frequency

Equal loudness contours

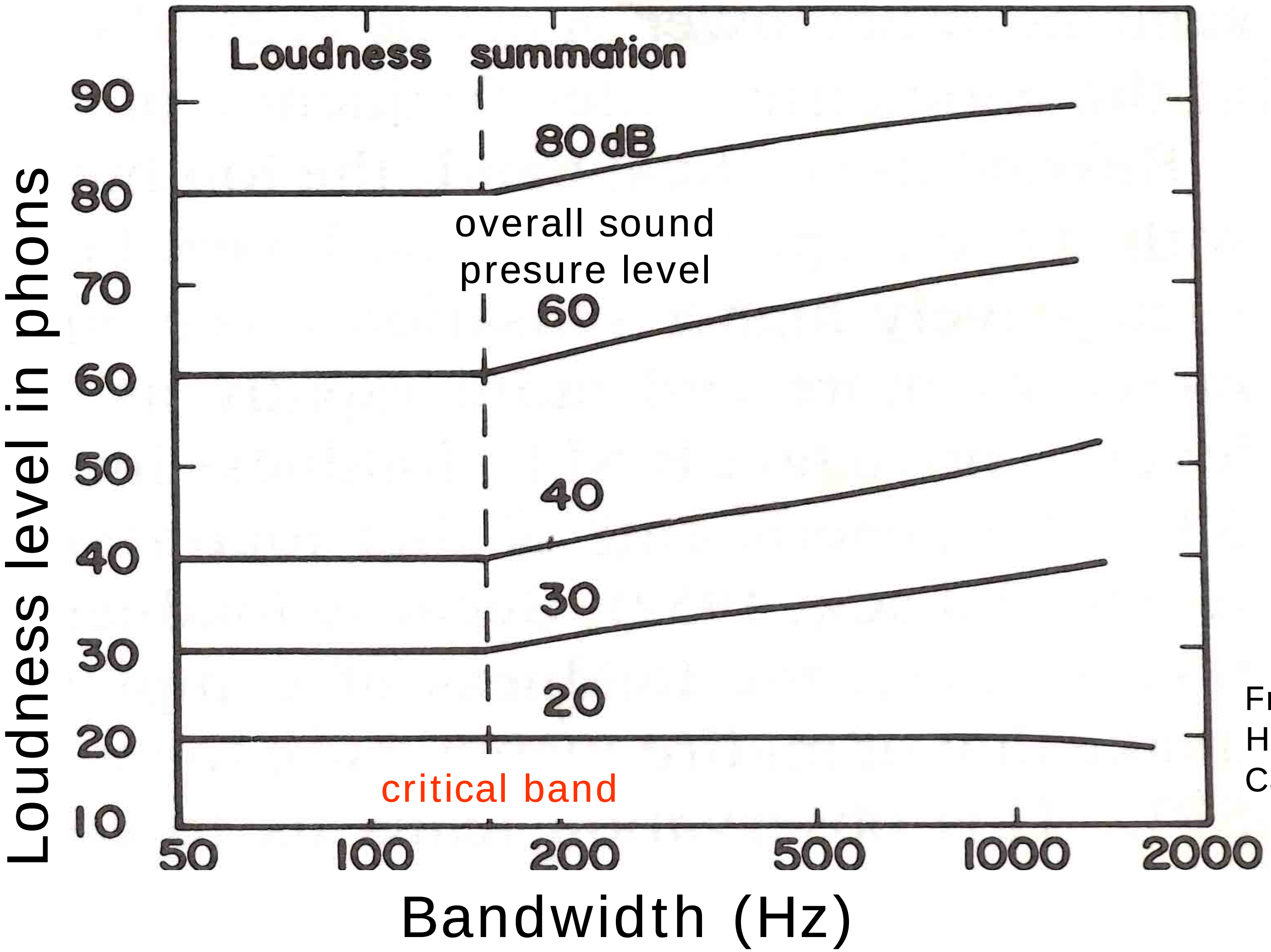


From Boullet (2005)

PhD Thesis

Loudness as a function of **bandwidth**

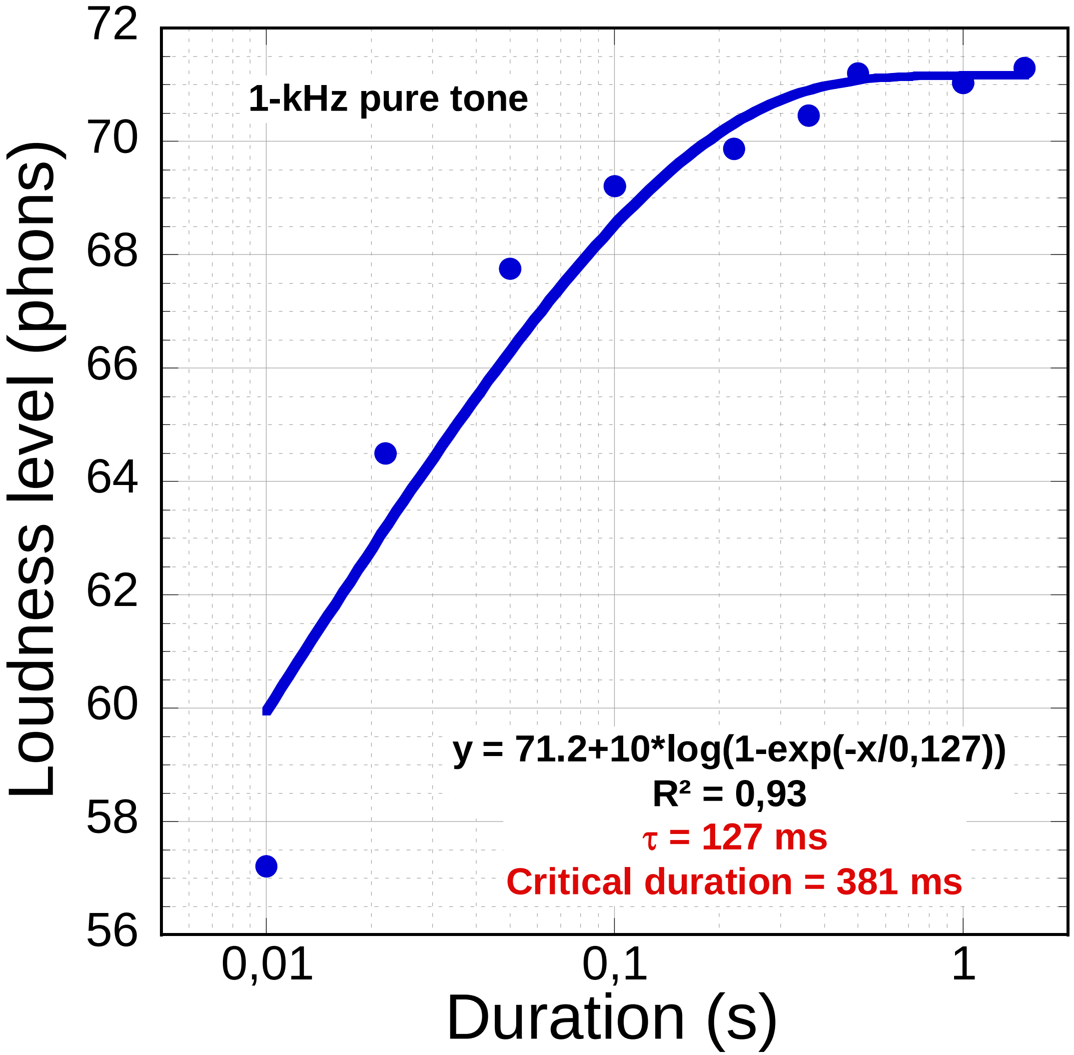
Spectral loudness summation



From Scharf (1978) in Handbook of perception, Carterette and Friedman

Loudness as a function of duration

Temporal loudness summation



From Boullet (2005)

PhD Thesis

Loudness models

Standards for steady sounds

ISO 532B, « Method for calculating loudness level », International Organisation for standardization (1975).

From Zwicker E., Acustica, 10, 304 (1960)

Zwicker E., J. Acoust. Soc. Am., 33, 248 (1961)

