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Revisiting Broner's 1978 JSV paper: THE EFFECTS OF LOW FREQUENCY NOISE ON PEOPLE

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Broner, N., (1978). The Effects of Low Frequency Noise on People – A Review. *Journal of Sound and Vibration*, 58(4), 483-500

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Presentation Contents

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Low Frequency Noise

- Study examples related to low frequency noise

1967	1974	1988	1996	…	2018
Human responses to intense low frequency noise and vibration	Effects of noise on people	Annoyance due to low frequency noise and the use of the dB(A) scale	Source and effects of low frequency noise		Effects of low frequency noise on human cognitive performances

- Low Frequency Noise Complaints

The New York Times, Feb 2018

The Guardian, Jul 2018

What is Infrasound?

- "Sound at frequencies range less than 20 Hz" [ANSI]
  - Natural infrasound
    - Earthquakes, volcanoes, waterfalls,…
    - Whales, elephants, giraffes,…
  - Man-made infrasound
    - Sonic booms, explosions, diesel engines, wind turbines,…
    - Singer Tim Storms (Guinness World Record – lowest note 0.8 Hz)

What is Low Frequency Noise?

- "Sound at frequency range from 0 - 100 Hz" [Broner, 1978]
- "Low frequency noise, the frequency range from about 10 Hz to 200 Hz" [Leventhall, 2004]
- "A low frequency sound is about 500 Hz and lower" [Primary Children's Hospital, 2016]

Problem Statement and Objective of BRONER's Study

- The existence of high levels of low frequency noise, in particular infrasound noise, has been reported in many environment
- Man-made sources of low frequency noise such as compressors, boilers, cars and ships, appear to present a potentially great hazard
- Some people reported nausea, disorientation and general unpleasantness which can occur due to low frequency noise
- The main goal of this 1978 study was to review the effects of low frequency noise which were not clear at that time

The Effects of Low Frequency

Effects : Annoyance

- Primary effect due to low frequency and infrasonic noise
  - “city fatigue” [Gavreau, 1968]
- Many reports related to low frequency problems
  - The annoyance due to low frequency noise is more common than previous believed
- Other low frequency noise nuisance problems
  - Concorde engine test bed, air-conditioning systems, …
  - Sleep disturbance
- “Loudness and annoyance are equivalent for noise containing high levels of low frequency noise” [Bryan, 1971; Tempest, 1973]

Effects : Hearing

The most common misconceptions – “infrasound cannot be heard”

