Auditory Noise-Tagging

Workshop 3: Navigating the latest advancements in c-VEP BCI: From experimental paradigms to decoding techniques

Hanneke Scheppink
Radboud University & Donders Institute for Brain, Cognition and Behaviour
Data-Driven Neurotechnology Lab
Nijmegen, the Netherlands

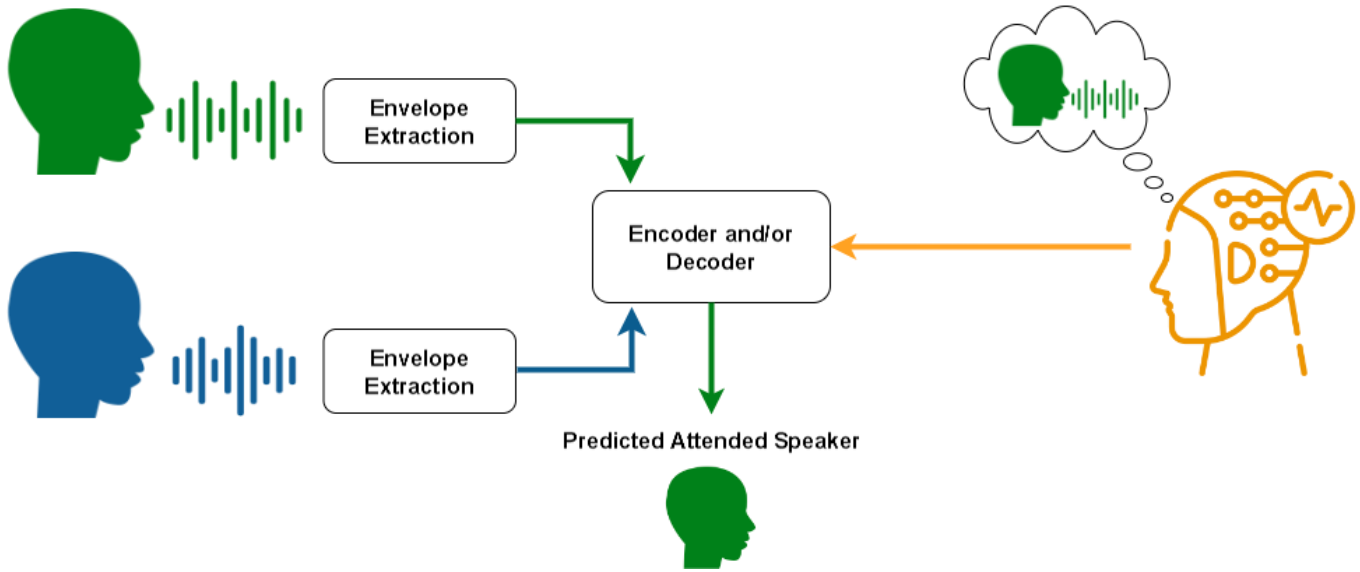
Radboud University

DONDERS INSTITUTE

AUDITORY NOISE-TAGGING

BACKGROUND

- Auditory attention decoding (AAD)



- Towards **neuro-steered hearing aids**

AUDITORY NOISE-TAGGING

BACKGROUND

Current state-of-the-art AAD[1]:

- 85% at 30s data window
- 80% at 10s

c-VEP BCIs:

- 100% within 1-4s (binary codes)[2]
- 100% within 300ms (white-noise codes)[3]

Can we use **noise-tagging for** AAD?

- Code-modulated auditory evoked potential (c-AEP)