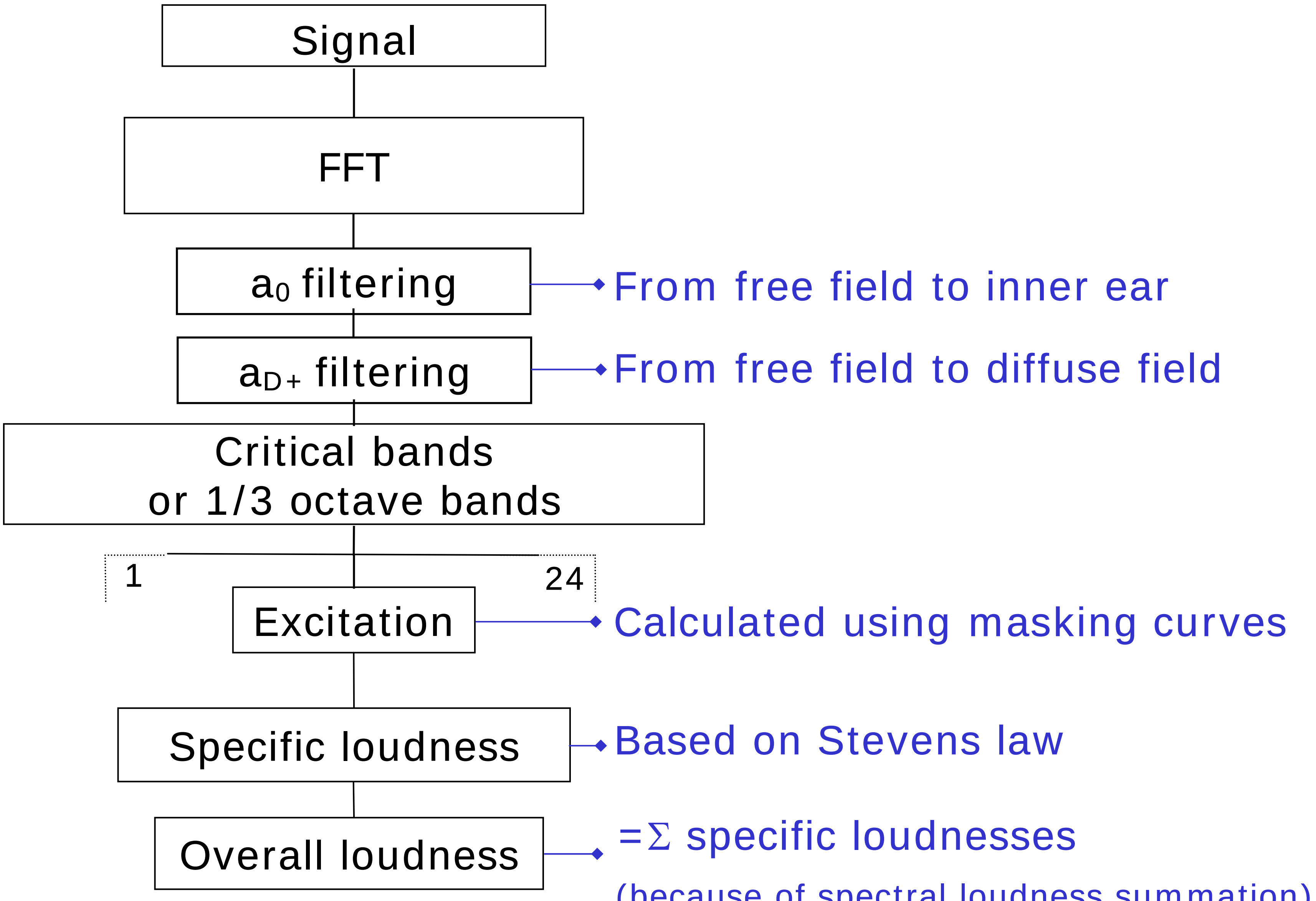
ANSI, S3.4-2005, « Procedure for the Computation of Loudness of Steady Sounds, », American National Standards Institute, New York (2005).

From Moore B. C. J. and Glasberg B. R., Acustica-Acta Acustica, 82, 335 (1996).

Moore B. C. J., Glasberg B. R., Baer T., J. Audio Eng. Soc., 45, 224 (1997).

Zwicker's model

Stationary sounds, free or diffuse field



Moore and Glasberg's model

Stationary sounds, free or diffuse field

Based on Zwicker's model

Differences:

1 –Auditory filters shapes,

2 –Excitation pattern,

3 - a_0 and a_{D+}

Loudness models for non-stationary sounds

- Zwicker E., “Procedure for calculating loudness of temporally variable sounds”, J. Acoust. Soc. Am., vol.62, n°3, 675-682, 1977.

- Zwicker E. et Fastl H., “Psychoacoustics: Facts and models”, 2nd Edit ion, Springer-Verlag, Berlin, 1999.

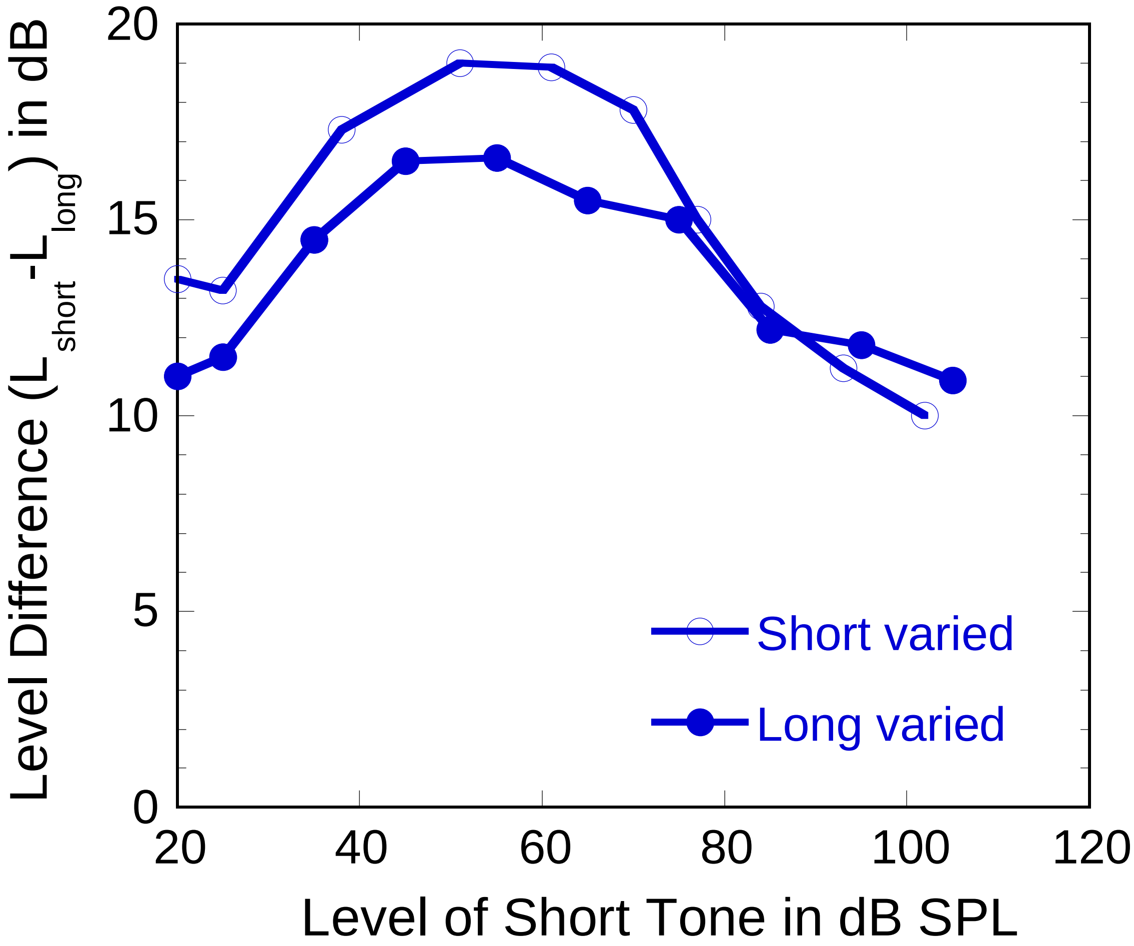
- Glasberg B. R. and Moore B. C. J., “ A model of loudness applicable to time-varying sounds”, J. Audio Eng. Soc., 50, n°5, 331-342, 2002.

Current researches

- **Loudness of non-stationary sounds**
  - Short duration signals
  - Long duration signals
- **Effect of context**
  - Induce Loudness Reduction (Recalibration)
  - Loudness Constancy
  - Binaural Loudness Summation
- **Spectral loudness summation and duration**

Loudness of non-stationary sounds

Short duration sounds



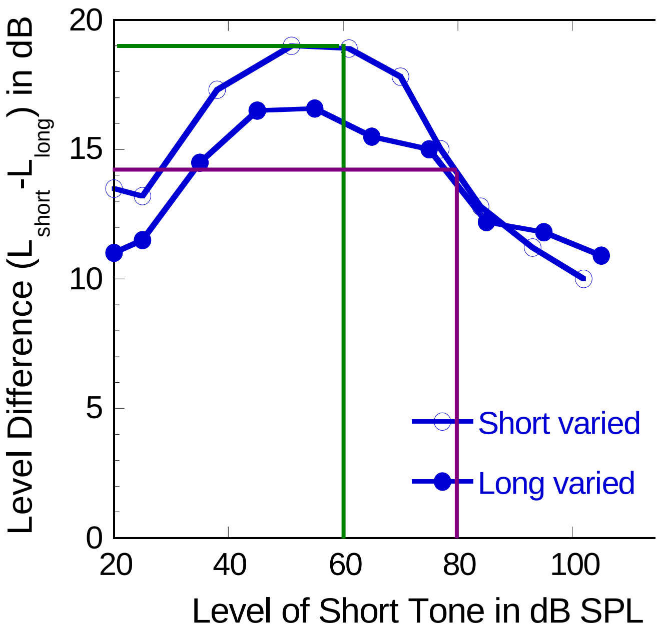
- Temporal integration =
  $L_{short} - L_{long}$
  short and long signal at equal loudness
- Temporal integration depends on level
- Temporal integration maximum for moderate levels

