What can be decoded in or near the ear

What can (**potentially**) be decoded from in or near the ear

Workshop in Cognitive Hearing (CogHear)

Organized by Mounya Elhilali, Shihab Shamma and Malcolm Slaney

Presentation by Preben Kidmose

Vision: Brain Decoding in Real-Life

Conventional EEG system

High-performance research and clinical EEG system

Ear-EEG based system

Discreet, unobtrusive and user-friendly devices for everyday life

Ear-EEG based hyperscanning

Intra- and inter-subject decoding in large groups of subjects in real-life settings

Agenda

- ❖ Introduction to ear-EEG
- ❖ The keyhole hypothesis
- ❖ Ear-EEG forward model
- ❖ What can (potentially) be decoded in or near the ear

References:

- S. Kappel et al., “**Ear-EEG Forward Models: Improved Head-Models for Ear-EEG**”, Frontiers in Neuroscience | Brain Imaging Methods (2019).
- K. Mikkelsen et al., “**On the keyhole hypothesis: High mutual information between Ear and Scalp EEG**”, Frontiers in Human Neuroscience (2017).
- C. Christensen et al., “**Auditory Steady-State Responses across Chirp Repetition Rates for Ear-EEG and Scalp EEG**”, EMBC (2018).
- C. Christensen et al., “**Towards EEG-assisted Hearing Aids: Objective Threshold Estimation Based on Ear-EEG in Subjects with Sensorineural Hearing Loss**”, Trends in Hearing, (2018).
- C. Christensenet al., “**Ear-EEG based objective hearing threshold estimation evaluated on normal hearing subjects**”, IEEE Tran. BME (2018).
- K. Mikkelsen et al., “**Automatic sleep staging using ear-EEG**” , BioMedical Engineering Online, September (2017).
- K. Mikkelsen et al., "**Accurate whole-night sleep monitoring with dry-contact ear-EEG**", Scientific Report, Nature, (2019).
- Y. Tabar et al., “**Ear-EEG for sleep assessment: a comparison with actigraphy and PSG**”, Sleep and Breathing, Springer (2020).
- F. Farooq et al.. “**Random Forest Classification for P300 Based Brain Computer Interface Applications**”. EUSIPCO (2013).
- S. Kappel et al., “**High-Density Ear-EEG**”, EMBC (2017).
- S. Kappel et al, “**Real-Life Dry-Contact Ear-EEG**”, EMBC (2018).

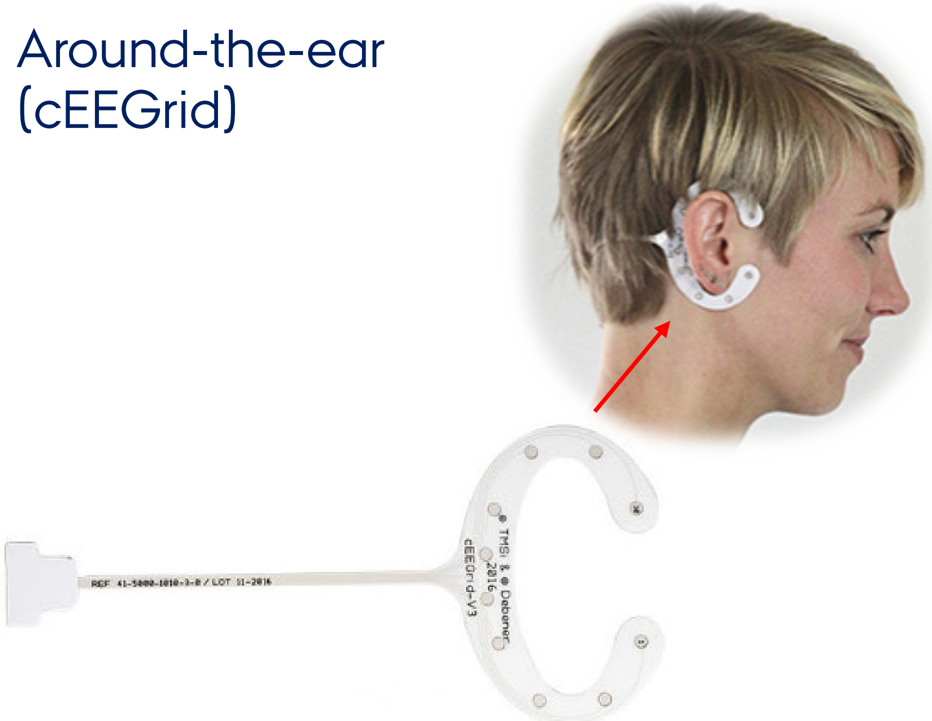
Feasibility

Features of a real-life EEG device:

- Discreet – or at least not stigmatizing
- Unobtrusive – benefits outweigh disadvantages
- Comfortable to wear
- Safe
- Scalable (to reach broad populations)
  - Affordable
  - Easy to use
  - (Preferably) non-invasive

Ear-EEG – embodiments and approaches

Around-the-ear
(cEEGrid)