Hearing threshold level

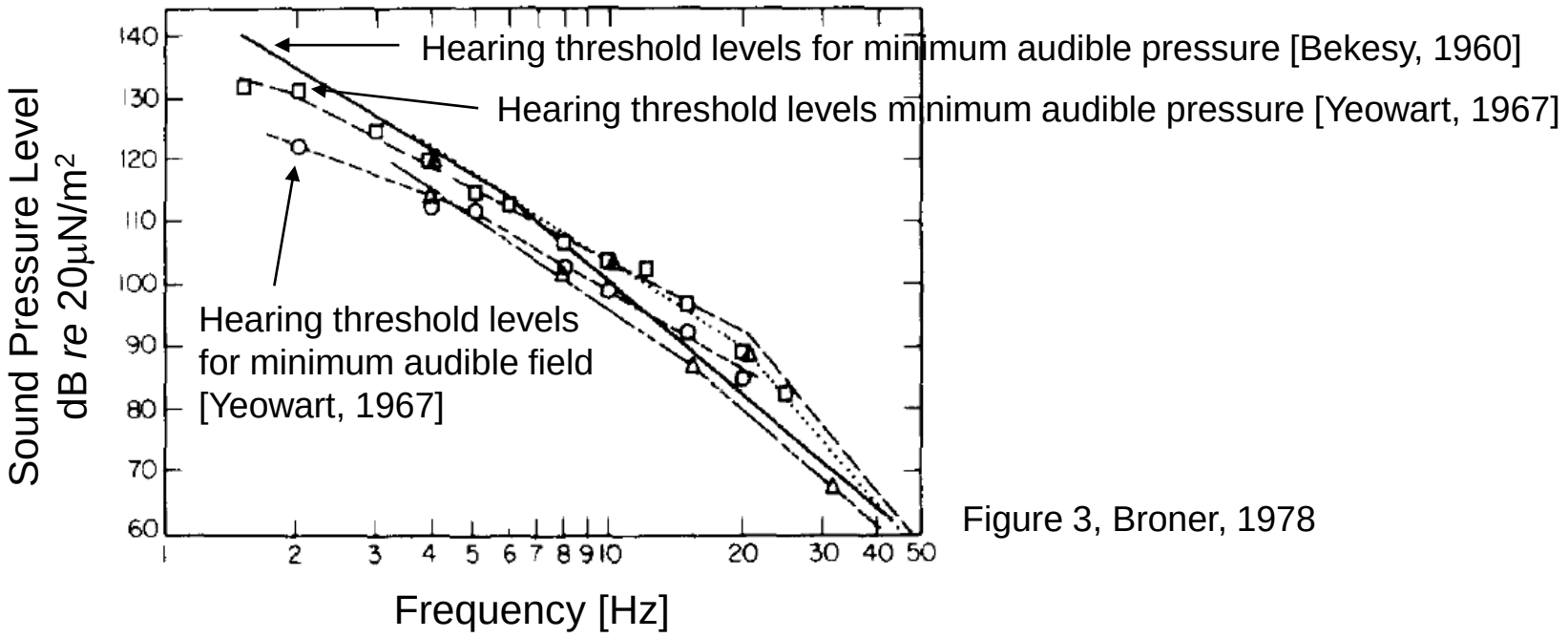


Figure 3, Broner, 1978

- Infrasound can be heard down to 1 Hz and below with high sound pressure
- Infrasound pure tone → perceived as “chugging”, “rough”, or “popping”
  - A person can hear associated harmonics of infrasound tone

Effects : Hearing

Temporary Threshold Shift (TTS)

- No TTS due to a 40-min exposure to a low frequency noise (2-15 Hz) at 115 dB A-SPL [Ramet, 1975]
- TTS greater than 10 dB in 11 of 21 subjects exposed for 3 min to 2, 10, 12 and 22 Hz tones at levels greater than 137 dB SPL [Alford, Jerger, Coats, Billingham, French, and McBrayer, 1966]

Middle Ear Pressure Build-Up

- The most consistent findings of infrasound and low frequency noise exposure
- Begins to occur for levels of infrasound between 127-133 dB
- This sensation can temporarily relieved by “Valsalva”

Communication Effect and Masking

- Speech intelligibility is not affected until the masking level of the low frequency components is 115 dB A-SPL [Yeowart, 1973; Yeowart, 1974]

  → The masking and communication effect of low frequency noise is not significant

Effects : Low Frequency Noise and Vibration

The action of low frequency noise on the body is different from that of vibration

- Very little absorption of acoustic energy by man (2% at 100 Hz)

  → Impedance mismatch
- Very high levels of noise are required to get the same order of magnitude of response as from vibration
  - At least 130 dB is required to produce harmful effect [Johnson, 1974]

Effects : Therapeutic Value of Low Frequency Noise

- J.F.J. Johnston, 1971, *Royal Military College of* Science, England, Infrasound – a short survey.
  - Blasts of high intensity sound
  - Help produce ovulation in women
  - Electrical stimulation of the brain at 42.5 Hz → rectify color blindness
  - High intensity (155 dB) whistle at 340 Hz recovered the sense of smell
- Low levels of infrasound (overall SPL 115 – 120 dB) possibly relax people [Evans, Tempest, 1972]
- Possibility of using infrasound below 1 Hz to ventilate the lungs (166 dB)
  - Broner notes this level is well above acceptable range

Many reports, but not very scientific. Infrasound does not have any practical application as a useful medical aid

Effects : Military Use of Low Frequency Noise

- Not applicable due to a large amount of sound power ($2x10^{11}$ W) and a extremely large facility (1100 m diameter)
- Possibly used as a non-lethal weapon
  - Inducing stress in an enemy force

BRONER's Conclusion on this :
The use of audio-frequency noise at high levels would seem to more practical

