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# Evaluation of sound stimuli to improve user comfort and facilitate detection via an auditory brain-computer interface



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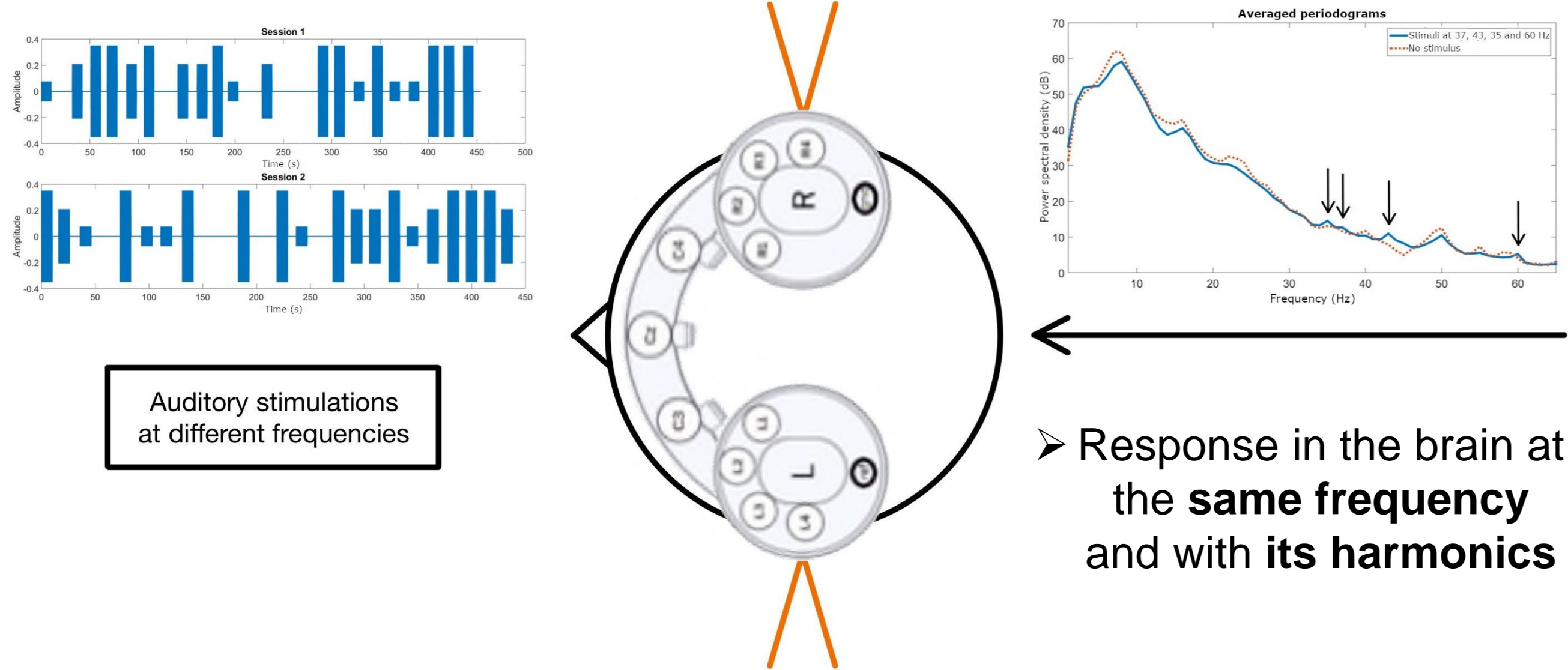
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Journées CORTICO

## Motivations

- **More comfortable carrier signals**
  - Amplitude-modulated **natural sounds**
  - **Imagined sounds**
- **Shorter stimulus durations**
- **Modulation frequencies easier to identify**
- **Lower sound levels**
- **Spatialisation**
  - Reinforcing separability in brain signals