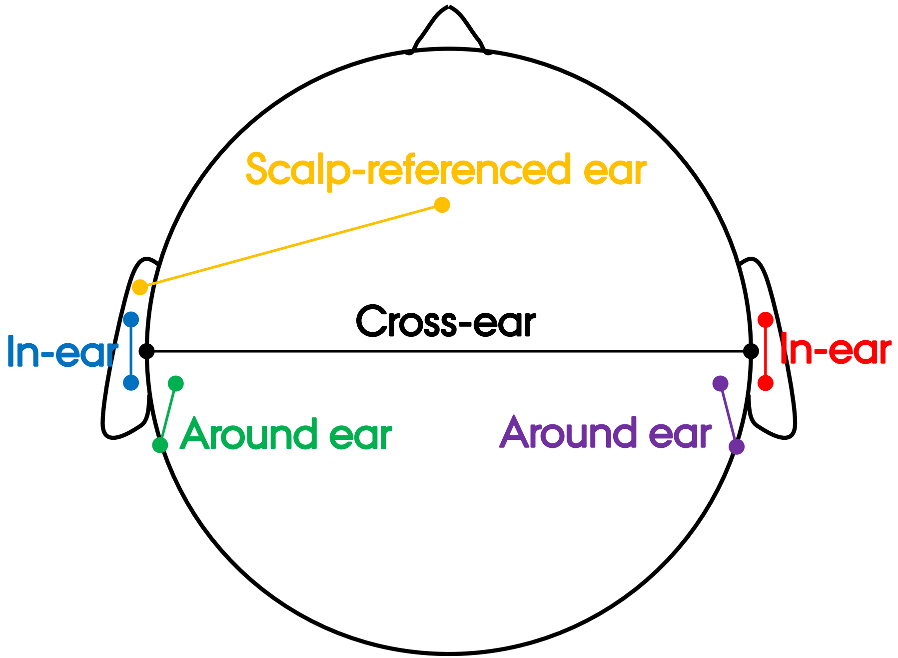


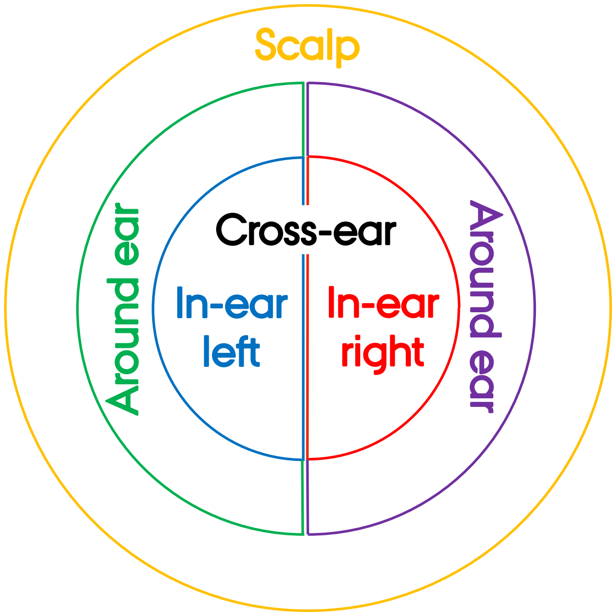
M.G. Bleichner and S. Debener. "Concealed, unobtrusive ear-centered EEG acquisition: cEEGrids for transparent EEG", Frontiers in human neuroscience (2017).

In-the-ear

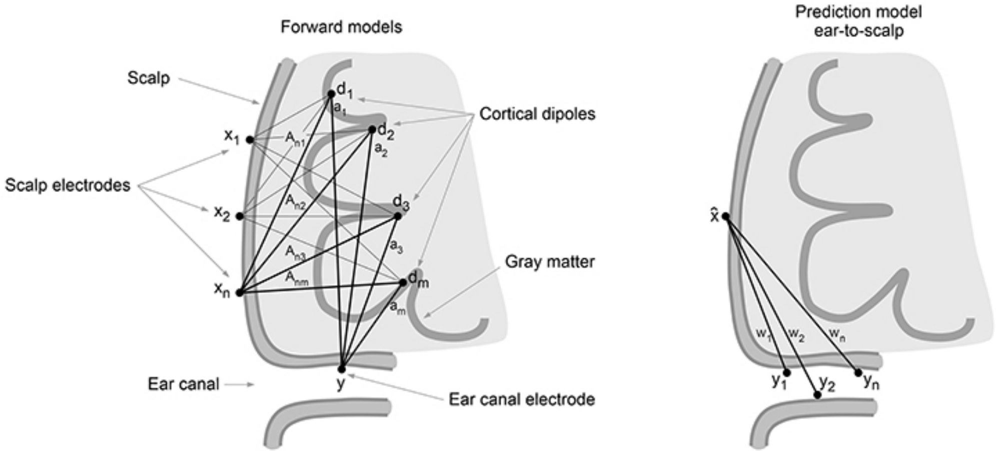
S.L. Kappel P. Kidmose. "High-density ear-EEG", IEEE Engineering in Medicine and Biology Society (2017).

Ear-EEG configurations





The keyhole hypothesis

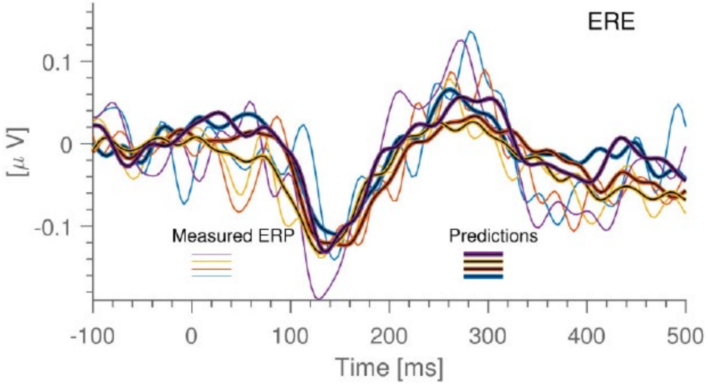


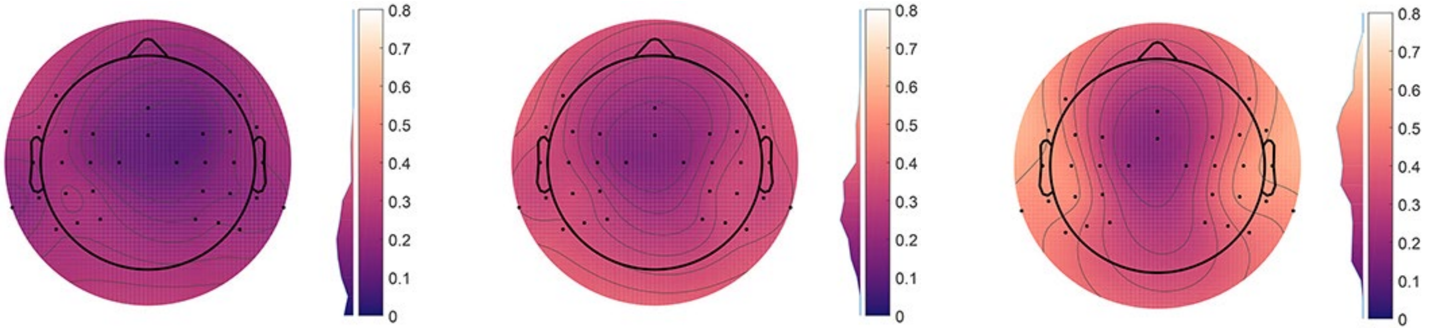
K. B. Mikkelsen, P. Kidmose, and L. K. Hansen. "On the keyhole hypothesis: high mutual information between ear and scalp EEG." Frontiers in Human Neuroscience (2017).

The keyhole hypothesis

The prediction model:
- generalizes over paradigms
- is stable over time and mental states
- can reconstruct ERPs
- can predict scalp topographies