[1] Geirnaert et al. (2021) *IEEE Signal Proc Mag* doi:10.1109/MSP.2021.3075932

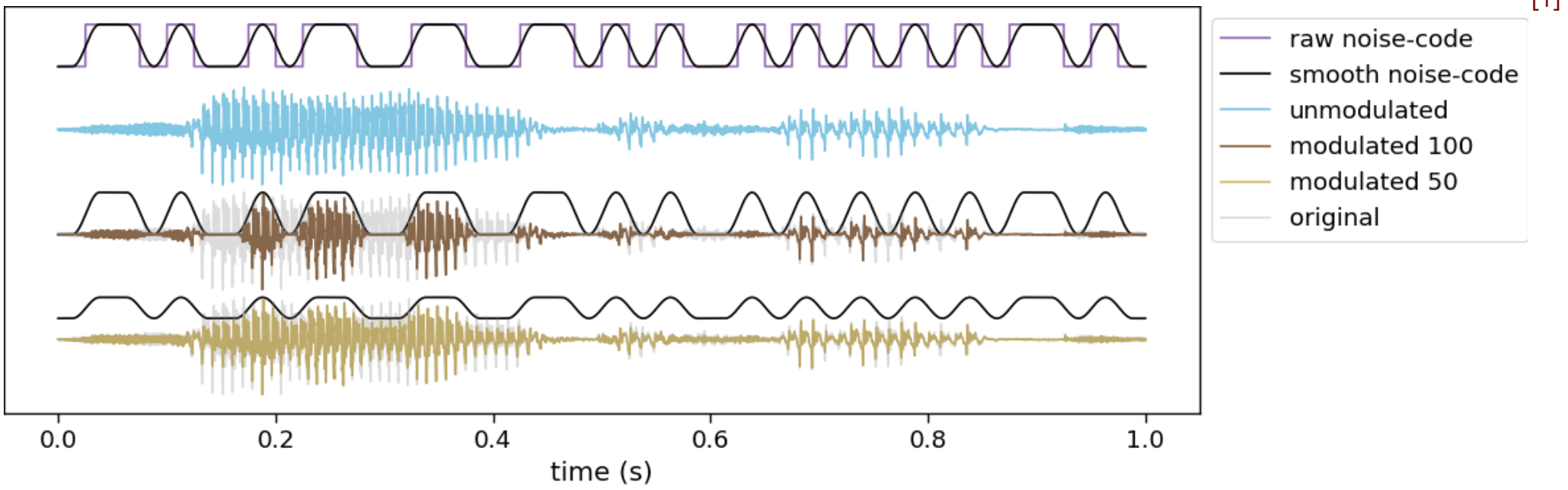
[2] Thielen et al. (2021) *J Neural Eng* doi:18(5):056007

[3] Shi et al. (2024) *NeuroImage* doi:10.1016/j.neuroimage.2024.120548

HOW TO USE NOISE-TAGGING FOR AAD

- Modulate the amplitude of the audio signal (speech)
- Different modulation depths

[1]



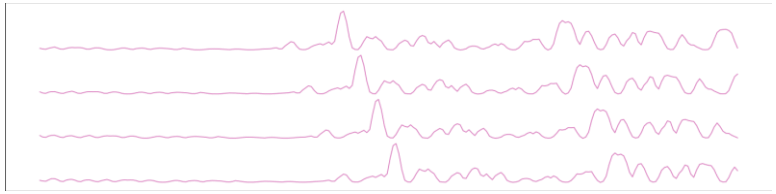
[1] Adapted from Scheppink et al. (2024)

AUDITORY NOISE-TAGGING

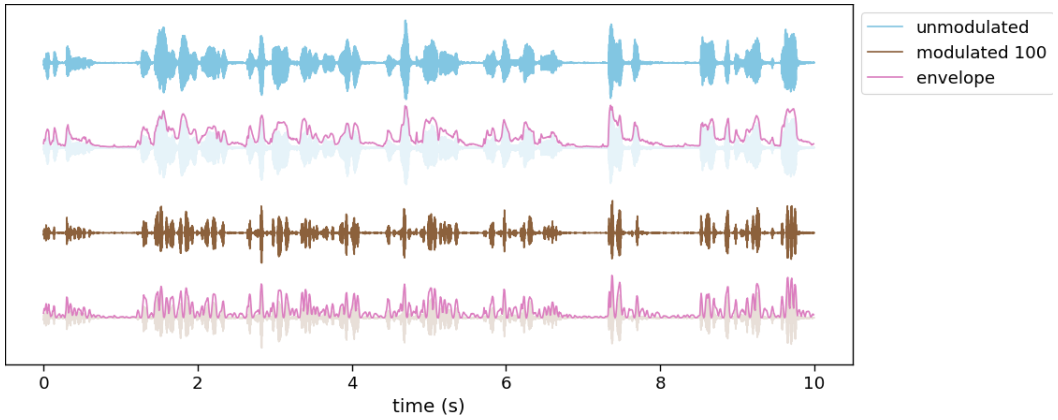
ANALYSIS

Envelope based CCA (eCCA)

- State-of-the-art in AAD
- $\mathbf{Z}_i = \mathbf{E}_i$



Reconvolution based CCA (rCCA)



$$\arg\max_{\mathbf{w},\mathbf{r}} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