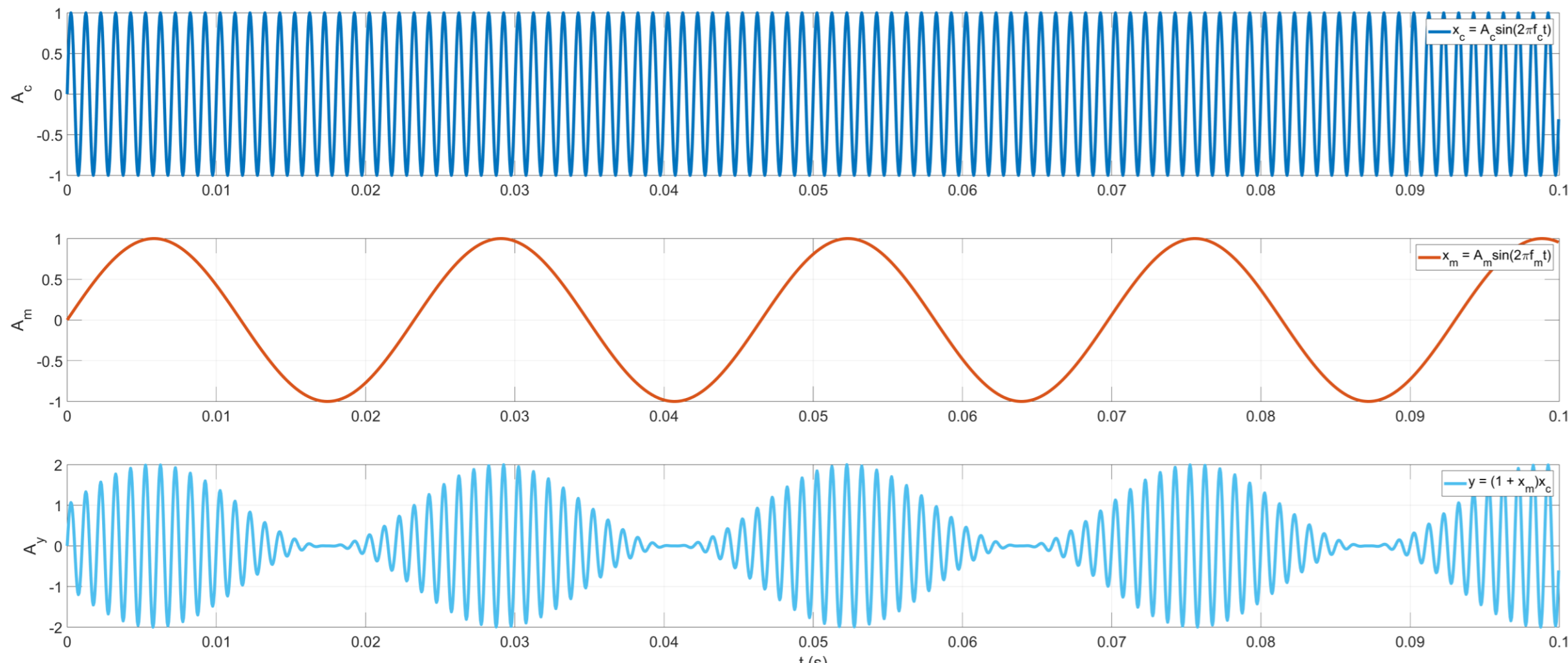
## Steady-State Auditory Evoked Potentials (SSAEPs)

- **Repeated stimulations**
  - Permanent « operating regime »
  - **Steady-state**
  - Measurable
- Repeated auditory stimulations [1]
  - **Amplitude modulation**
    - Continuous sinusoidal sound
    - Burst sequences (reinforce modulation frequency)
  - **35 - 100 Hz**