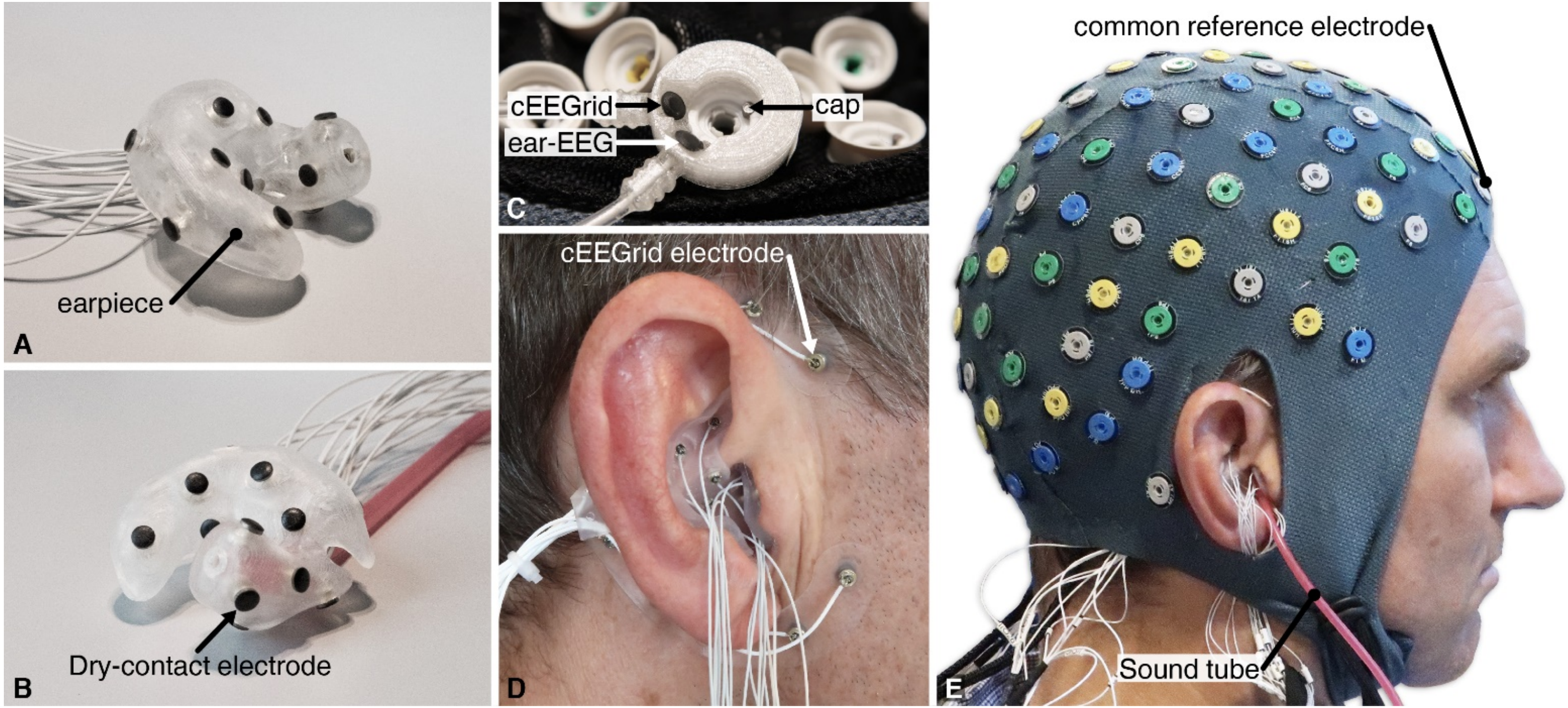
MMN – scalp based predictions of ear-EEG





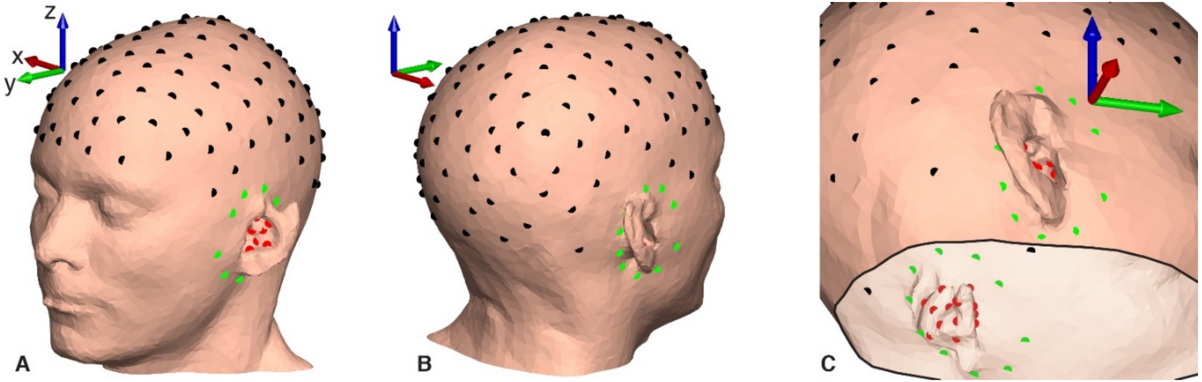
K. B. Mikkelsen, P. Kidmose, and L. K. Hansen. "On the keyhole hypothesis: high mutual information between ear and scalp EEG." Frontiers in Human Neuroscience (2017).