Journalist's Speculation

Myths associated with low frequency noise and infrasound

- "One of the many causes of allergies, nervous breakdowns and other unpleasant phenomena of modern life"
- "Sound Ray Developed as a Killer"
- "Does Infrasound Make Drivers Drunk?"
- Cause of brain tumors and cot deaths

  → No scientific evidence

Effects of Low Frequency Noise on Human Performance

- A number of studies have been carried out to investigate reaction time, visual acuity, vigilance and cognitive functions
  - Some degree of performance degradation in selected tasks due to infrasound [Hood, Leventhall and Kyriakides, 1971; Evans and Tempest, 1972; Bryan and Tempest, 1972;Leventhall, 1973; Hood, 1973;Bruel and Oleson, 1973]
  - However there were researchers who did not find performance degradation

Reference	Signal	Experiment	Comment
Smith *et al.*, 1970	70 Hz tone at 122.8 ± 10 dB	Sensory-motor task	No decrement in the performance
Poulton and Edwards, 1974	102 dBC	1. Tracking with peripheral lights 2. 5-choice task 3. Visual vigilance	Arousal effect for "green noise"

- More Studies - No significant effects due to infrasound [Harris, Sommer, Johnson, 1974; Borredon, 1972; Borredon and Nathie, 1973; Johnson, 1973; Von Gierke, 1973; Slarve and Johnson, 1974]

  → However, these studies limited to short duration of exposure (8 min max)

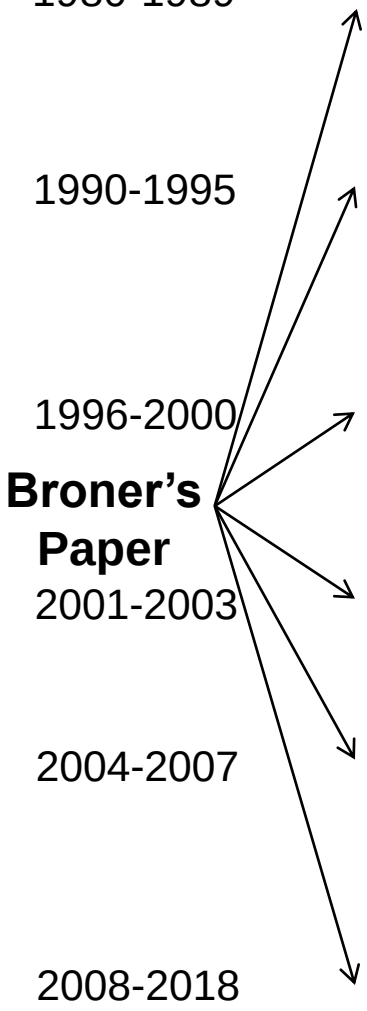
Conclusions of BRONER's Paper

- Effects of infrasound are similar to those of higher frequency noise and over-rated
- Most studies are weak in experimental methodology and the scientific reporting
- Little information exists with respect to longer duration exposures

Summary of minimum threshold levels for infrasonic effects due to short term exposures [Johnson, 1973]

Effect	Threshold level (dB)
Whole-body	>140
Respiration	>166
Auditory	>130
Performance	>120-130
Annoyance	>55 L_{DN}, f > 5Hz >120 L_{DN}, f < 5Hz

Impact of the Study : # of Citation of 1978 BRONER's (184)



Westman, J.C., and Walters, J.R. (1981). Noise and stress: a comprehensive approach. *Environmental Health Perspectives* 41, 291. cited by **126**

"sleep disturbance has been reported in response to low frequency noise in the 20-100 Hz"

Persson, K., Bjorkman, M., and Rylander, R. (1990). Loudness, annoyance and dBA in evaluating low frequency sounds. *Journal of Low Frequency Noise, Vibration and Active Control,* 9(1), 32-45. cited by **43**

Delyukov, A.A. and Didyk, L.,. (1999). The effects of extra-low frequency atmospheric pressure oscillations on human mental activity. *International journal of biometeorology,* 43(1), 31-37. cited by **29**

"significant changes in attention and short-term memory functions"

Ouis, D.,. (2001). Annoyance from road traffic noise: a review. *Journal of environmental psychology,* 21(1), 101-120. cited by **383**