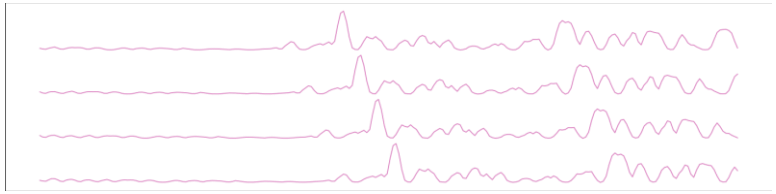
$$\hat{y} = \arg\max_{i} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

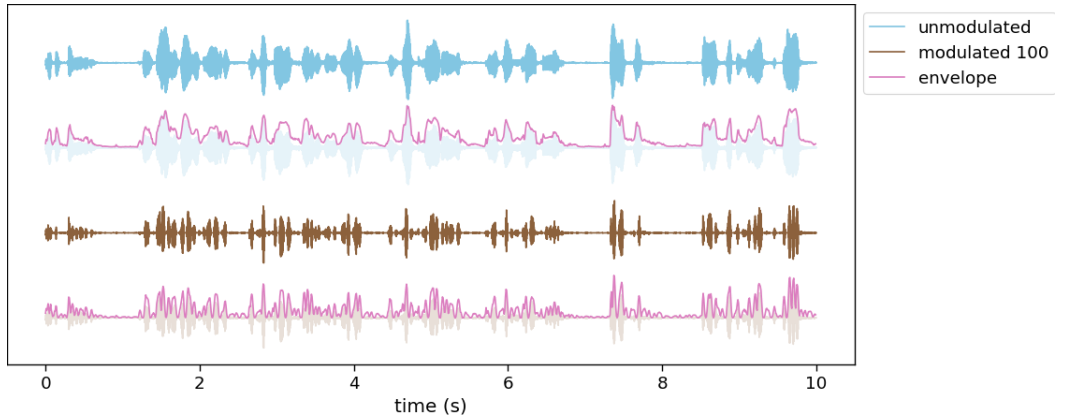
AUDITORY NOISE-TAGGING

ANALYSIS

Envelope based CCA (eCCA)

- State-of-the-art in AAD
- $\mathbf{Z}_i = \mathbf{E}_i$



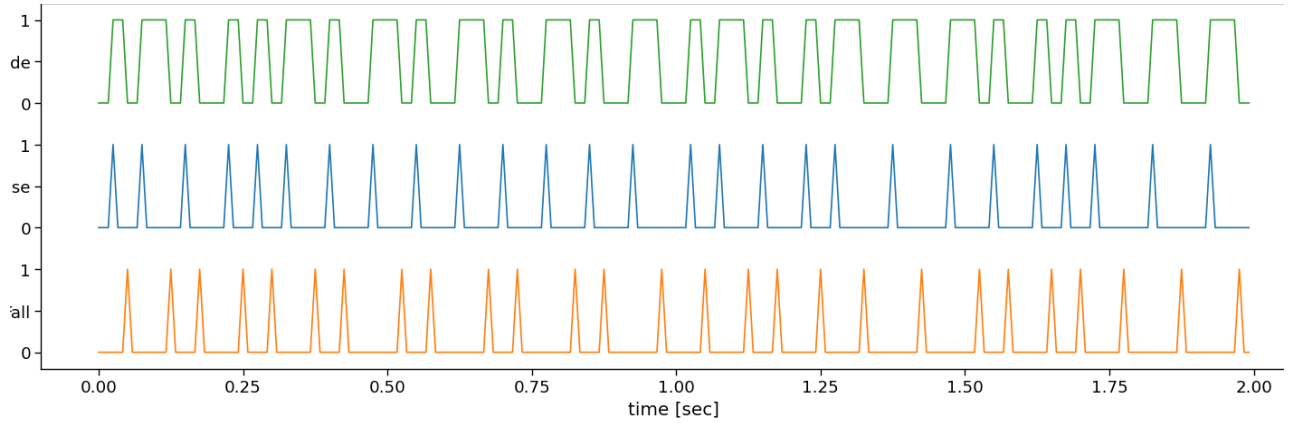


$$\arg\max_{\mathbf{w},\mathbf{r}} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

$$\hat{y} = \arg\max_{i} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

Reconvolution based CCA (rCCA)