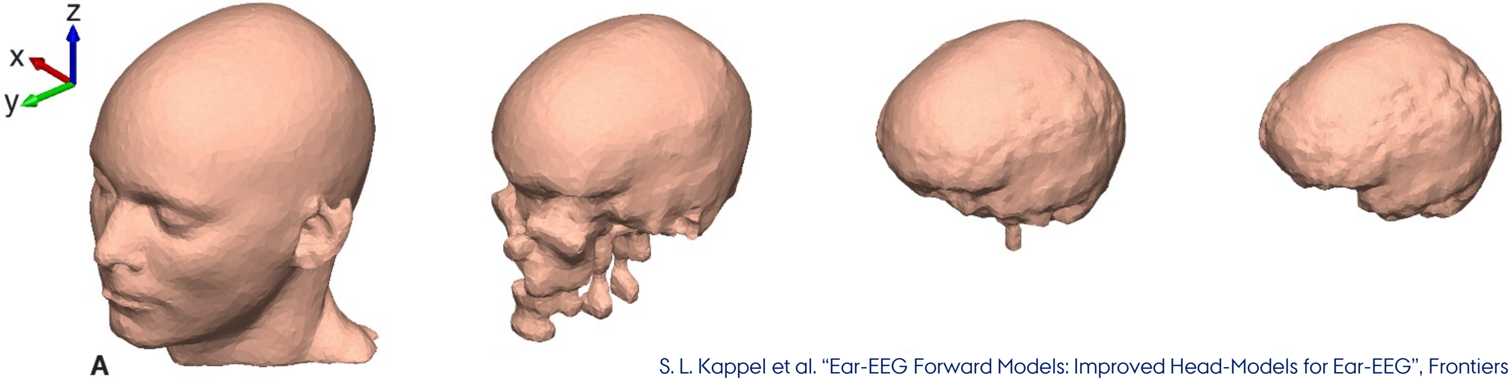
Experimental setup



S. L. Kappel et al. “Ear-EEG Forward Models: Improved Head-Models for Ear-EEG”, Frontiers in Neuroscience, 2019.

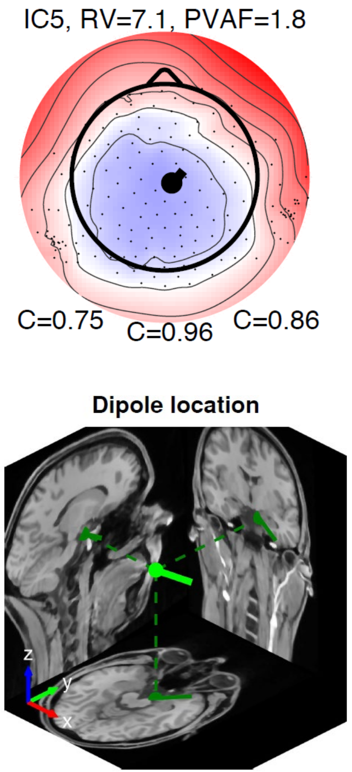
Forward model

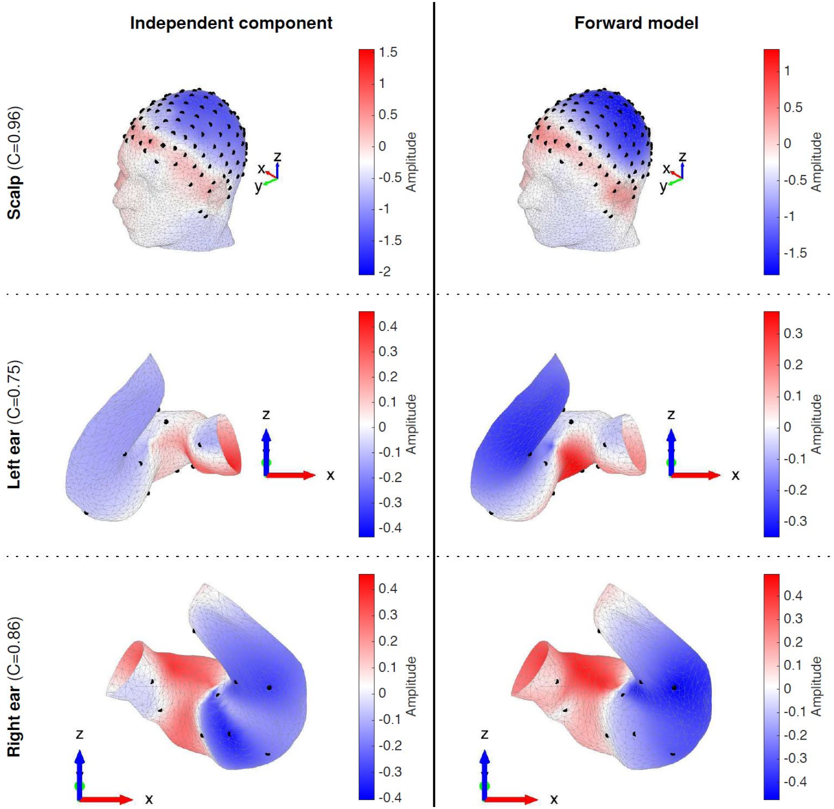




S. L. Kappel et al. "Ear-EEG Forward Models: Improved Head-Models for Ear-EEG", Frontiers in Neuroscience, 2019.

Validation of forward model





S. L. Kappel et al. "Ear-EEG Forward Models: Improved Head-Models for Ear-EEG", Frontiers in Neuroscience, 2019.

Sensitivity maps

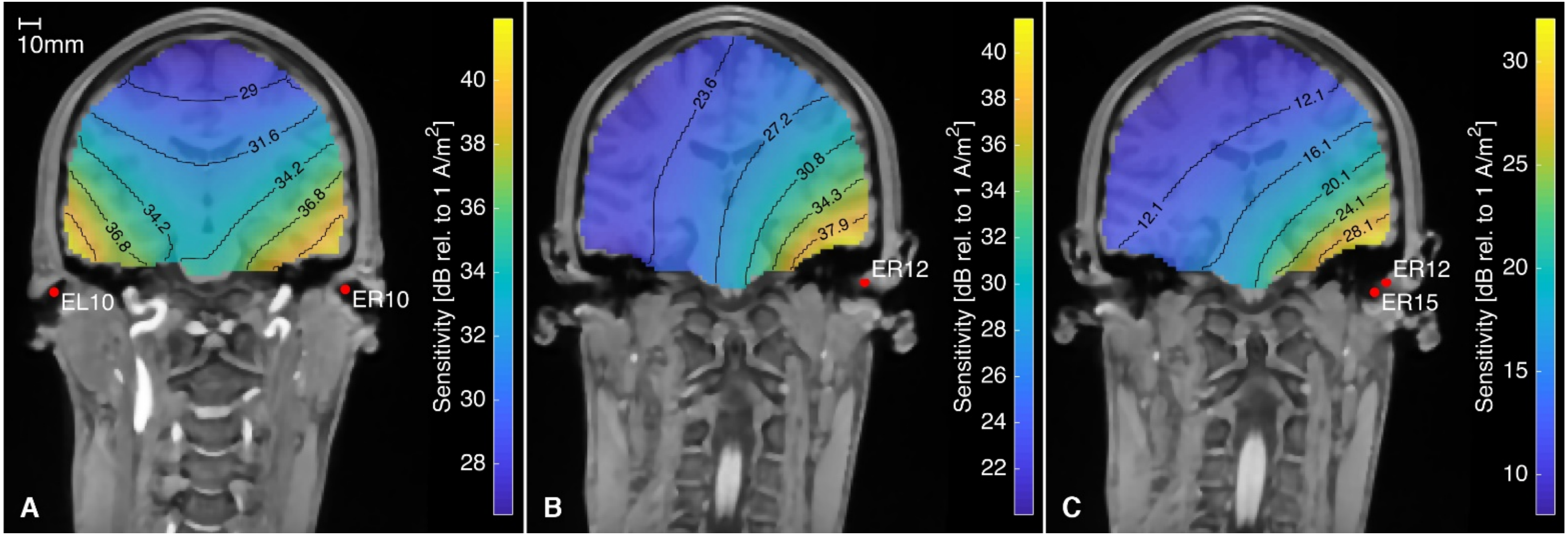
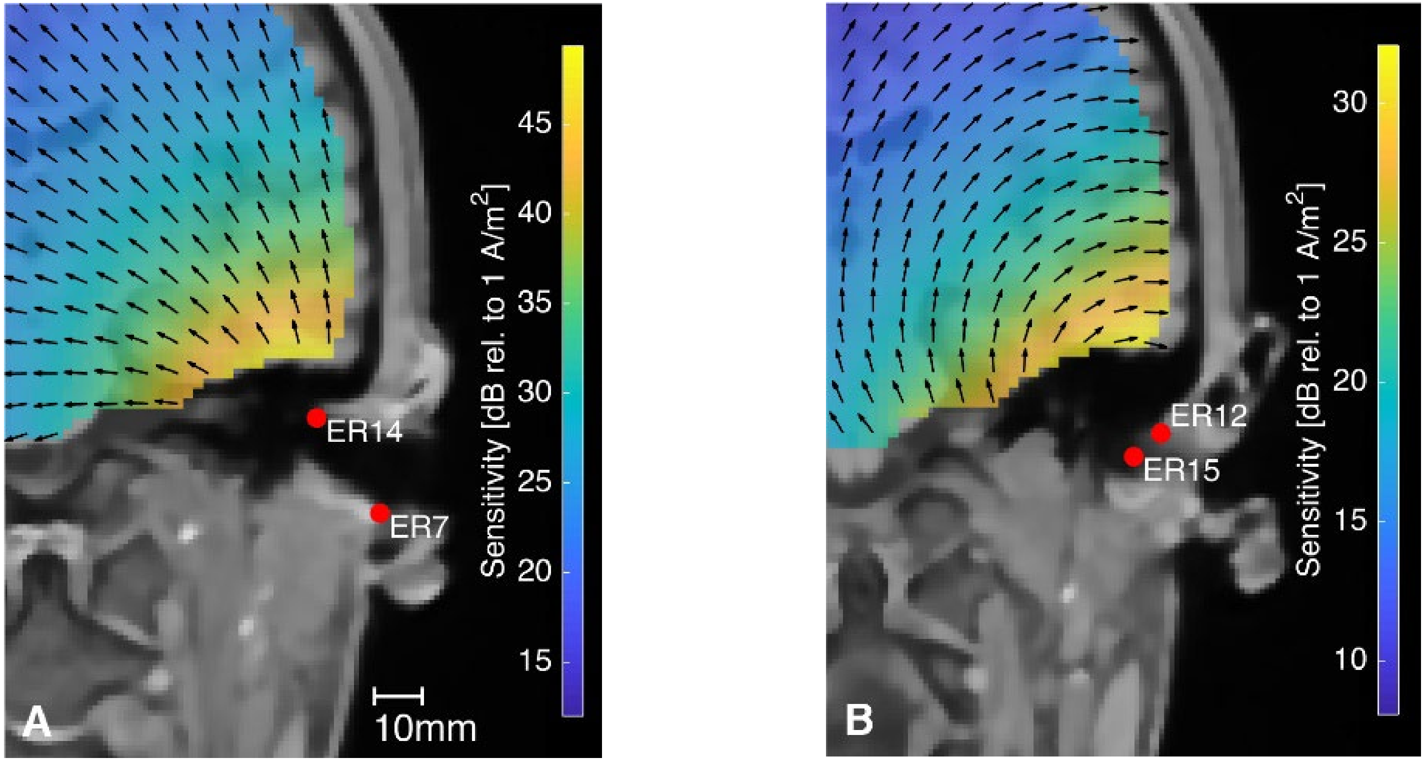