## Previous experiment

### Auditory stimulations [2]



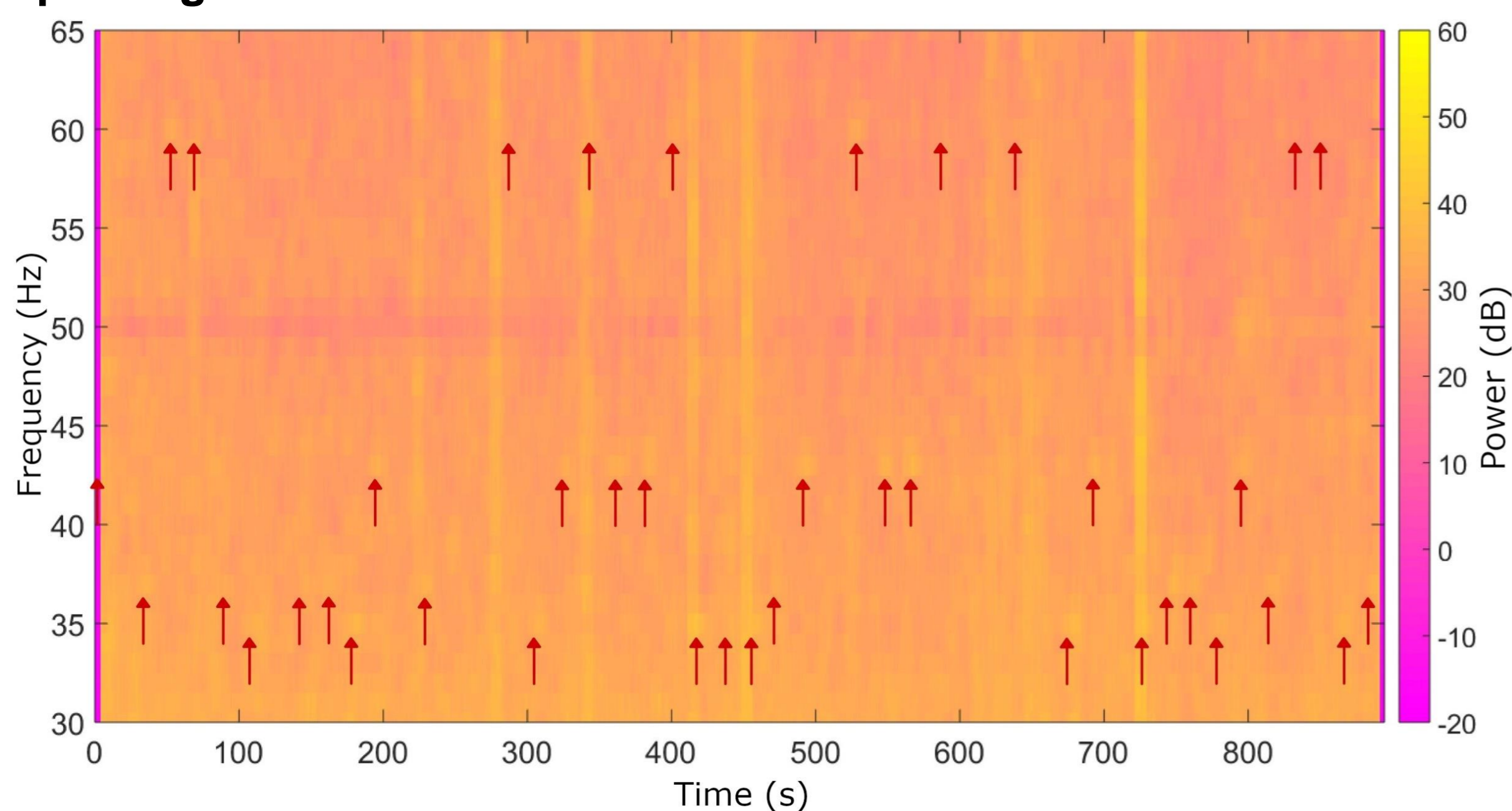
Carrier frequency $f_c$ (Hz)	Modulation frequency $f_m$ (Hz)
2500	37
1000	43
500	35
500	60