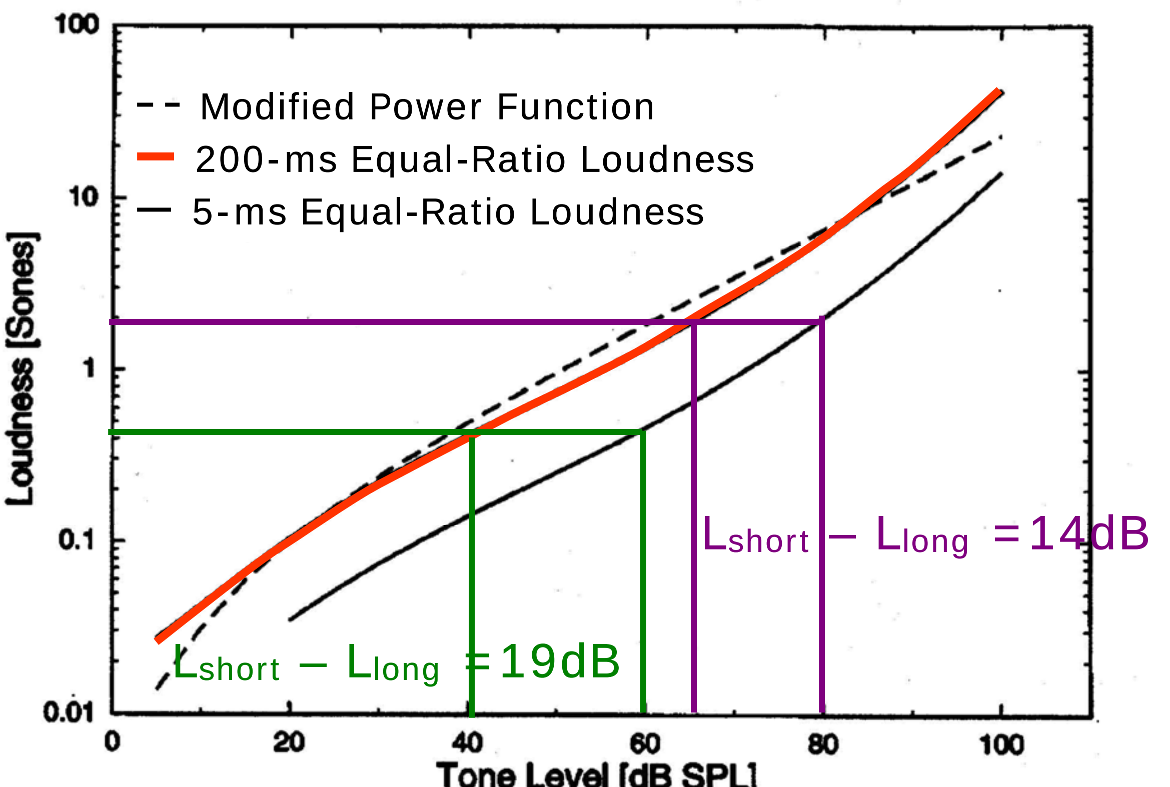
From Florentine et al., JASA 1996

Loudness of non-stationary sounds

Short duration sounds

Loudness functions are not linear





From Florentine et al., JASA 1996

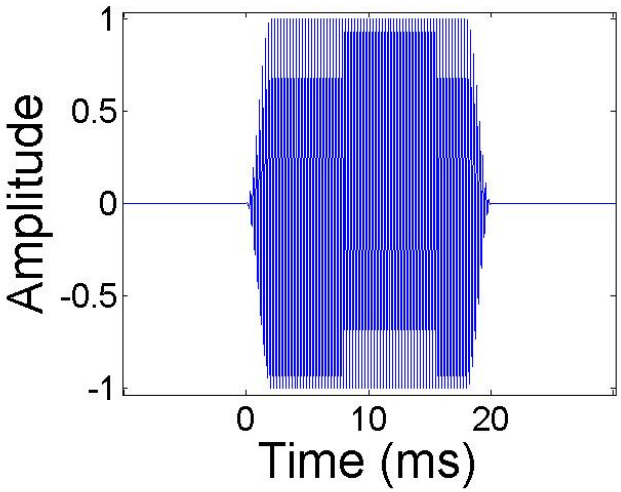
Short duration sounds

- These loudness functions show features similar to the mechanical input/output measurement at the basilar membrane
- Temporal integration of loudness does not depends on level

Loudness of non-stationary sounds
Environmental short-duration sounds

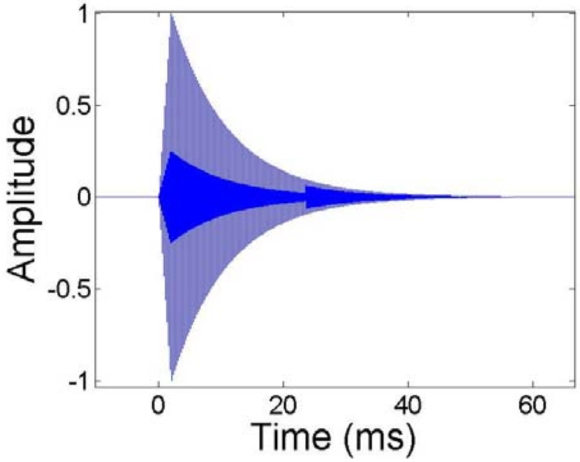
Most studies:

Rectangular envelope



Environmental sounds:

Exponential envelope



$$N = kE^aT^b$$

N: loudness

E: energy

T: sound duration

a, b: constants

From Meunier et al., ICA 2001, Forum Acusticum 2002

Environmental short-duration sounds

- $N = kE^aT^b$
- Determination of a and b
- a: loudness functions for environmental short duration sounds
- b: loudness as a function of duration

Loudness of non-stationary sounds

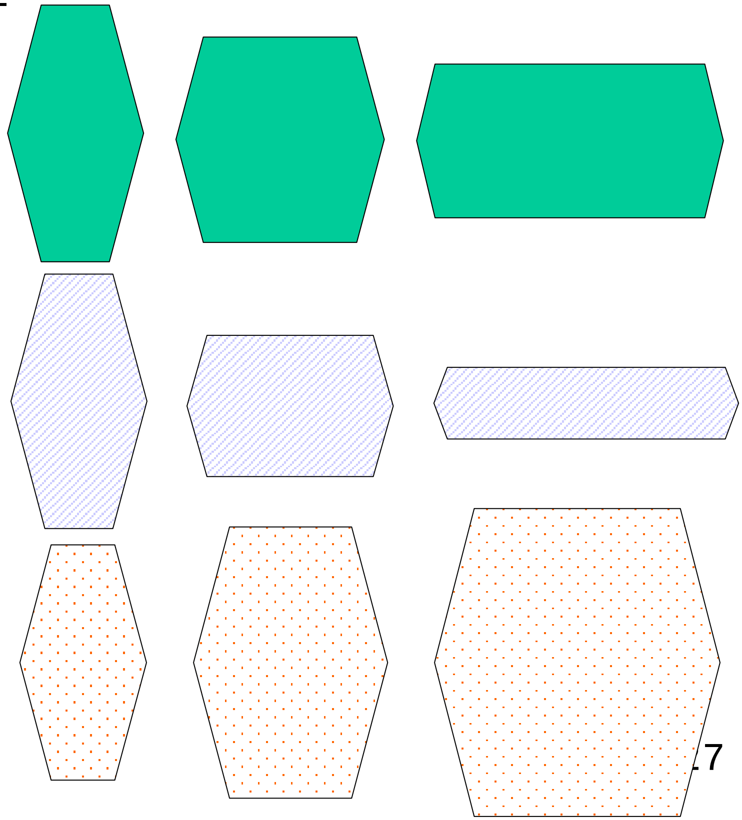
Environmental short duration sounds

Loudness as a function of duration

Three relationships between loudness and duration were found in different studies :

- <u>Loudness is constant when Energy is constant</u>:

Equal energy rule
for duration less than the critical duration
loudness = constant if
Energy = Intensity x duration = constant



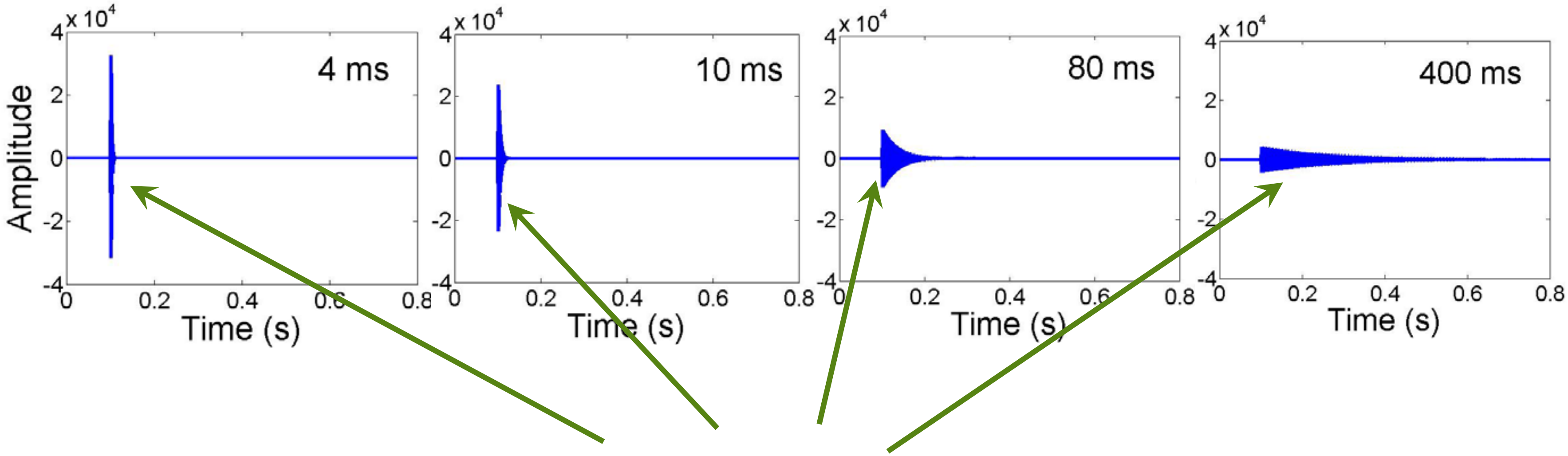
- <u>Loudness is constant when Energy decreases as duration increases</u>