- Originates from c-VEP domain
- $\mathbf{Z}_i = \mathbf{M}_i$

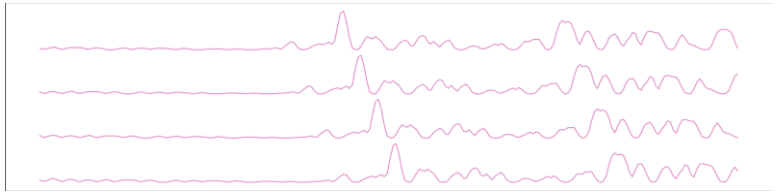


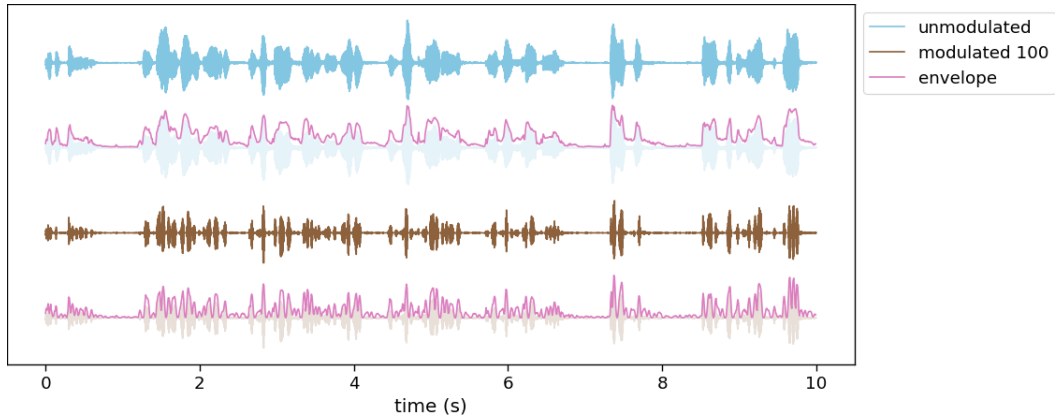
AUDITORY NOISE-TAGGING

ANALYSIS

Envelope based CCA (eCCA)

- State-of-the-art in AAD
- $\mathbf{Z}_i = \mathbf{E}_i$



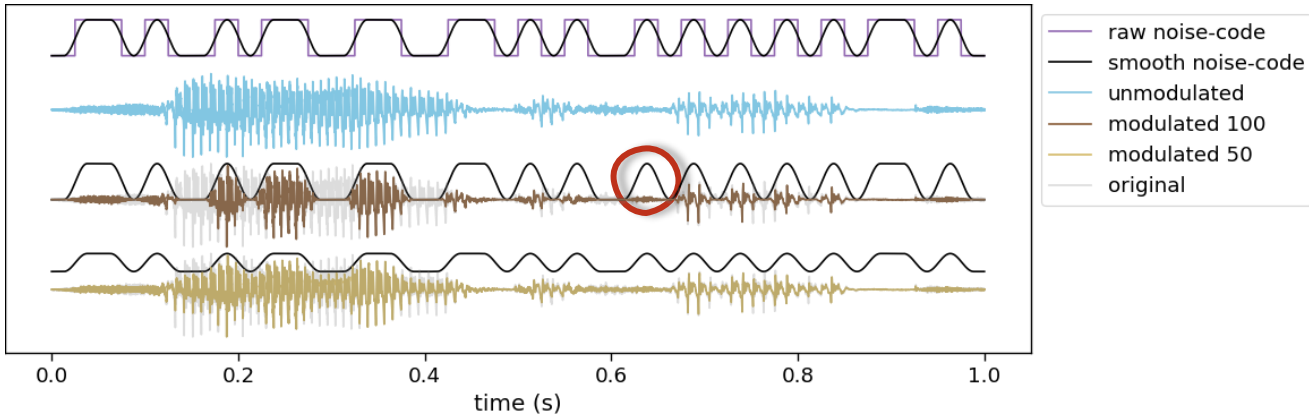


$$\arg\max_{\mathbf{w},\mathbf{r}} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

$$\hat{y} = \arg\max_{i} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

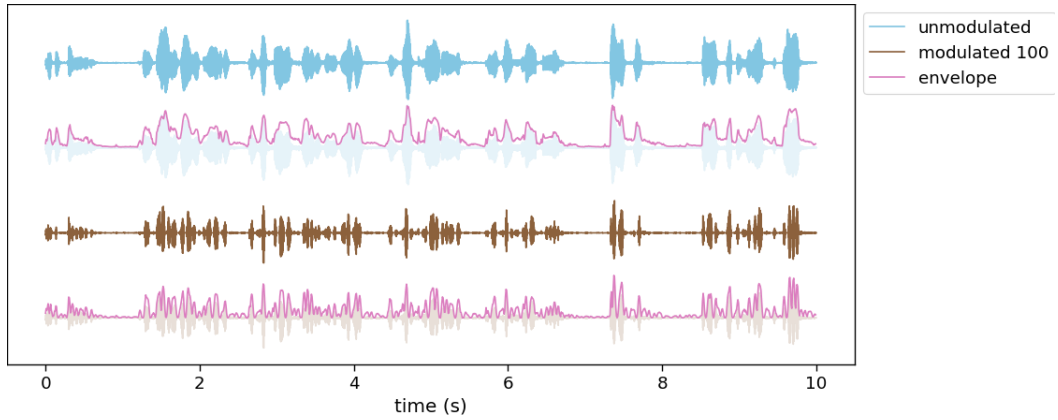
Reconvolution based CCA (rCCA)