Schust, M. (2004). Effects of low frequency noise up to 100 Hz. *Noise and Health,* 6(23), 73. cited by **73**

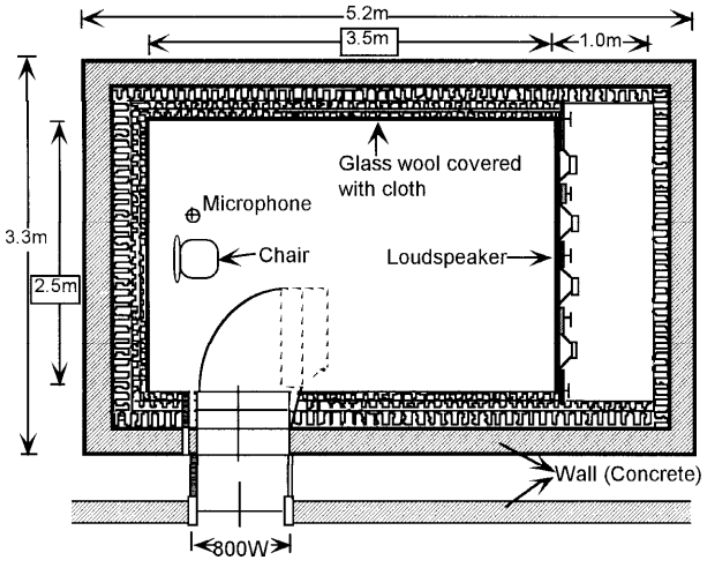
Pawlaczyk-Luszczynska, M., Dudarewicz, A., Szymczak, W., and Sliwinska-Kowalska, M. (2010). Evaluation of annoyance from low frequency noise under laboratory conditions. *Noise and Health,* 12(48), 166. cited by **18**

"Annoyance of low frequency noise was not rated higher than annoyance from broadband noise"

More Recent Studies

"Weak in experimental methodology and scientific reporting"

- Unpleasantness and acceptable limits of low frequency sound [Inukia, Nakamura and Taya, 2000]
  - Unpleasantness is one of the most representative negative feeling
  - Experiment
    - Stimuli – pure tone in the range from 20 Hz to 250 Hz and 500 Hz (B&K 104)
      - Subjects can control stimuli (1 dB step)
    - Subjects – 27 females and 12 males (age from 19 – 62)
    - Apparatus



- 46cm diameter loudspeakers mounted in the wall
- Background noise – 16 dB

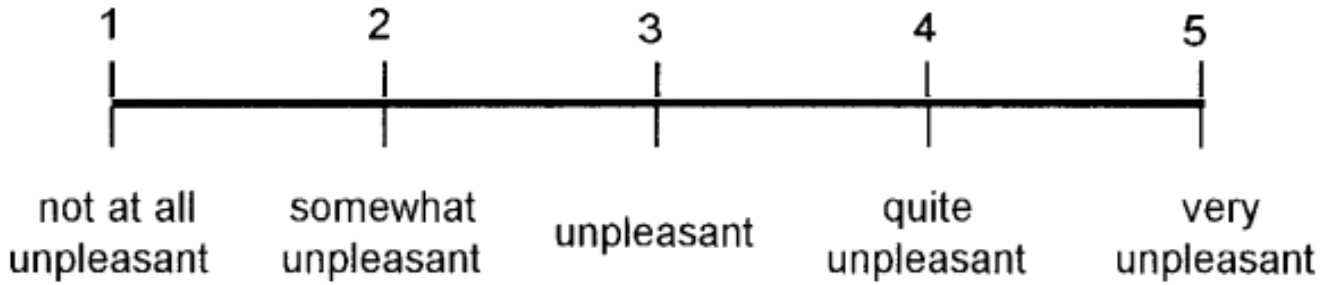
Figure 1, Inukia *et al.,* 2000

More Recent Studies

"Weak in experimental methodology and scientific reporting"

- Unpleasantness and acceptable limits of low frequency sound [Inukia, Nakamura and Taya, 2000]
  - Levels of unpleasantness