- <u>Loudness is constant when Energy increases as duration increases</u>

Loudness of non-stationary sounds

Environmental short duration sounds

Loudness as a function of duration



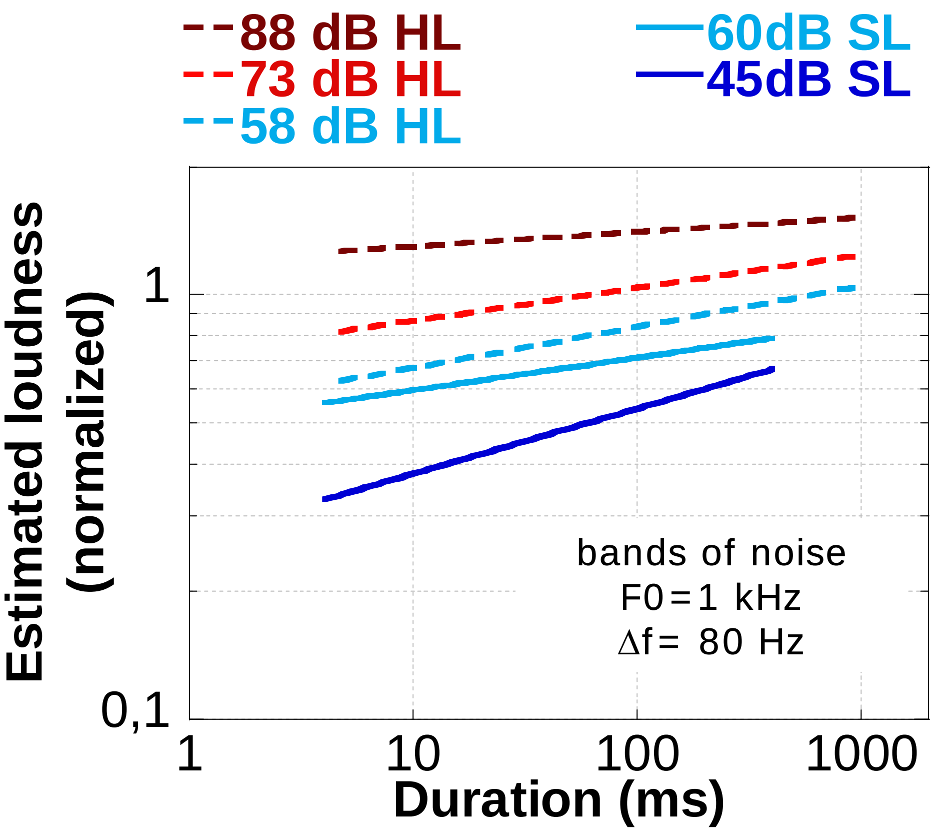
Energy = $E = \int_0^T \left| p((t) \right|^2 dt$ = constant

From Meunier et Rabau., Acoustics 08

Loudness of non-stationary sounds

Environmental short duration sounds

Loudness as a function of duration



- When Energy constant, Loudness varies as a power function of Signal Duration.
- Exponent depends on the level of the signal.
- Softer signals:

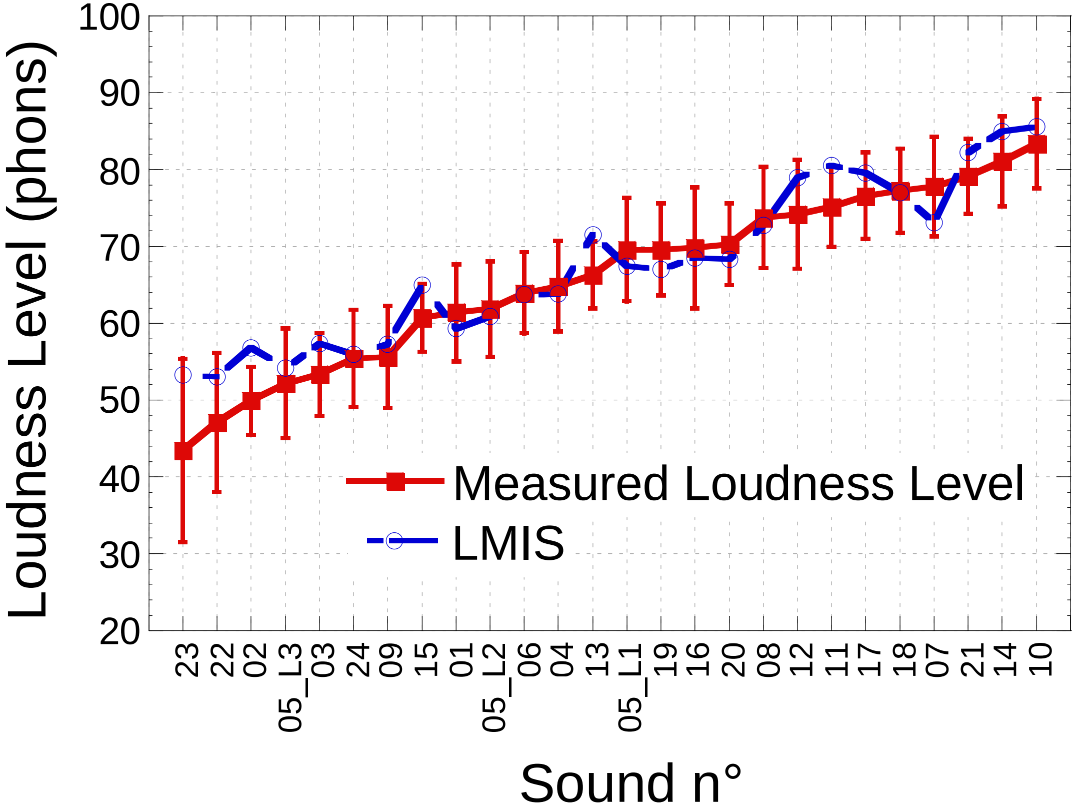
Loudness constant when Energy decreases as duration increases

- Louder signals:

Loudness constant when Energy constant as duration increases

From Meunier et Rabau., Acoustics 08

Loudness Model for Impulsive Sound (LMIS)

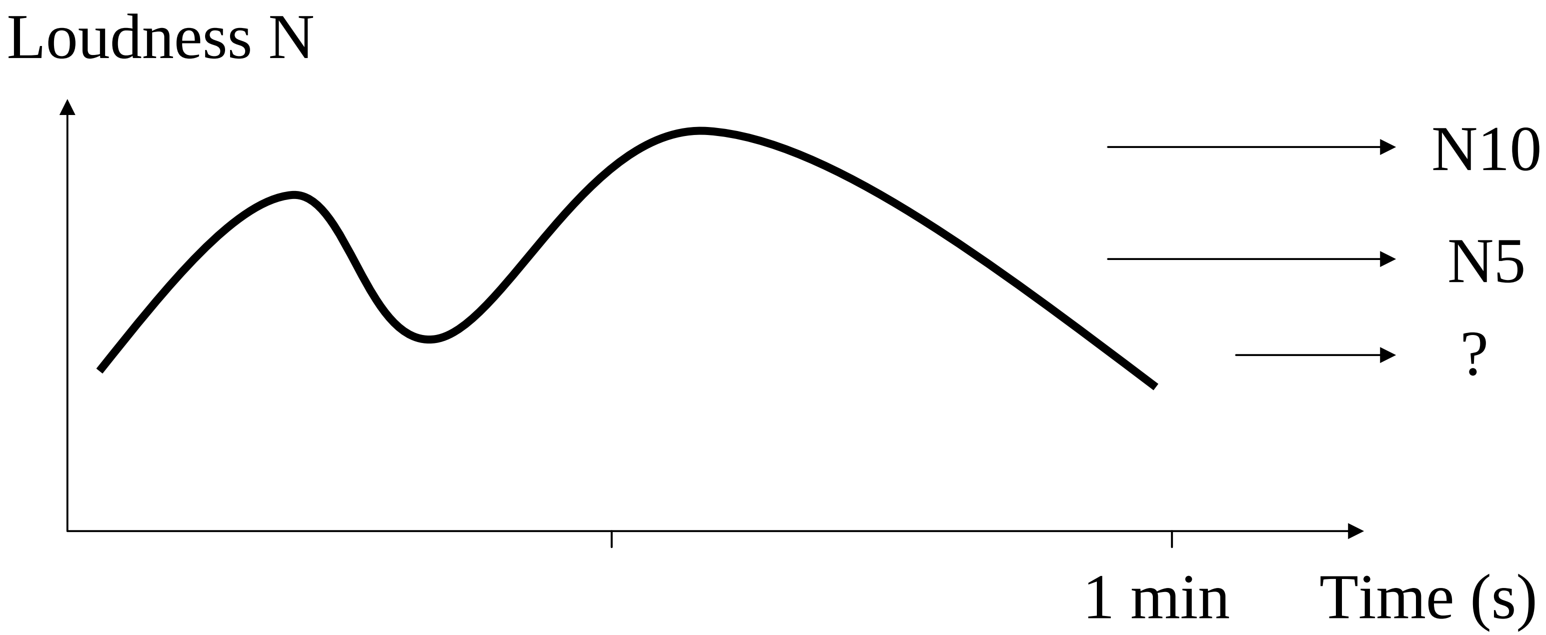


From Boullet et al. in preparation

Loudness of non-stationary sounds

Long duration sounds

- How does listeners judge overall loudness of time-varying sounds ?