- 2 sessions (8 minutes each)
- 4 conditions (see tab for modulations)
- **10 randomised stimulations per condition** (10 seconds each)

### Sound reproduction and measurement of brain signals



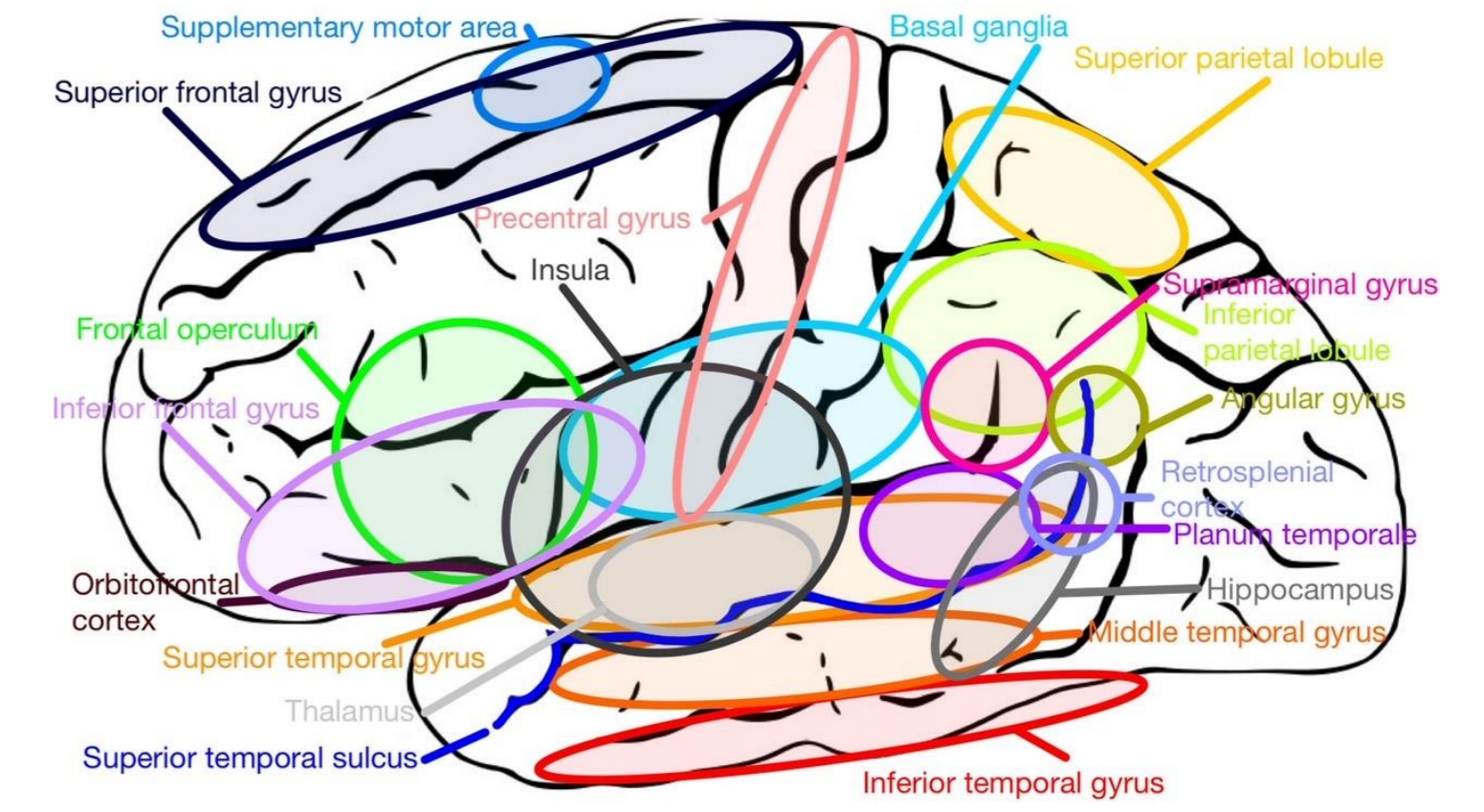
### Spectrogram



Arrows point to the powers detected over time according to the modulations

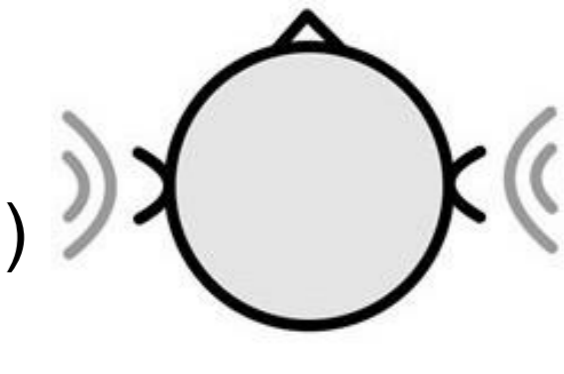
## Individual factors influencing sound signal processing zones

- **Handedness** [3]