Figure 2, Inukia *et al.,* 2000



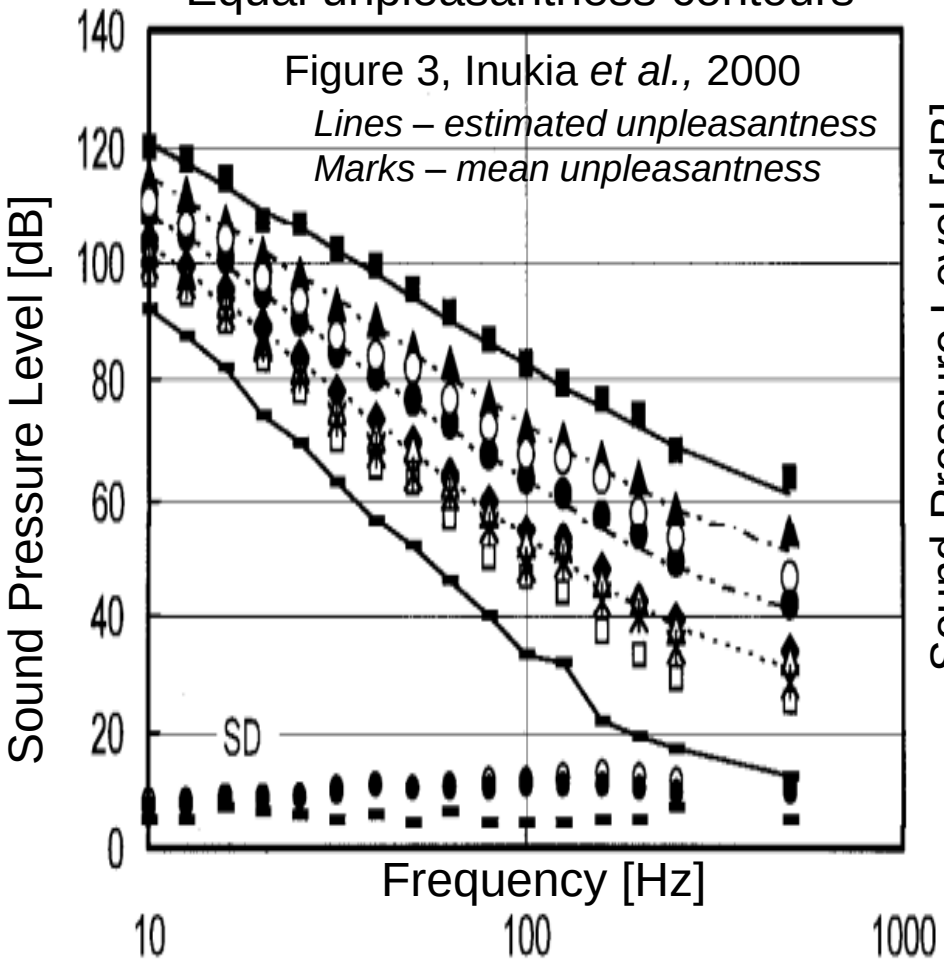
  - Test Procedure
    1. Playing sound
    2. Adjust sound by the subject response
    3. Repeat 1 and 2