Long duration sounds

- Kuwano and Namba (Psychol. Res., 1985) and Fastl (5th Oldenburg Symp. Psych. Acoutics, 1991):

  Sound events proeminent in level strongly influence global loudness

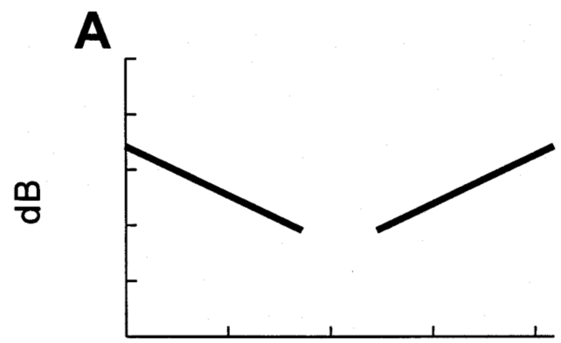
- Susini et al. (Acta Acustica, 2002):

  Recency effect: related to the temporal position of the highest contour peak

⇒ Global loudness: combination of highest levels, of their temporal position and their duration of emergence

Loudness of non-stationary sounds
Temporal asymmetry

Loudness change of tones with linearly varying levels



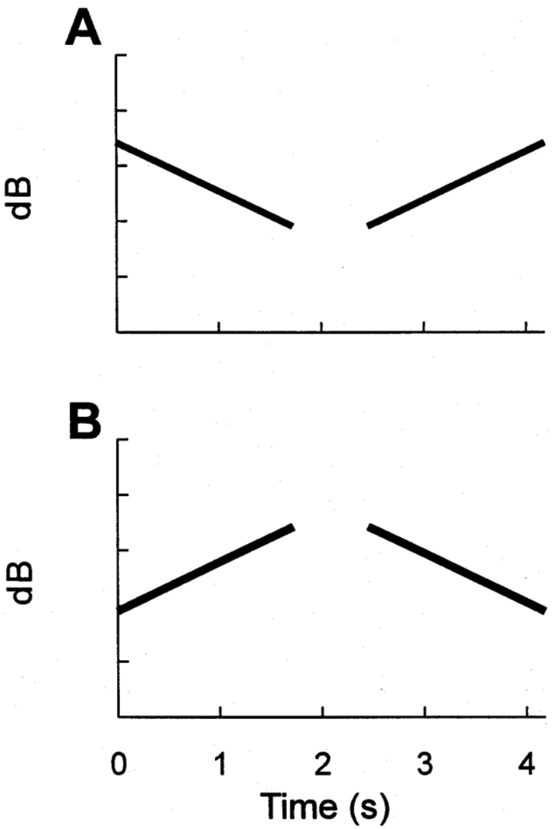
Loudness change: asymmetric

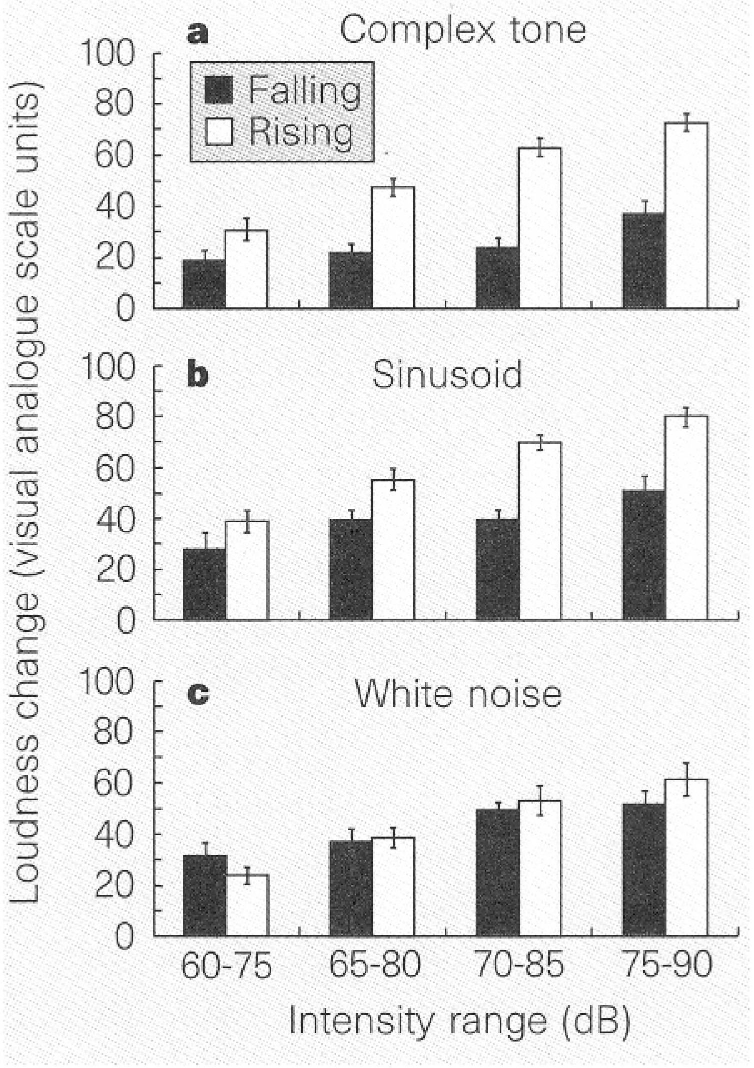
Asymmetry depends on:

- direction of change (increasing vs. decreasing)
- range of levels (high vs. low).