  - Left brain dominance for language
    - 95 - 99% **right-handed**
    - 70 - 80% **left-handed**
- **Gender** [4]
  - **Men** = Mainly dependent on the left cerebral hemisphere
  - **Women** = Hemispheric balance
- **Musical expertise** [5]



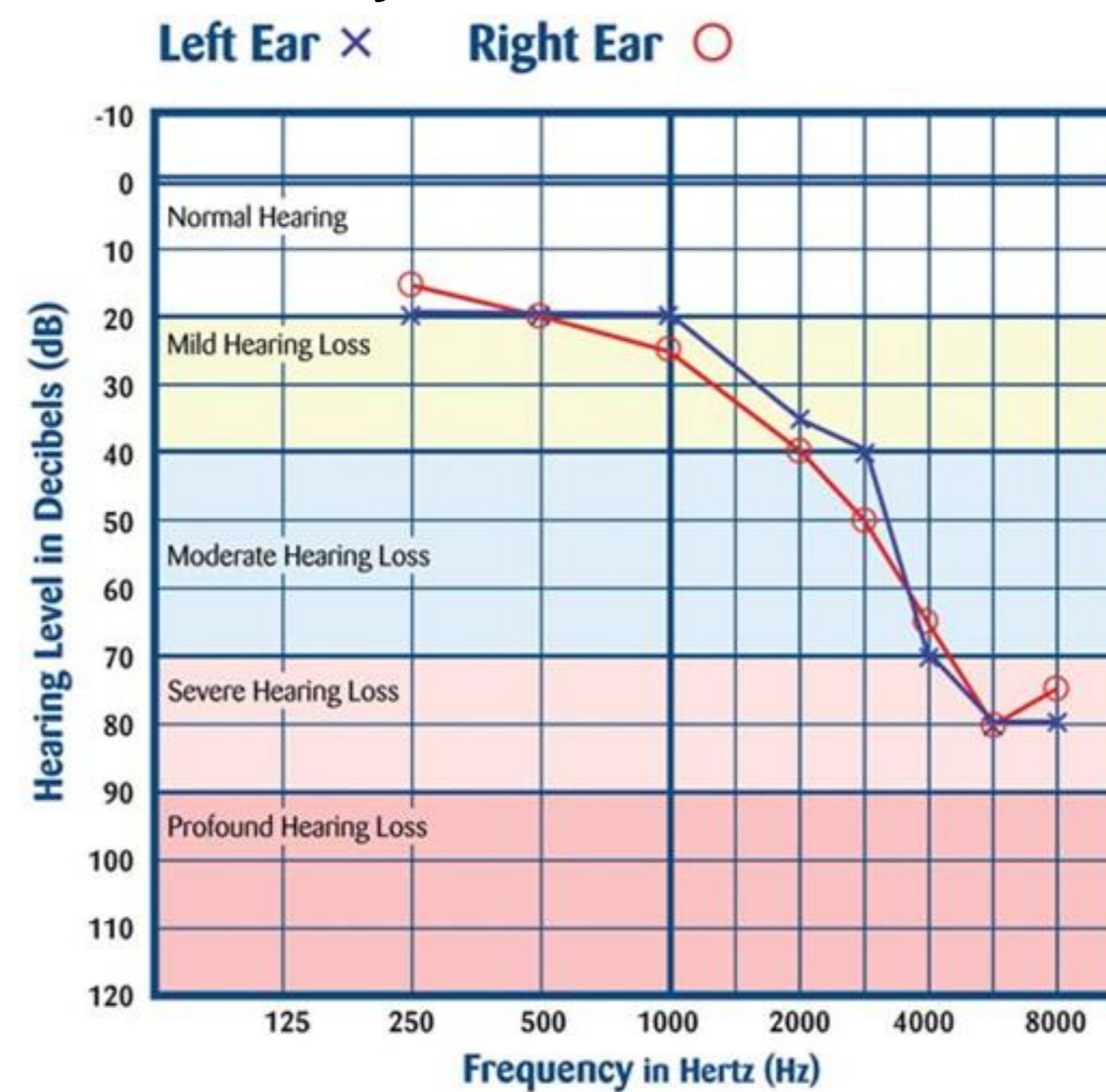
## Next experiment: Effect of carrier signals on brain activity and user's preference