FIGURE 11 | The sensitivity distribution for different electrode configurations, based on an ear-EEG forward model for Subject C. **(A)** Between-ears electrode configuration, **(B)** Ear electrode to an infinite reference, **(C)** Within-ear electrode configuration.

S. L. Kappel et al. "Ear-EEG Forward Models: Improved Head-Models for Ear-EEG", Frontiers in Neuroscience, 2019.

Sensitivity maps

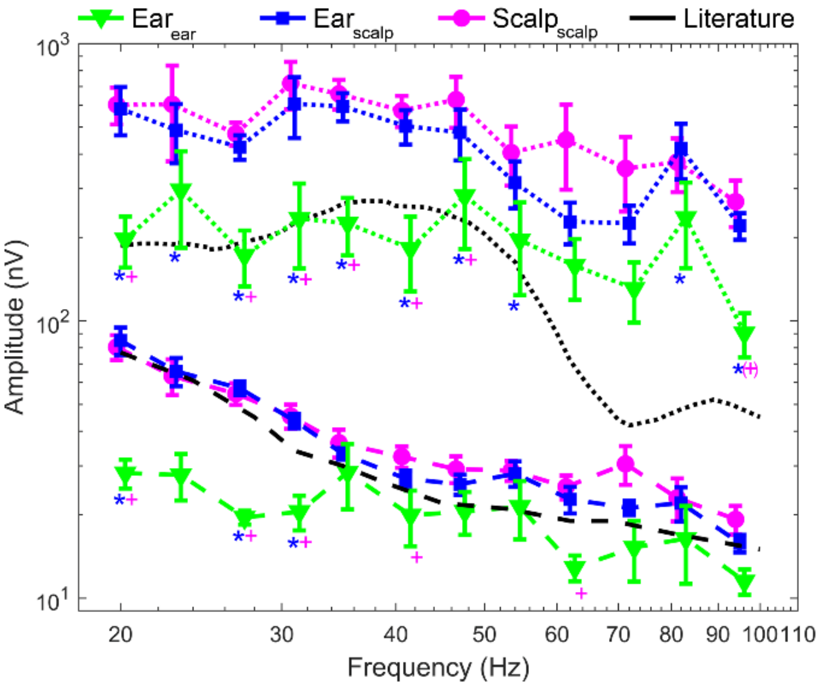


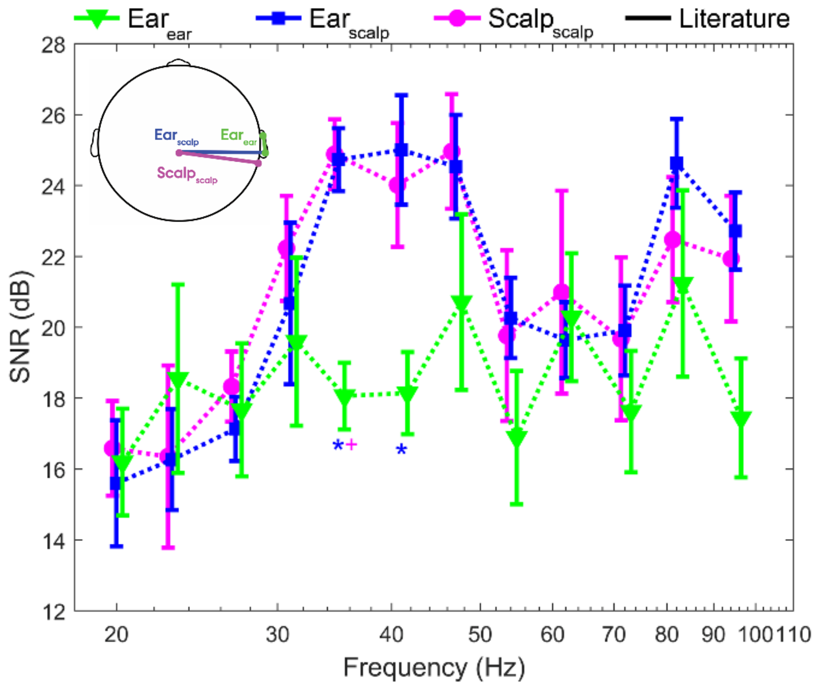
S. L. Kappel et al. "Ear-EEG Forward Models: Improved Head-Models for Ear-EEG", Frontiers in Neuroscience, 2019.

What can (potentially) be decoded from ear-EEG?