John G. Neuhoff , Nature, 1998, 395, 123-124

Loudness of non-stationary sounds
Temporal asymmetry

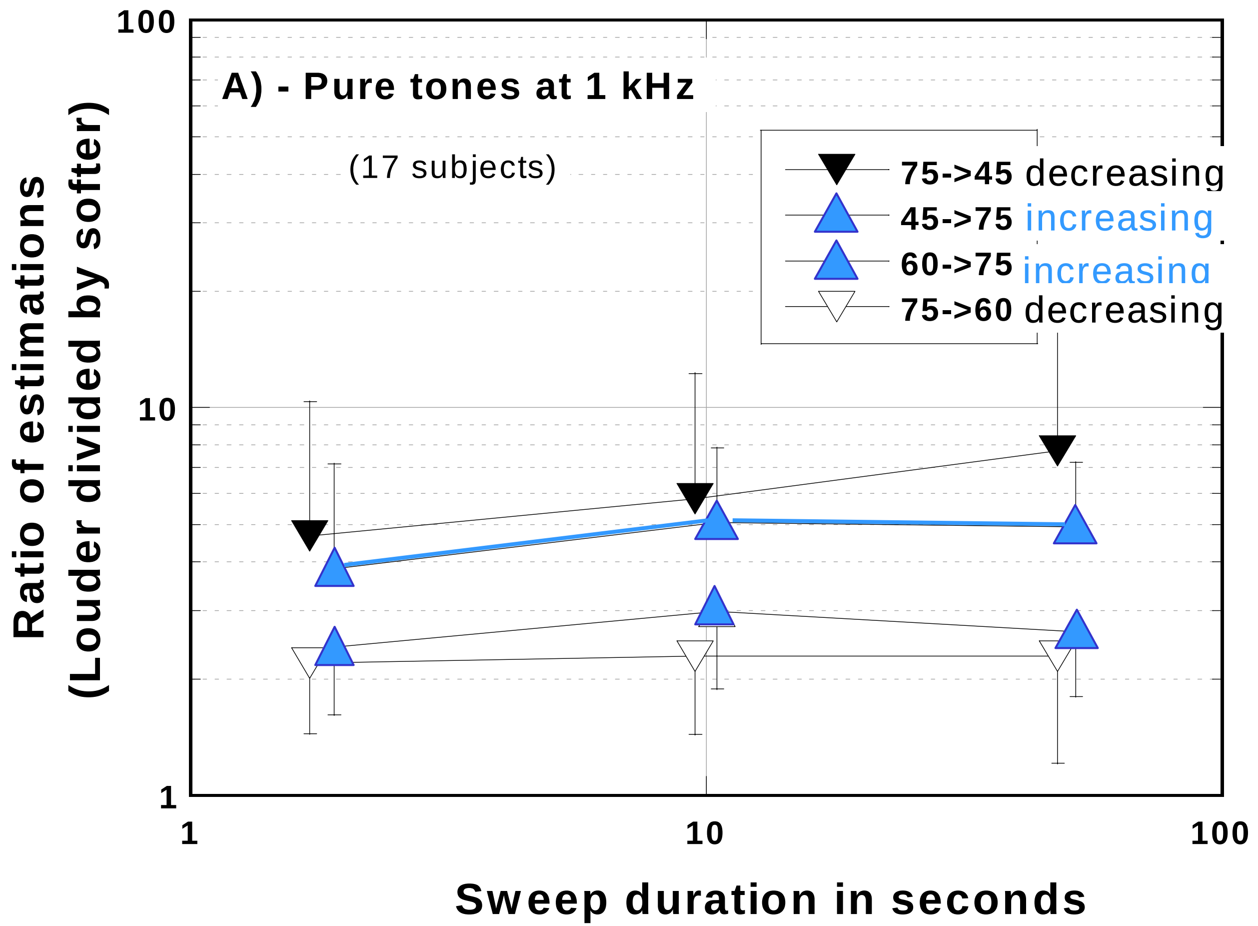




John G. Neuhoff , Nature, 1998, 395, 123-124

Loudness of non-stationary sounds

Temporal asymmetry

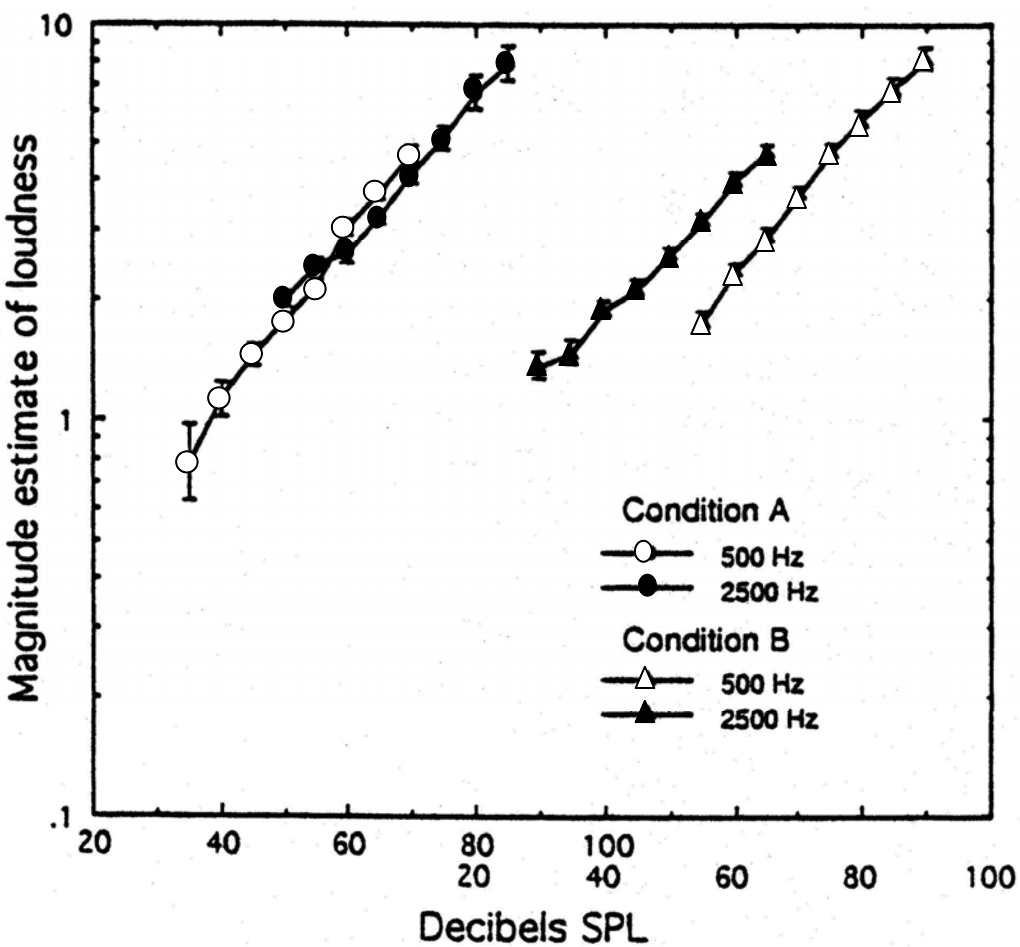


Canévet et al., Acta Acustica, 2003

Effect of context

Induced Loudness Reduction (ILR)

A preceding higher-level tone (inducer) reduces the loudness of a lower-level tone (test tone)



A: 500-Hz tones relatively low SPLs and 2500-Hz tones high SPLs

B: reverse

Marks, J. Acoust. Soc. Am., 1996

Effect of context
Induced Loudness Reduction (ILR)

Amount of ILR depends on:

- Tone levels
- Frequency separation between inducer and test tone
- Duration of inducer and test tone
- Time separation between inducer and test tone
- Individual differences

Review in Epstein, J. Acoust. Soc. Am., Online, 2007

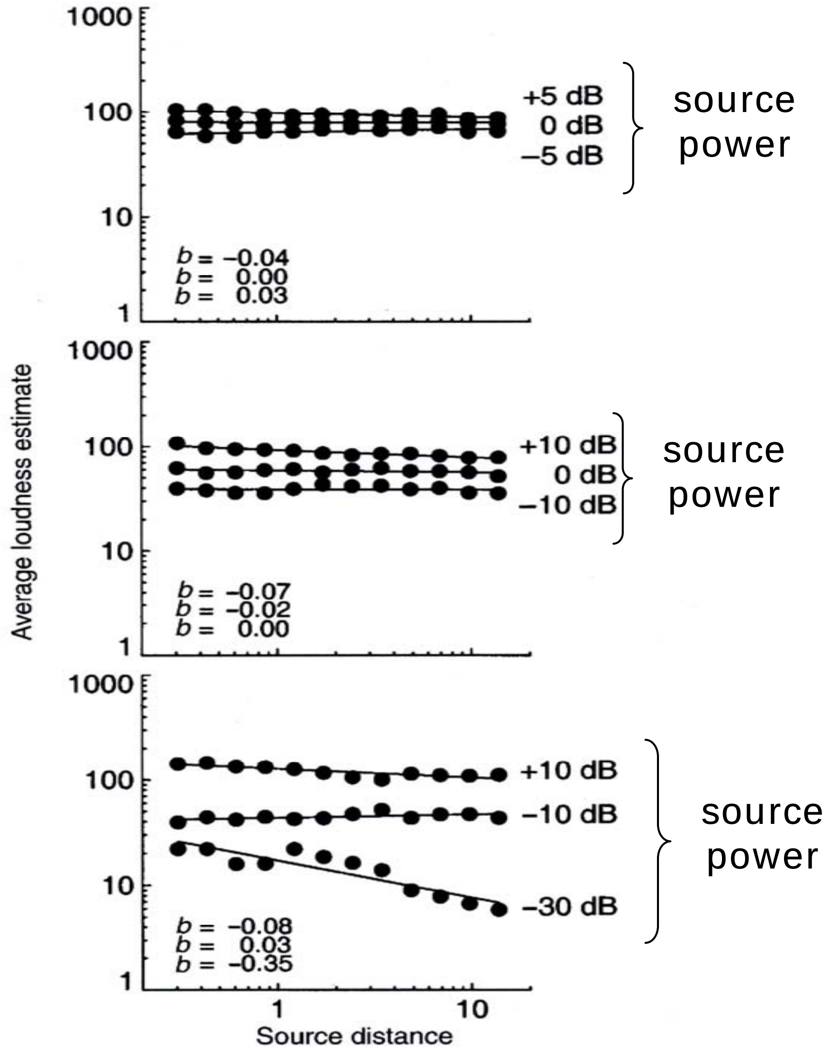
Effect of context
Loudness Constancy

Intensity changes at the ear may be due to

- Source power changes
- Source distance

Loudness Constancy

Loudness contant for fixed source power and variable source distance



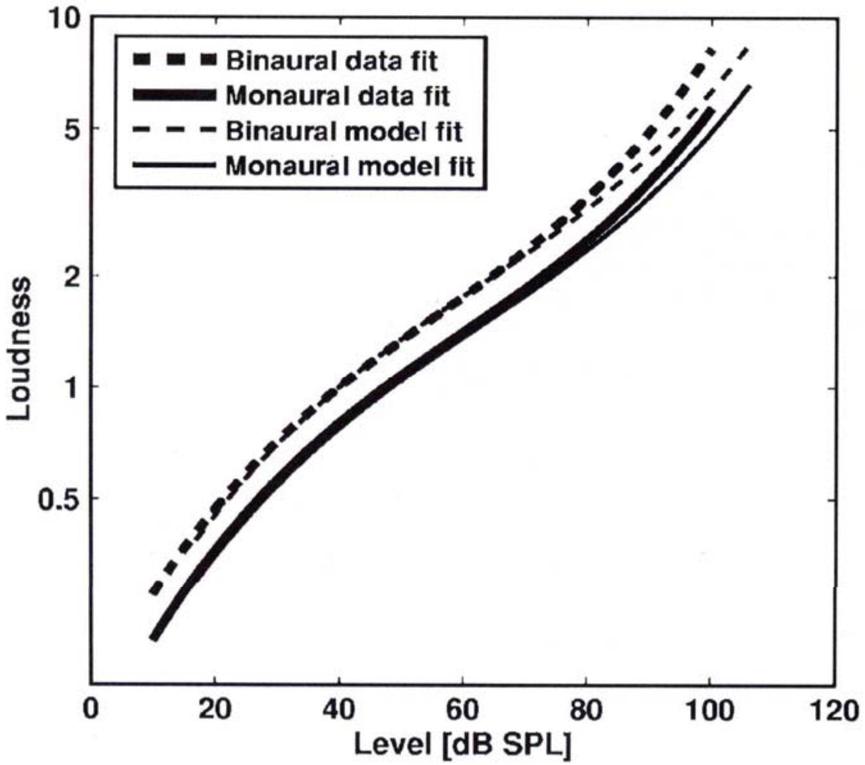
Zahorik and Wightman, Nature neuroscience, 2001

Effect of context

Binaural Loudness Summation (BLS)