- **Different carrier signals**
  - **Sine wave (reference)**
    - $f_c = 1000$  Hz
  - **Natural sounds**
    - Cicadas
    - Purring of a cat
  - **Brown noise**
- **Presentation**
  - 2 sessions (10 minutes each)
  - 4 conditions
  - **20 pseudo-randomised stimulations per condition** (10 seconds each)
- **Measurement of brain signals**



### Pre-experiment questionnaires

#### Audiometry



#### Edinburgh Handedness Inventory [6]

		Left (L)	Right (R)	No preference	Not applicable
1	Writing				
2	Throwing				
3	Comb				
...					
12	Staple paper sheets				

#### General questionnaire

Identifier:

Gender:

Age:

How would you assess your state of mind?

Unpleasant feelings:  Pleasant feelings

Sleepiness:  High arousal

What is your dominant state?

Do you have tinnitus?

Do you suffer from hyperacusis?

Have you consumed caffeine/theine in the last 24 hours?

Have you smoked in the last 24 hours?

Have you consumed alcohol and/or narcotics in the last 24 hours?

Have you taken any medication in the last 24 hours?

Are you familiar with brain-computer interfaces technologies and controlling connected objects using your brain signals?

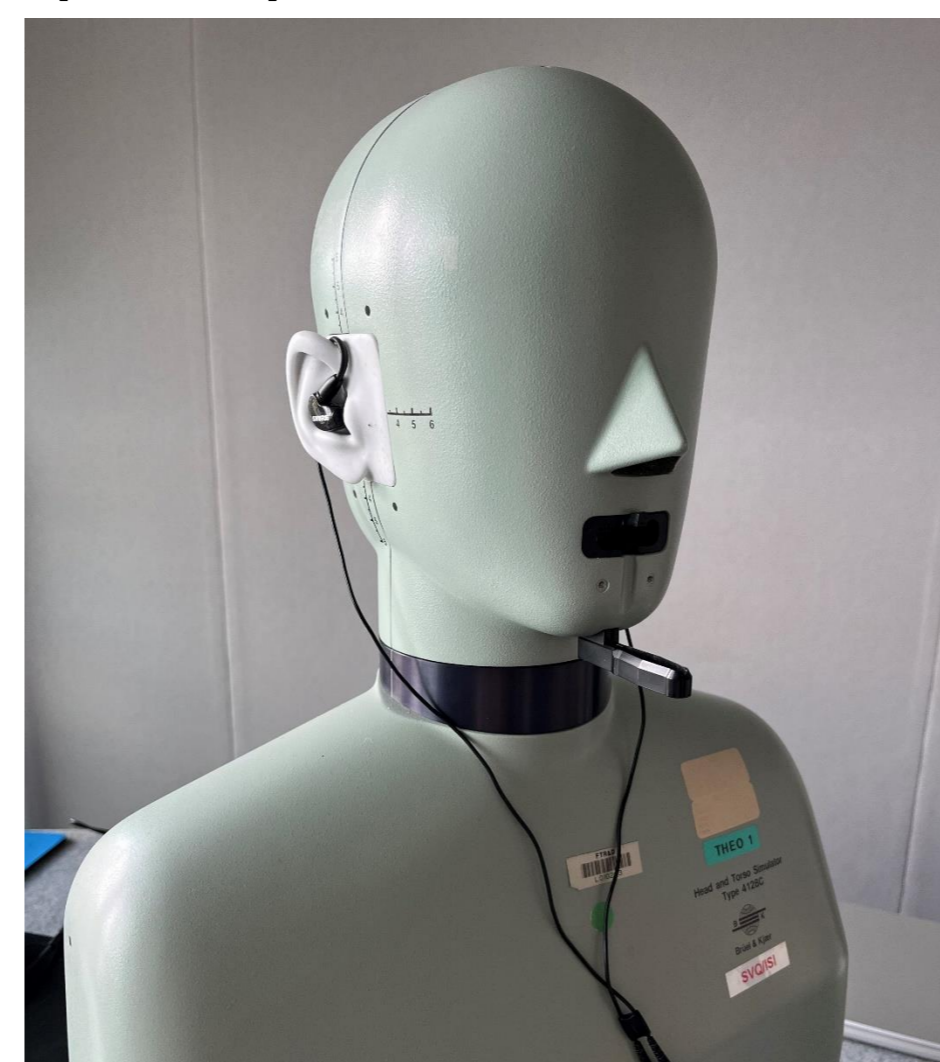
Are you used to hearing tests?