Neural processes		Examples
Sensory pathways (auditory pathway)	←	Auditory steady-state responses
Attention (auditory attention)		
Imagined processes	←	Rhythm perception
Oscillations	←	α-band modulation
Decision making / task related responses	←	P300 BCI (spelling matrix)
Sub-conscious / subliminal		
Syntax / Semantic / Context (language perception)		
Mental states	←	Sleep stages

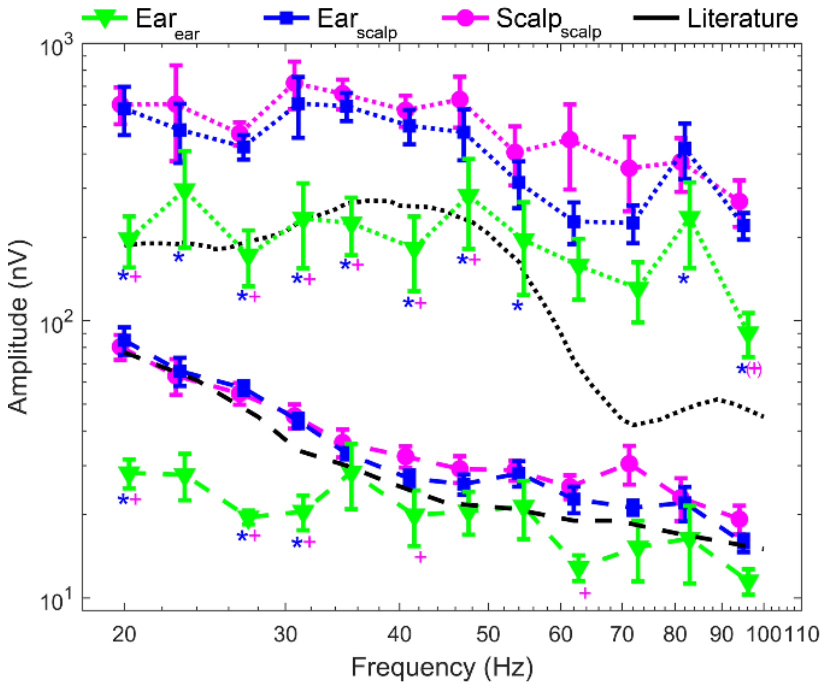
ASSR vs Repetition Rate

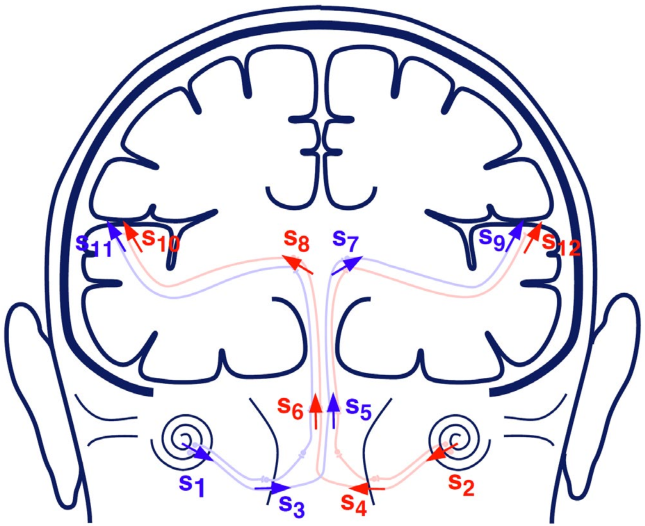




C. B. Christensen et al. “Auditory Steady-State Responses across Chirp Repetition Rates for Ear-EEG and Scalp EEG”, EMBC 2018.