Binaural loudness = A x monaural loudness

A: from 1.3 to 2 depending on study



From Marozeau et al. J. Acoust. Soc. Am., 2006

Effect of context

BLS as a function of stimulus and listening conditions

Stimuli

- Monitored Live Voice (MLV) spondees
- Recorded spondees
- Tones

Listening conditions

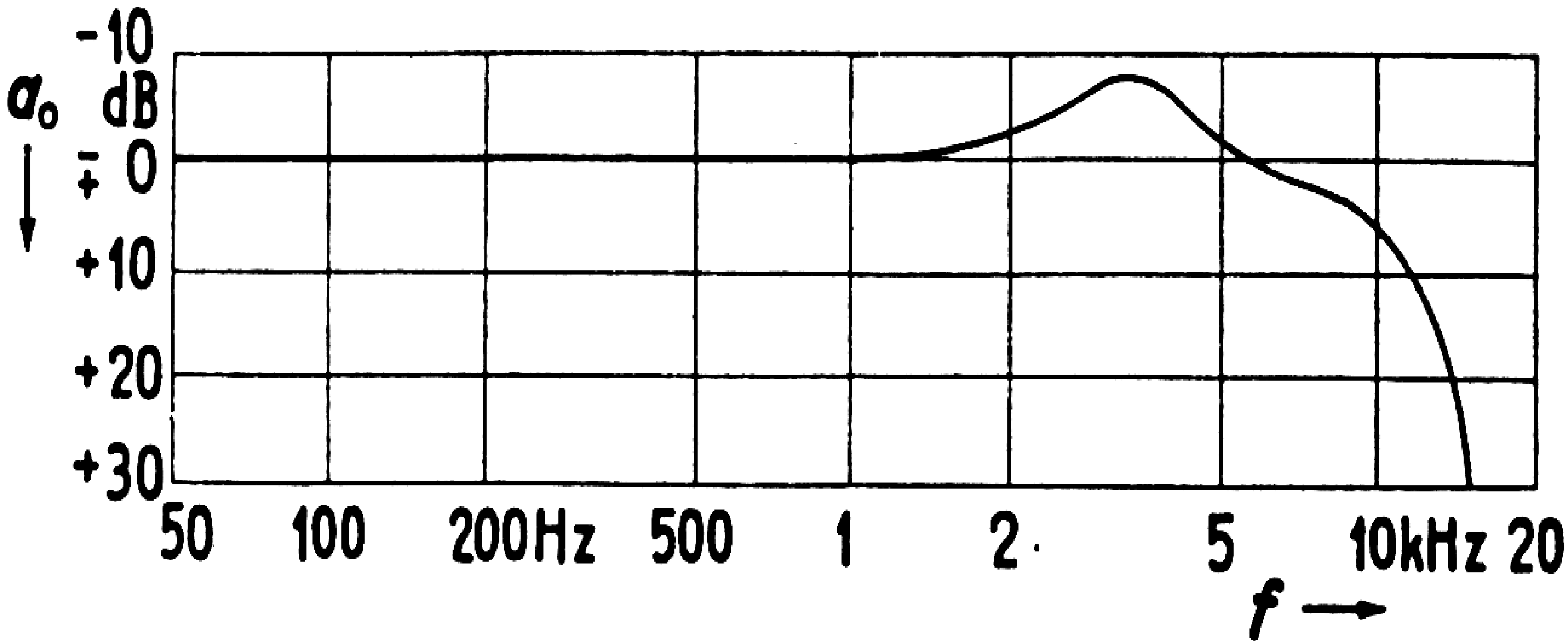
- Earphone
- Loudspeakers

BLS for tones or recorded spondees > BLS for MLV

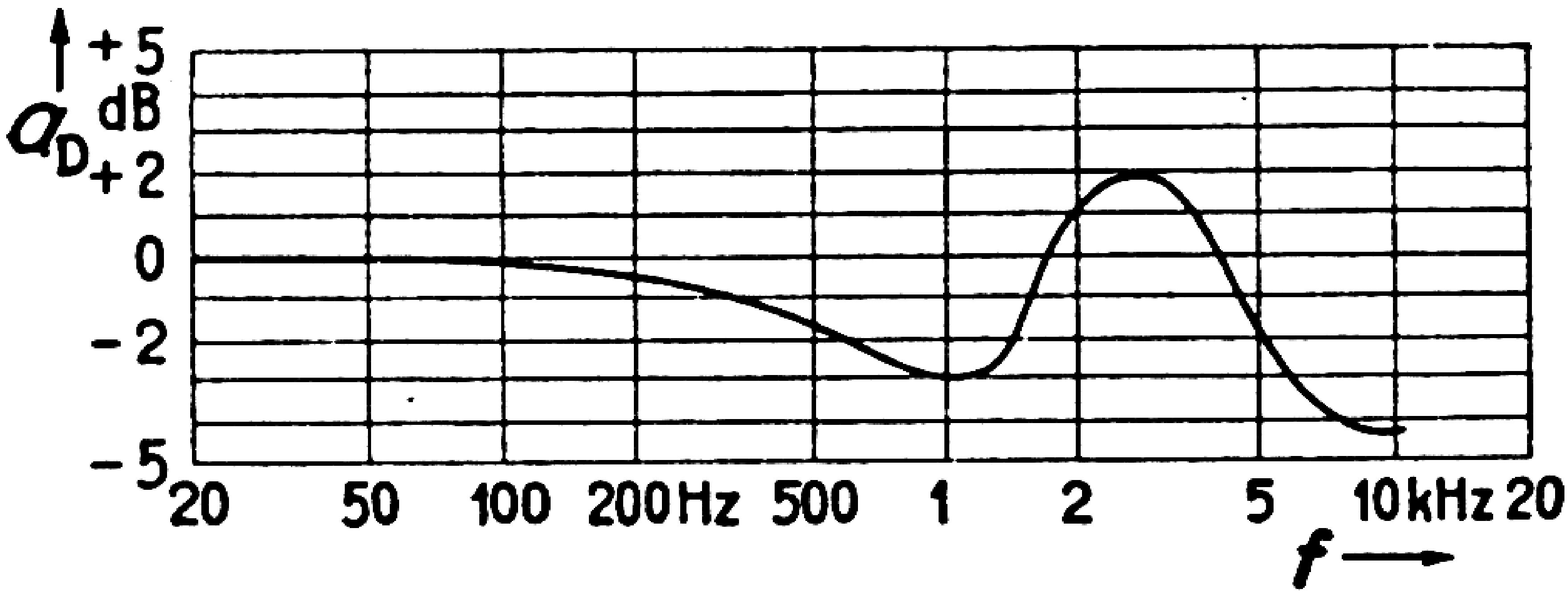
BLS for earphones > BLS for Loudspeakers

BLS in laboratory conditions > BLS out of the laboratory

From Florentine J. Acoust. Soc. Am., 2008



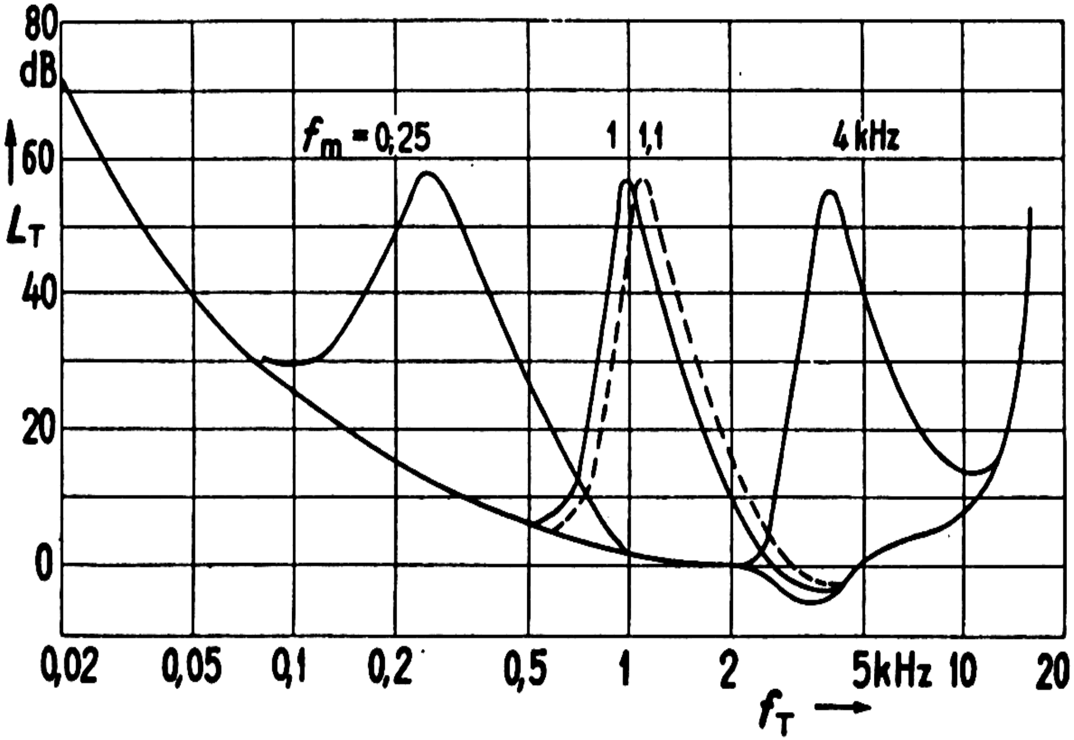
-10
a_0 dB
∓ 0
+10
+20
+30
50
100
200Hz
500
1
2
5
10kHz
20
f