- Originates from c-VEP domain
- $\mathbf{Z}_i = \mathbf{M}_i$



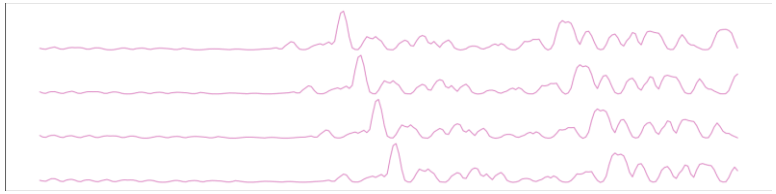
AUDITORY NOISE-TAGGING

ANALYSIS



Envelope based CCA (eCCA)

- State-of-the-art in AAD
- $\mathbf{Z}_i = \mathbf{E}_i$

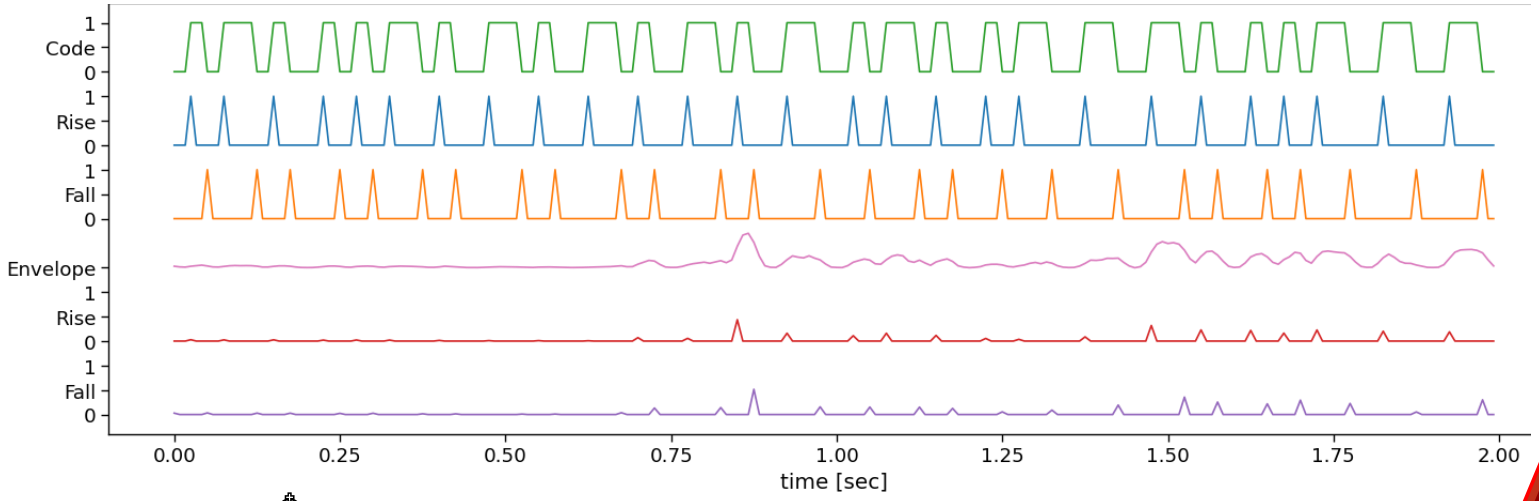


$$\arg\max_{\mathbf{w},\mathbf{r}} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

