Loudness in the occluded ear canal: are we still missing 6 dB?

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The project: in-ear noise dosimetry

To finally answer the question “is this worker properly protected against noise?”
If $L_p' = L_p$, is risk of hearing damage the same?

A recent study (Theis et al., 2012) suggests that the auditory response to a given in-ear SPL is different in the occluded ear.
The missing 6 dB problem

- **Since 1933:** several researchers have shown experiments in which ear sensitivity seemed to be different at low frequencies depending on whether they were using earphones or a loudspeaker as a source.
The missing 6 dB problem

• Since 1933: several researchers have shown experiments in which ear sensitivity seemed to be different at low frequencies depending on whether they were using earphones or a loudspeaker as a source.

• 1978: Killion identified masking from physiological noise as the main reason to explain the threshold differences at low frequencies.

• 1982: Rudmose identified the “source location effect” as the most influential factor to explain other authors’ reported differences at supra-threshold levels.
The source location effect

Further sound source appears up to 4 dB louder! (Rudmose, 1982)

Or even 20 dB louder! (Zahorik et al., 2001)
The source location effect (Volk & Fastl, 2011)

« the same sound-pressure time-functions in the auditory canals ensure the same loudness in loudspeaker and headphone reproduction » (Völk & Fastl, 2011)
More questions! (Keidser et al., 2000)

« listeners tend to select an average of 10 dB higher level for low-frequency at 500 Hz when listening with the ear occluded than when listening with the ear open» (Keidser et al., 2000)
Research question

If $L_{p'} = L_p$, is the loudness perceived the same?
Experimental design

- Acquisition system
  - Open-ear SPL
  - Occluded-ear SPL
  - Sound Booth
  - Earplug
  - Audio balance adjustment
  - Experimenter
In-ear apparatus

Open ear

Occluded ear

Probe-tube

Probe-tube

External microphone to measure earplug attenuation
Earplug attenuation

Estimated earplug attenuation as measured on 18 subjects

Frequency (Hz) vs. Attenuation (dB)
Loudness balance procedure
Data processing

\[ AILDEL = \frac{1}{n} \sum_{i=1}^{n} [L_{\text{left}} - L_{\text{right}}] \]

\[ n = 3 \]

Interaural level difference at equal loudness

Left Ear Occluded (task 1)

\[ AILDEL_1 = \Delta_{\text{earplug},1} + \Delta_{\text{subject}} \]

Right Ear Occluded (task 2)

\[ AILDEL_2 = -\Delta_{\text{earplug},2} + \Delta_{\text{subject}} \]

Average effect of the earplug

\[ \Delta_{\text{earplug}} = \frac{\Delta_{\text{earplug},1} + \Delta_{\text{earplug},2}}{2} \]

\[ = \frac{AILDEL_1 - AILDEL_2}{2} \]
RESULTS

Average effect of the earplug (N=18)

\[ \Delta_{\text{earplug}} \text{(dB)} \]

-6 -4 -2 0 2 4 6

125 250 500 1k 2k 4k 8k

Frequency (Hz)
Conclusions

• Headphones vs. loudspeaker → **solved in literature**

• Open vs. occluded → previous results were most likely caused by loudness measurement artifacts such as the **source location effect**

**General conclusion: loudness does not depend on the type of acoustic load applied to the ear**

**Future works: explain results from Theis et al. (2012)**
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Thank you!


Experimental design

Protocol

- 2 tasks: earplug in left ear, earplug in right ear
- Stimuli: 1/8 oct narrow band noise samples (phase-uncorrelated) at 50 phons
- 7 test frequencies (kHz): 0.12, 0.25, 0.5, 1, 2, 4, 8
- 3 adjustments per test frequency
- Balance resolution: 1 dB in each ear
- Balance range: ± 15 dB SPL in each ear
- Test duration: ~ 70 minutes / subject

Subjects

- Number: 18
- Age: from 22 to 50
- Gender: 7 women, 11 men
- Audiometry profile: thresholds of 25 dB HL, or less, from 125 to 8000Hz
- No ear abnormalities spotted

Instrumentation

- FitCheck headphones (Michael & Associates)
- Custom double-flanged earplugs
- Knowles FG miniature electret microphones
- PXI-4462 acquisition module (National Instruments)
- 2 computers connected to the same local network
- Software: Matlab, PureData