#### Goldsmiths Musical Sophistication Index [7]

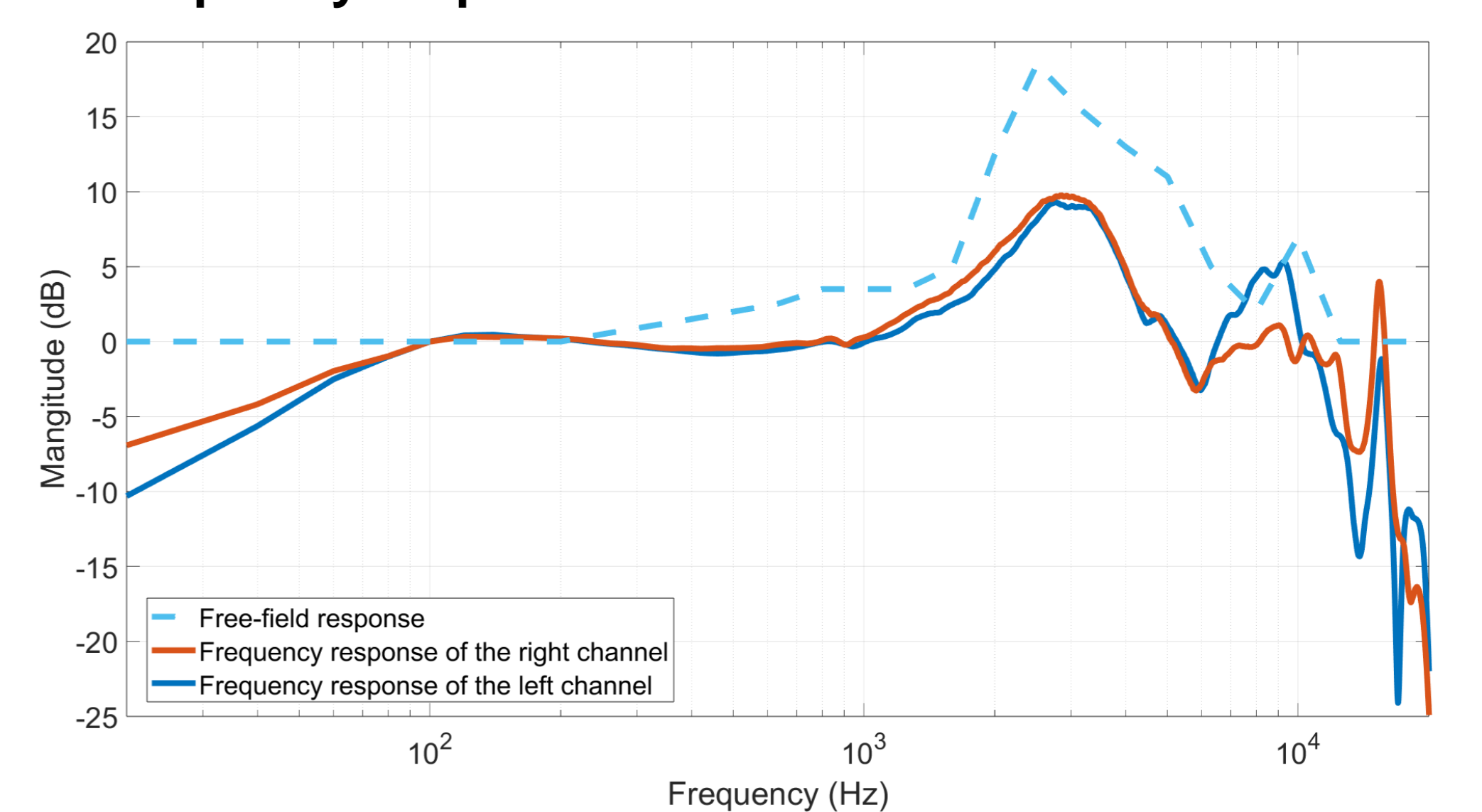
1	I spend a lot of my free time doing music-related activities.	Likert scale
2	I can compare and discuss differences between two performances or versions of the same piece of music.	Likert scale
3	When I sing, I have no idea whether I'm in tune or not.	Likert scale Negative item
...		
18	I can play __ musical instruments.	Ordinal scale

### Equalisation of sound stimuli

#### Head And Torso Simulator (HATS)



#### Frequency responses



[1] H. Higashi and al., "EEG auditory steady state responses classification for the novel BCI", in 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, (Boston, MA), p. 4576- 4579, IEEE, aug. 2011.

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[3] M. C. Corballis, G. Badzakova-Trajkov and I. S. Häberling, "Right hand, left brain: genetic and evolutionary bases of cerebral asymmetries for language and manual action", Wiley Interdisciplinary Reviews: Cognitive Science, vol. 3, p. 1-17, jan. 2012.

[4] P. D. MuLenn, "WOMEN: A MORE BALANCED BRAIN?", Zygon, vol. 31, p. 421-439, sept. 1996.

[5] L. Bonetti, E. Brattico, F. Carlomagno, G. Donati, J. Cabral, N. Haumann, G. Deco, P. Vuust and M. Kringelbach, "Rapid encoding of musical tones discovered in whole-brain connectivity", NeuroImage, vol. 245, p. 118735, june 2021.

[6] R. C. Oldfield, "The assessment and analysis of handedness: the edinburgh inventory", Neuropsychologia, vol. 9, no. 1, p. 97-113, 1971.

[7] D. Müllensiefen, B. Gingras, L. Stewart and J. J. Musil, "Goldsmiths musical sophistication index (gold-msi) v1.0: Technical report and documentation revision 0.3", 2013.