$$\hat{y} = \arg\max_{i} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

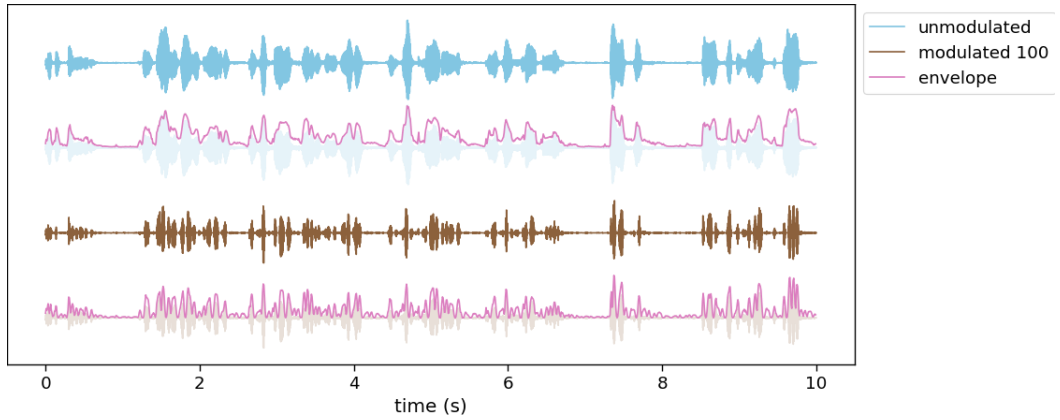
Reconvolution based CCA (rCCA)

- Originates from c-VEP domain
- $\mathbf{Z}_i = \mathbf{M}_i$



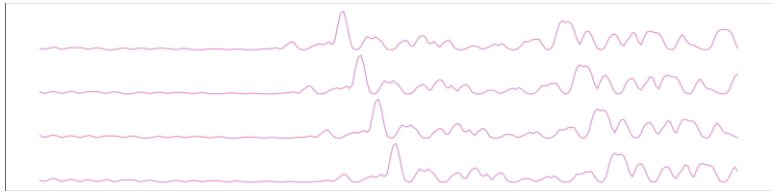
AUDITORY NOISE-TAGGING

ANALYSIS



Envelope based CCA (eCCA)

- State-of-the-art in AAD
- $\mathbf{Z}_i = \mathbf{E}_i$

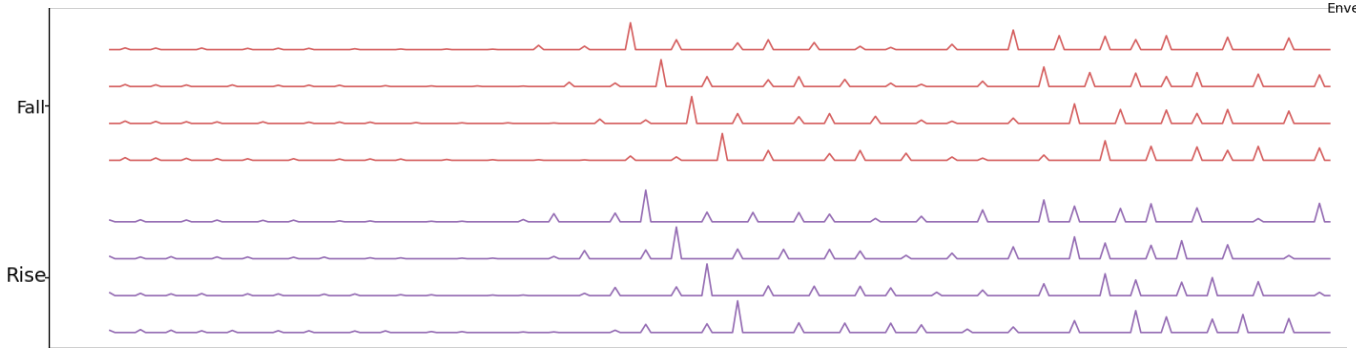


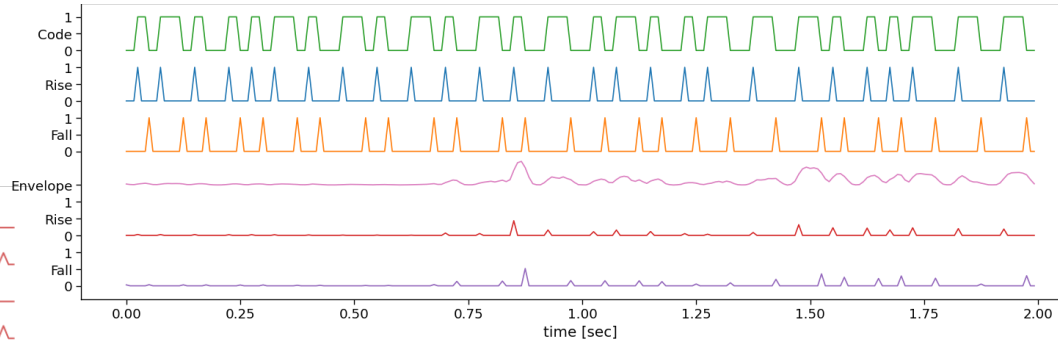
$$\arg\max_{\mathbf{w},\mathbf{r}} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

$$\hat{y} = \arg\max_{i} \rho(\mathbf{w}^\top \mathbf{X}, \mathbf{r}^\top \mathbf{Z}_i)$$