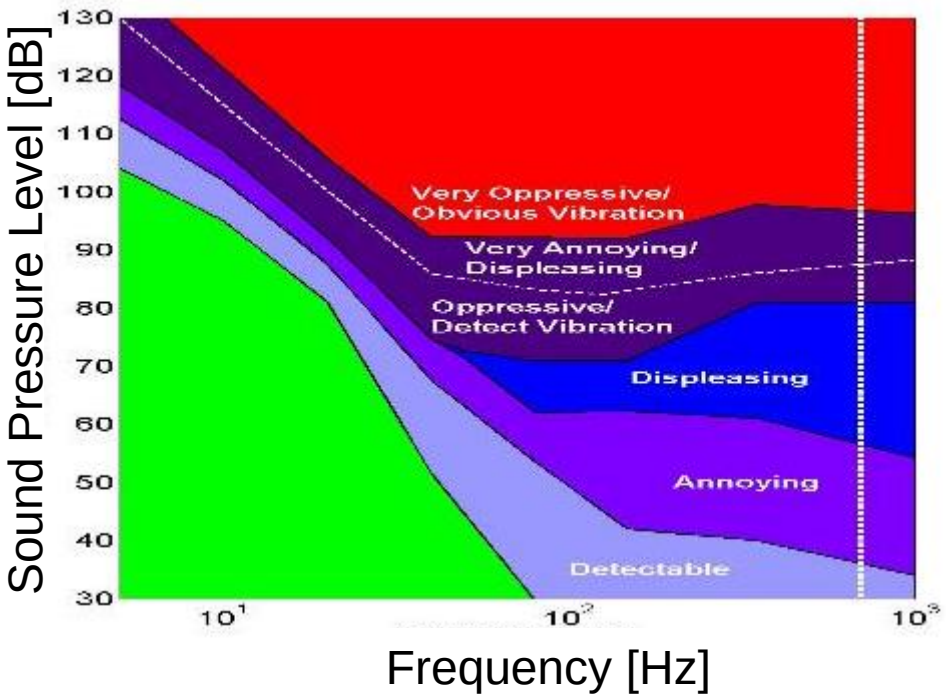
More Recent Studies

"Weak in experimental methodology and scientific reporting"

- Unpleasantness and acceptable limits of low frequency sound [Inukia, Nakamura and Taya, 2000]

Equal unpleasantness contours





(Tokita and Nakamura, 1981)

More Recent Studies - Effects

- Annoyance [Leventhall, 2004]
  - Subjective test to measure annoyance rating
    - Subjects asked to imagine themselves relaxing in their homes in the evening and to rate annoyance
    - Choice on a semantic scale ranging from ‘Not Annoying’ to ‘Extremely Annoying’
  - Low frequency noise annoyance >> High frequency noise annoyance

    → dBA underestimates annoyance for frequencies below 200 Hz

- Hearing Threshold [Muhlhans, 2017]

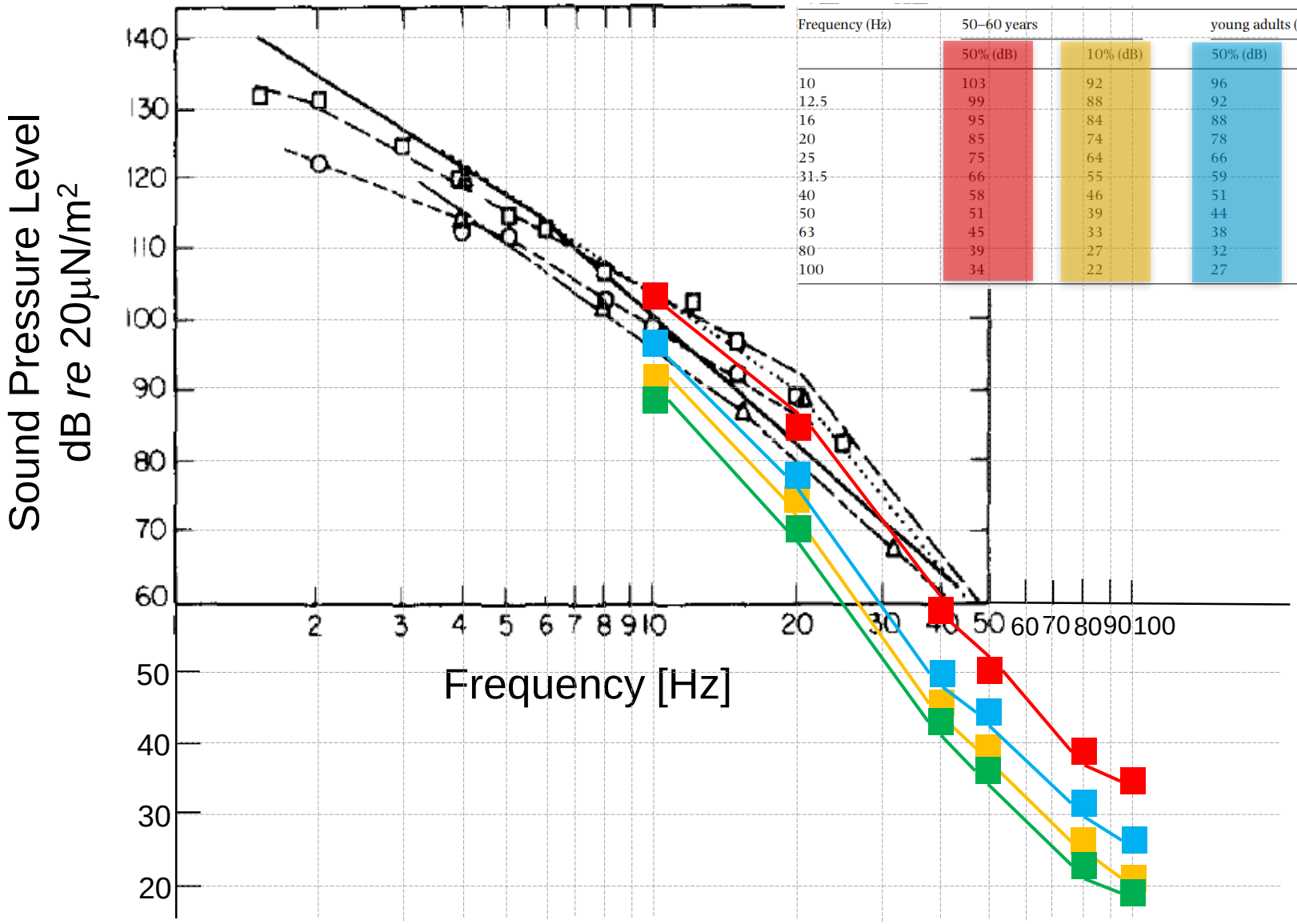
Frequency (Hz)	50–60 years		young adults (ISO 226)	
	50% (dB)	10% (dB)	50% (dB)	10% (dB)
10	103	92	96	89
12.5	99	88	92	85
16	95	84	88	81
20	85	74	78	71
25	75	64	66	59
31.5	66	55	59	52
40	58	46	51	43
50	51	39	44	36
63	45	33	38	30
80	39	27	32	24
100	34	22	27	19