ASSR Source Model

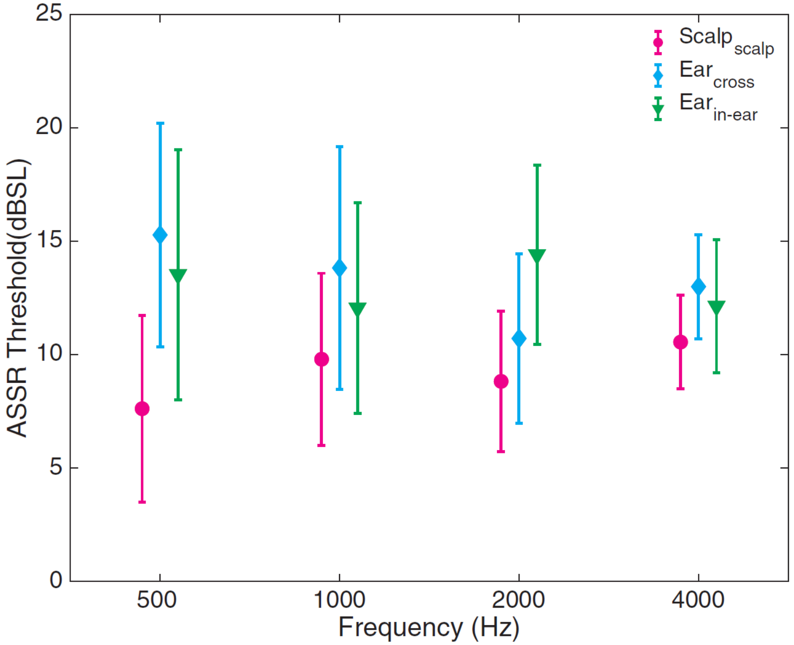


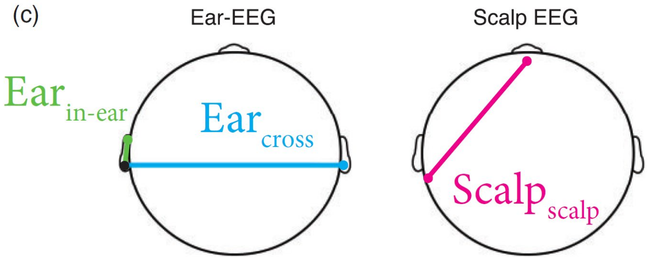


$$x_m(t) = \sum_{n=1}^{N} w_{m,n} a_n \cos(\omega_s t + \varphi_n)$$

$$= b_m \cos(\omega_s t + \varphi_m)$$

Hearing Threshold Assessment



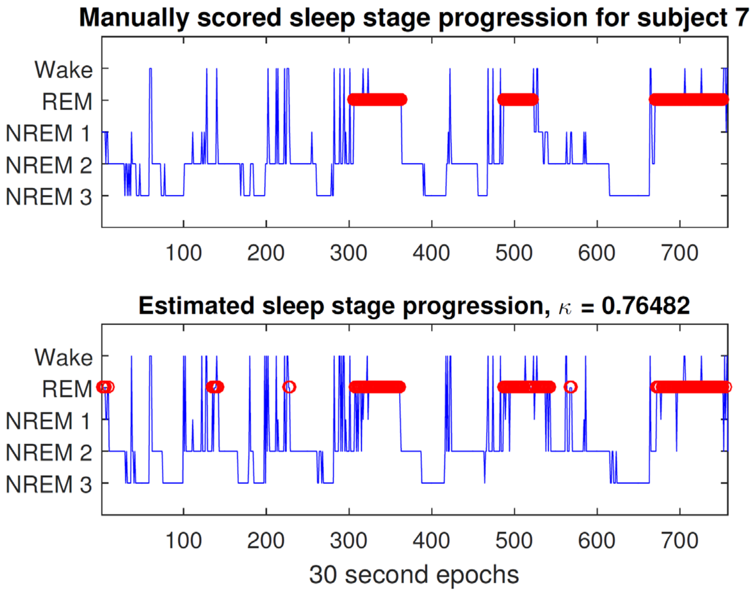


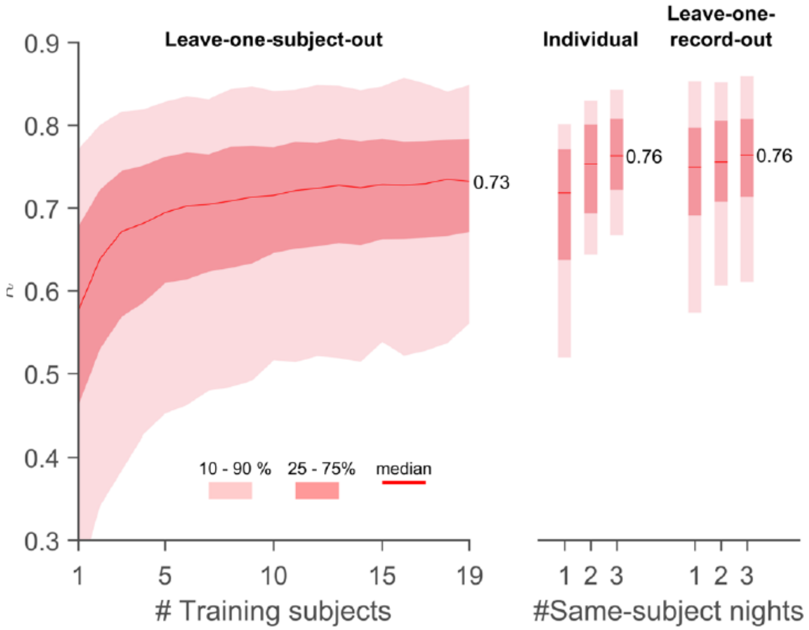
15 subjects with normal hearing (≤ 20 dB HL) and
19 subjects with sensorineural hearing loss (30 to 65 dB HL).

C. B. Christensen et al., "Ear-EEG based objective hearing threshold estimation evaluated on normal hearing subjects", IEEE Transactions on Biomedical Engineering, 2018.
C. B. Christensen et al. "Toward EEG-Assisted Hearing Aids: Objective Threshold Estimation Based on Ear-EEG in Subjects with Sensorineural Hearing Loss", Trends in Hearing, 2018.

Ear-EEG based Automatic Sleep Staging

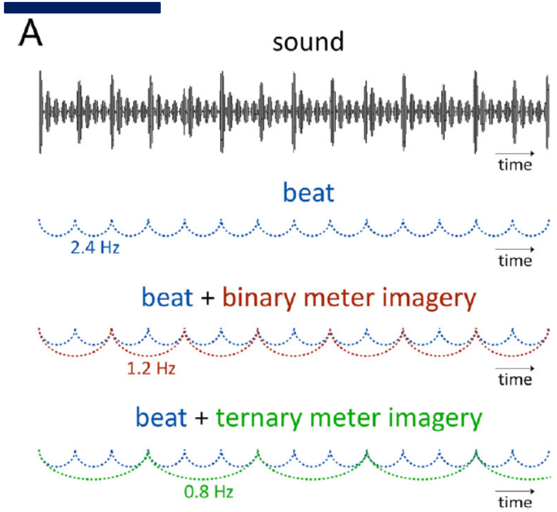
20 subjects, 80 full-night recordings.

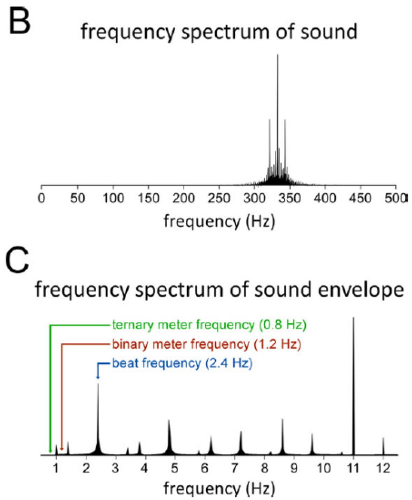


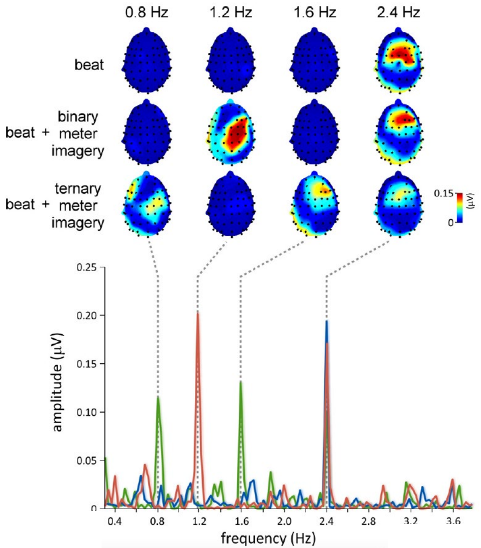


K. Mikkelsen et al., "Automatic Sleep Staging using Ear-EEG". Biomedical Engineering Online (2017).
K. Mikkelsen et al., "Accurate whole-night sleep monitoring with dry-contact ear-EEG." Scientific reports (2019).

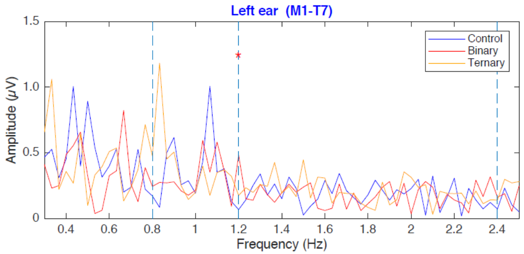
Beat perception

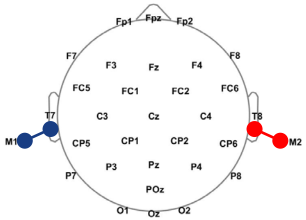


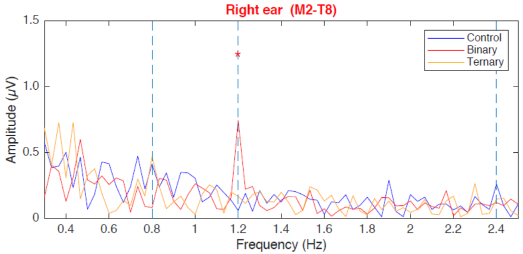




S. Nozaradan et al., "Tagging the neuronal entrainment to beat and meter", Journal of Neuroscience (2011).







Heidi Bliddal et al., pilot data, unpublished.