+5
dB
a_D
+2
0
-2
-5
20
50
100
200 Hz
500
1
2
5
10 kHz
20
f

Excitation

Masking curves



Experiment 1
Loudness of synthesized noises

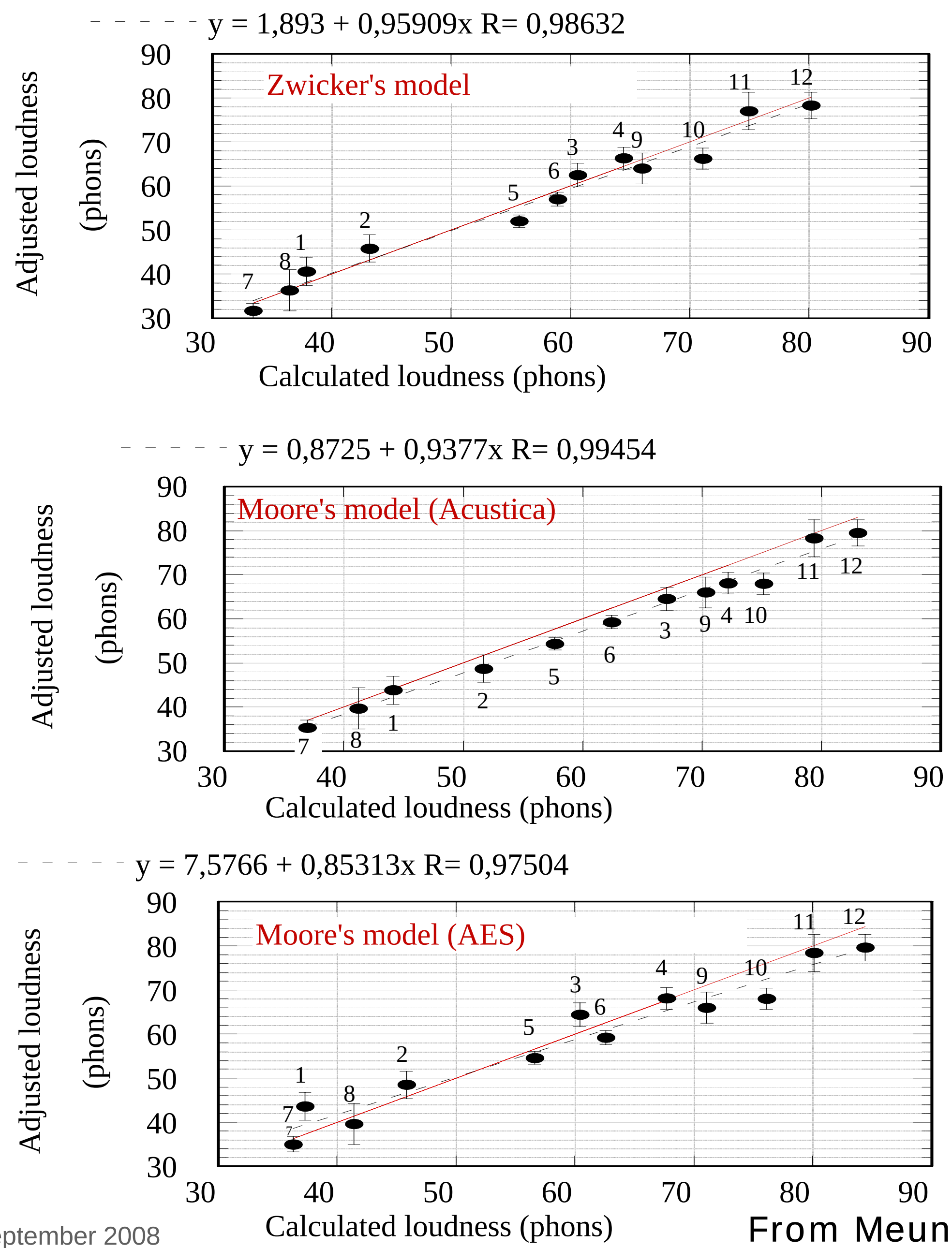
Physical parameters of the twelve synthesized noises

sound number	Central frequency (Hz)	bandwidth (Hz)	Level (dB SPL)
1	400	50	40
2	400	420	40
3	400	50	60
4	400	420	60
5	1420	120	30
6	1420	1000	30
7	1420	120	50
8	1420	1000	50
9	3000	240	60
10	3000	2040	60
11	3000	240	70
12	3000	2040	70

- 8 listeners

From Meunier et al. InterNoise 2000

Experiment 1 : synthesized noises



From Meunier et al. InterNoise 2000

Experiment 1
Loudness of environmental noises

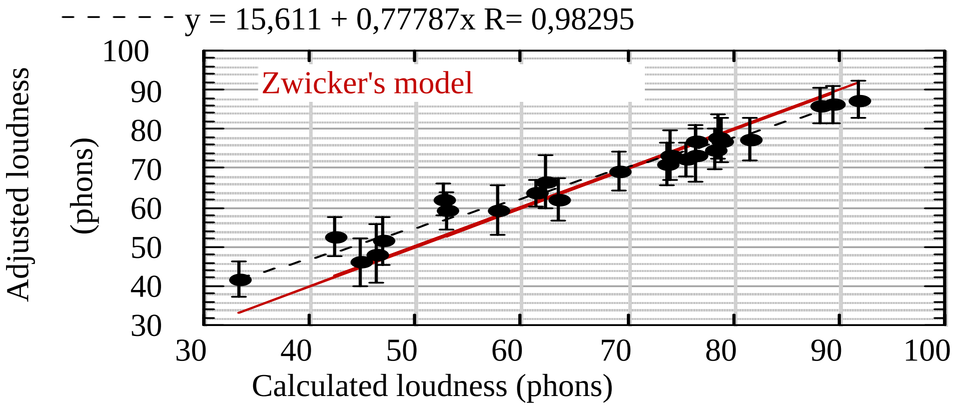
Twenty four enrironmental sound (steady over 1 s)

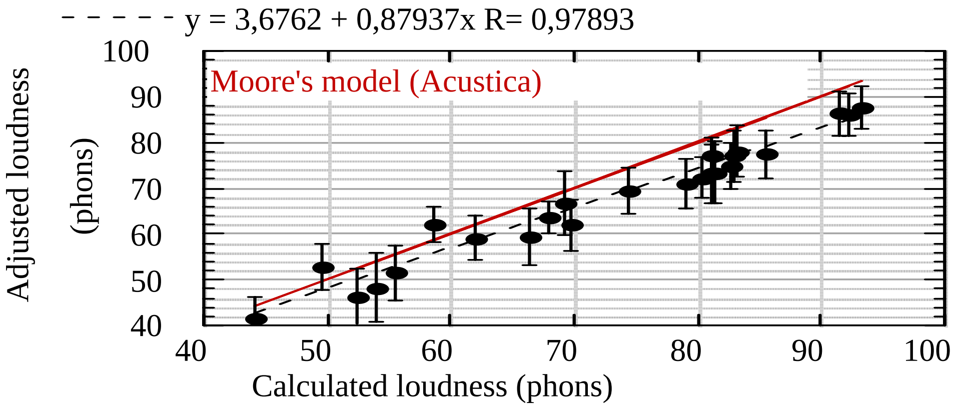
Sound	Abbreviation
Blowlamp	Blowlamp
Guitare	Guitare
Harmonica	Harm
Rumpled paper	Paper
Computer hard disk	Disk
Telephon in an Anecho•c Chamber	Tel_AC
Telephon in an office	Tel
Bicycle in an Anecho•c Chamber	Bicy_Ac
Bicycle	Bicy
Car	Car
Woman voice	Voice_W
Man voice	Voice_M
Flute at 39 dB SPL	Flute_39
Flute at 54 dB SPL	Flute_54
Flute at 69 dB SPL	Flute_69
Flute at 84 dB SPL	Flute_84
Motorcycle at 28 dB SPL	Moto_28
Motorcycle at 43 dB SPL	Moto_43
Motorcycle at 58 dB SPL	Moto_58
Motorcycle at 73 dB SPL	Moto
Drilling at 35 dB SPL	Drill_35
Drilling at 50 dB SPL	Drill_50
Drilling at 65 dB SPL	Drill_65
Drilling at 80 dB SPL	Drilling

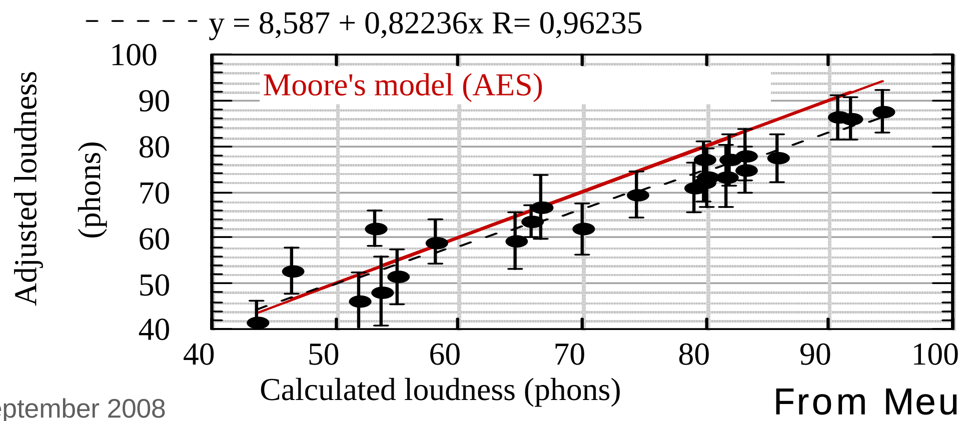
- 24 listeners

From Meunier et al. InterNoise 2000

Experiment 2 : environmental noises







From Meunier et al. InterNoise 2000