Reconvolution based CCA (rCCA)

- Originates from c-VEP domain
- $\mathbf{Z}_i = \mathbf{M}_i$

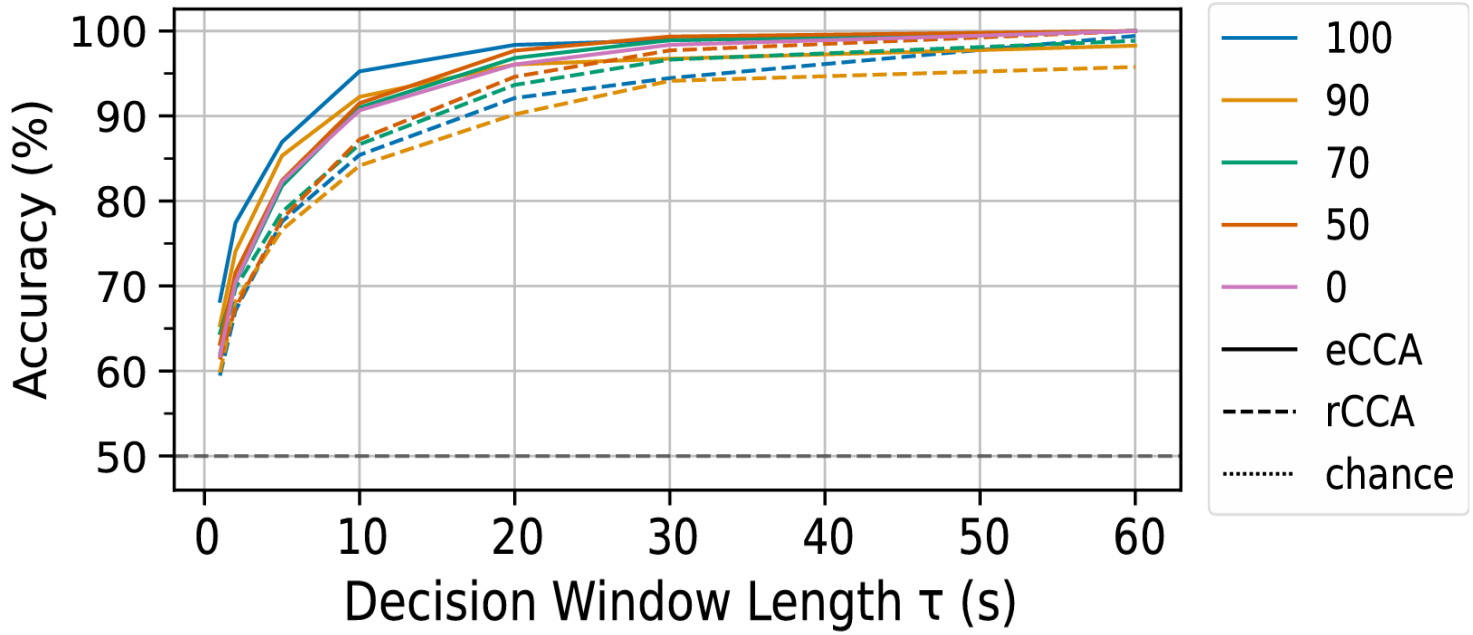




AUDITORY NOISE-TAGGING

MODULATED AUDIO PERFORMS BETTER THAN UNMODULATED

- Decoding is improved by noise-tagging for eCCA
- rCCA tries to find noise-tag; not optimal yet
- n = 5



AUDITORY ATTENTION DECODING IMPROVED WITH NOISE-TAGGING

Preliminary study

- Small sample size
- Sequential presentation

Future:

- Improve rCCA
  - Incorporate context and salience in events
  - Optimize hyperparameters
- Optimize codes for audio, e.g. speech

ACKNOWLEDGEMENTS

Data-Driven Neurotechnology Lab (neurotechlab.socsci.ru.nl)

- Jordy Thielen
- Michael Tangermann
- Sara Ahmadi

BCI lab

- Peter Desain

Join the Data-Driven Neurotechnology Lab @ Donders Institute
Let's leverage machine learning techniques to enhance brain-computer interfaces! If you are interested also in the psychology of learning and self-introspection, then join our team and the European Doctoral Network DONUT as **PhD candidate**!