Example: P300 Brain-Computer Interface

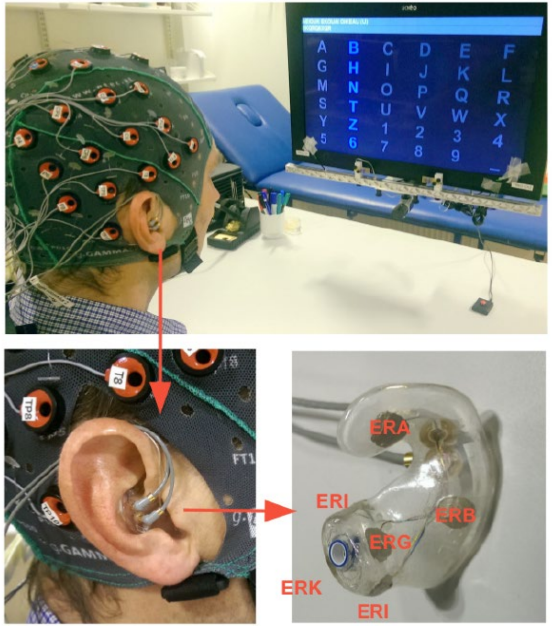
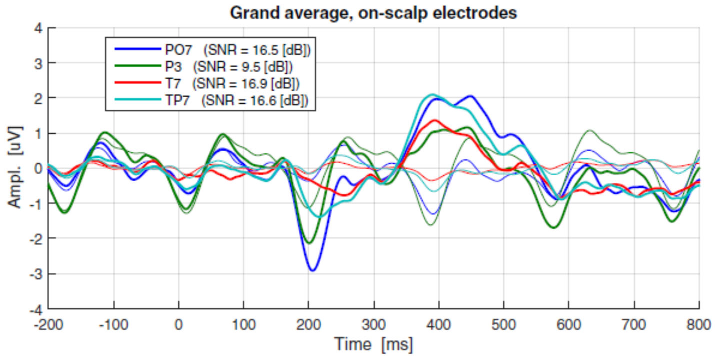
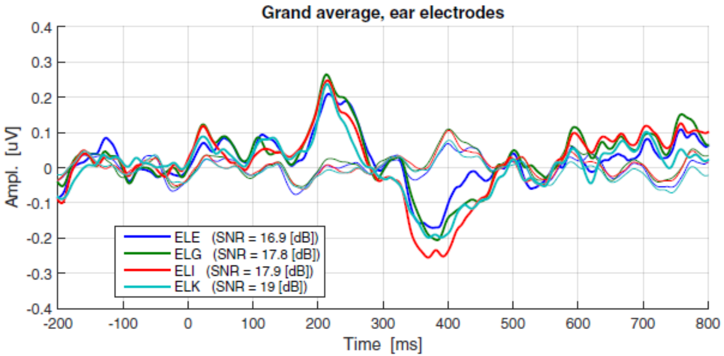


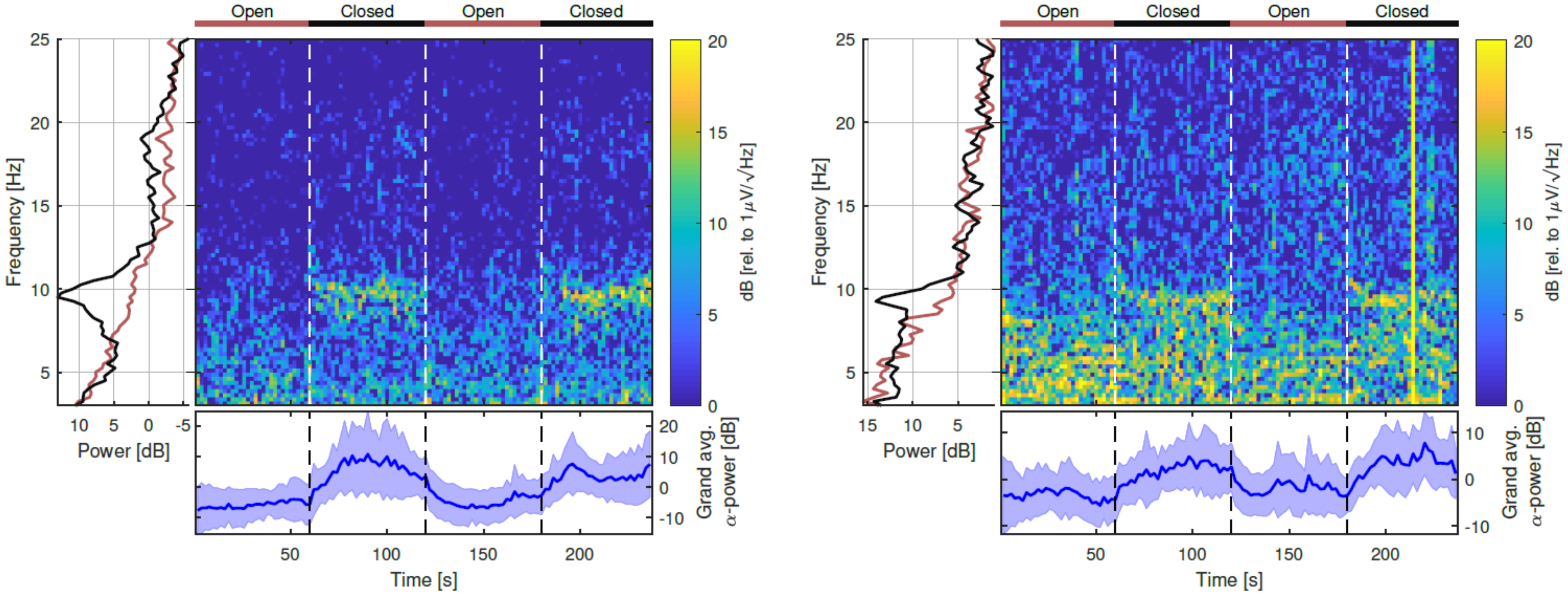
Fig. 1. The experimental setup. Top: subject equipped with EEG cap and EarEEG attending the visual paradigm on the screen. Lower left: earpiece placed in the ear; the visible cables connects the electrodes on the earpiece to the amplifier. Lower right: earpiece with electrodes; labels superimposed on the image indicates the electrode names.





F. Farooq and P. Kidmose, "EarEEG based visual P300 Brain-Computer Interface." IEEE Conference on Neural Engineering (2015).

Lab and real-life recording



(a) Lab, ear-scalp electrode configuration ELE-Cz

(b) Real-life, ear-scalp electrode configuration ELE-Cz

S. L. Kappel and P. Kidmose. "Real-life dry-contact ear-EEG", *EMBC* (2018).


.... thank you