Hearing Threshold for low frequency noise

50% - median level
10% - most sensitive part

More Recent Studies

- Hearing Threshold - [Muhlhans, 2017] vs. [Yeowart, 1967; Bekesy, 1960]



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50	51	39	44	36
63	45	33	38	30
80	39	27	32	24
100	34	22	27	19

More Recent Studies - Effects

- Temporary Threshold Shifts (TTS) [Berglund and Hassmen, 1995]
  - Recent studies consistently show that TTS does occur with exposure to low frequency noise
  - Possible permanent threshold shifts

Exposure parameters and example results of TTS studies

Reference	Exposure	TTS	Recovery
Backteman, 1983	119-133 dB 2-12 Hz, 3 min	11/21 subjects 3-8 kHz >10 dB	
Mills *et al.*, 1983	90 dB 63 Hz, 8 h	TTS 13-18 dB	Up to 48 h

More Recent Studies

- Sleep Quality [Waye, Agge, Clow and Hucklebridge, 2004]
  - The effect of night-time exposure to low frequency noise
  - Night-time exposure to low frequency noise may induce cortisol awakening response
  - Longer time to fall asleep after low frequency noise exposure
- Wind Turbine Noise
  - The prevalence of noise annoyance was higher than expected [Pedersen and Waye, 2004]
  - The low frequency part of the spectrum plays an important role in the noise at the neighbors [Moller and Pedersen, 2011]
  - Infrasound from wind turbines is not audible and no serious health effects found [Bolin, Bluhm, Eriksson and Nilsson, 2011]
  - Night-time wind turbine noise limits should be set conservatively to minimize harm [Shepherd, McBride, Welch, Dirks and Hill, 2011]
  - The noise emissions of wind turbines disturbed the sleep and cause daytime sleepiness [Nissenbaum, Aramini, Jeffery, Hanning and Christopher, 2012]

Concluding Comments

- More scientific and precise experiments in recent studies
- Results of hearing thresholds are similar even after 30 or 40 years
- But need more research on effect of low frequency noise

Thank you