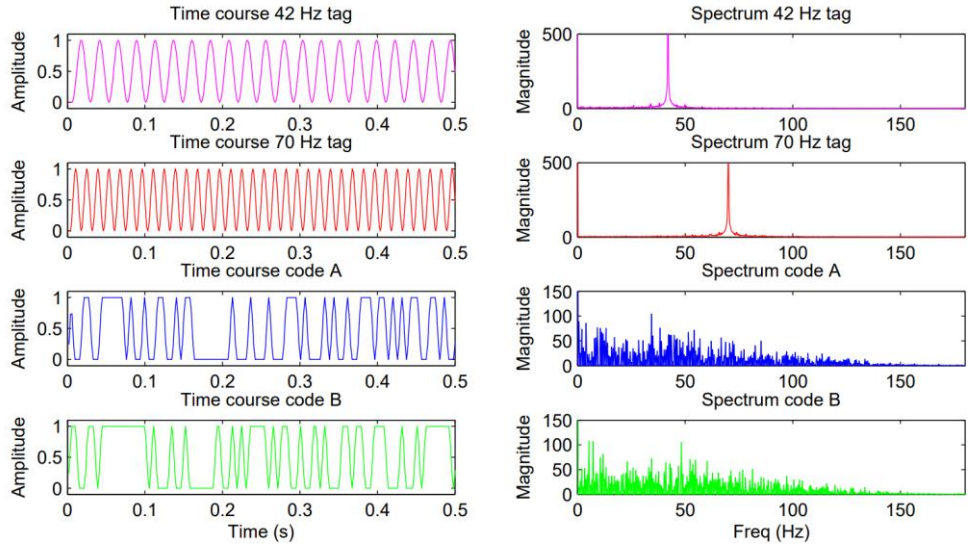
Primer on posters:

- 64 (Tue): Towards gaze-independent c-VEP BCI: A pilot study
- 61 (Thu): Exploring new territory: Calibration-free decoding for c-VEP BCI
- 63 (Thu): Towards auditory attention decoding with noise-tagging: A pilot study

AUDITORY TAGGING

Farquhar et al. (2008)

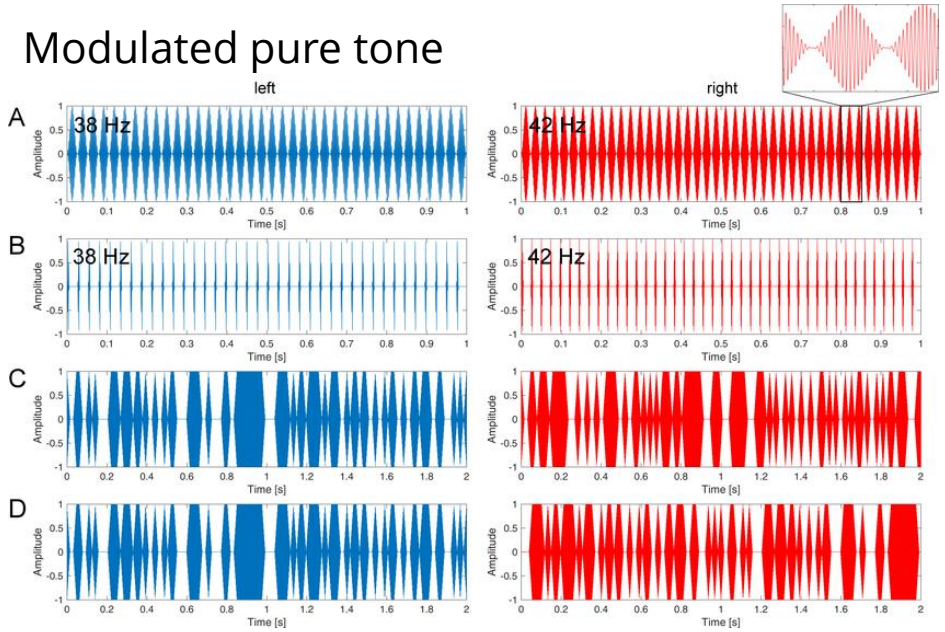
- Modulated saw-tooth tone



- Decoding performance 56% (vs 64%)
- n = 3

Spüler et al. (2018)

- Modulated pure tone



- Decoding performance; 54% (vs 51% SSAEP)
- Alpha band lateralization; 71.8% (vs 70.7% SSAEP)
- n = 10