A visual Brain-Computer Interface for gaze-free communication

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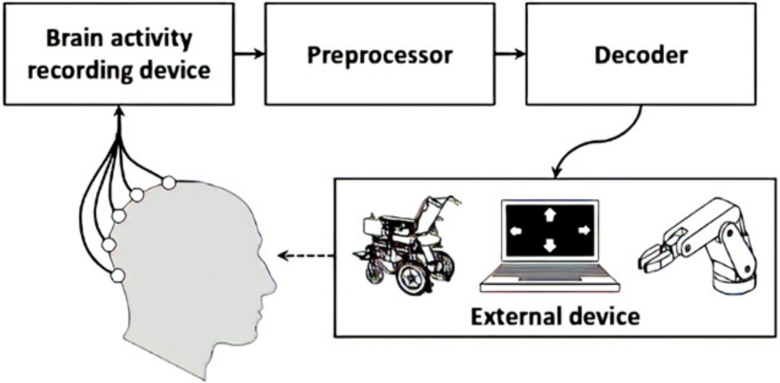
The Locked-in Syndrome: a functioning mind trapped in a paralyzed body

Severe paralysis leads to **Locked-in Syndrome**, due to

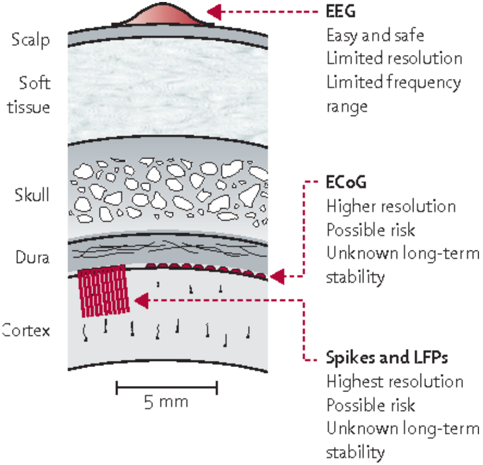
- Stroke
- Traumatic brain injury
- Neurodegenerative diseases
- . . .

Communication requires **assistive technology**

A solution: the Brain-Computer Interface (BCI)

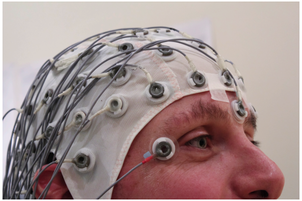


Recording the brain activity

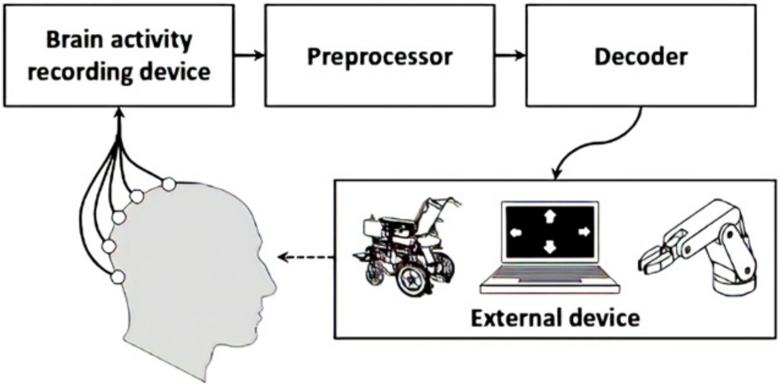


EEG measures the electrical field on the scalp: noise and some brain activity

+ Non-invasive
+ Cheap
+ No durability issues
- Limited resolution
- Low signal-to-noise ratio



The visual event-related potential paradigm



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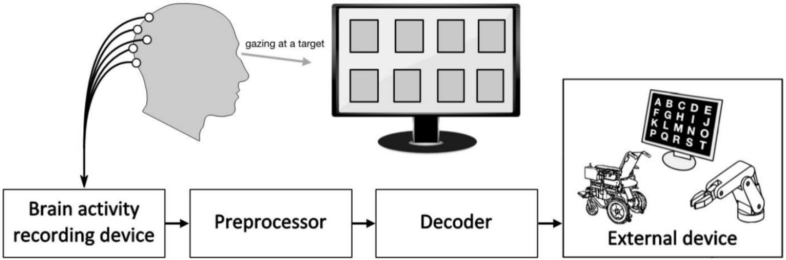
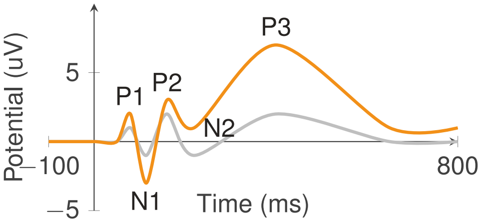
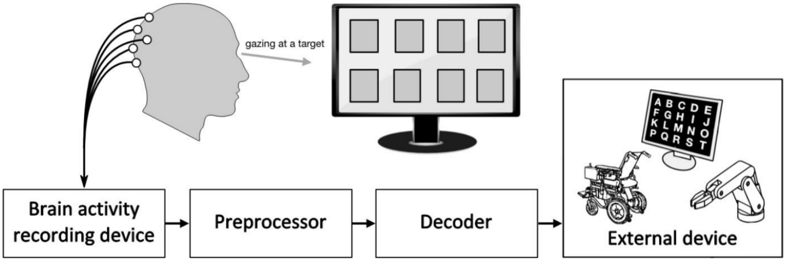


The visual event-related potential paradigm





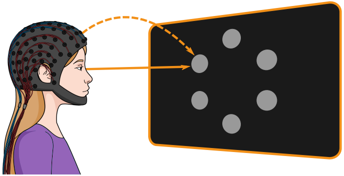
Problem: Eye motor impairment prevents gazing at targets

Visual skills related to disease affect BCI operation

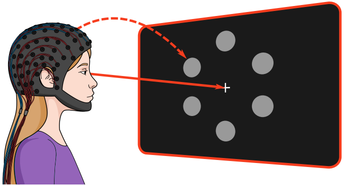
Fried-Oken et al., 2020

- Visual fixation
- Eyelid function
- Ocular motility
- Binocular vision
- Involuntary movement
- Field of vision

Overt visuospatial attention

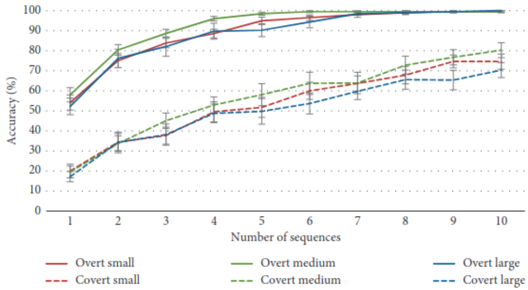


Covert visuospatial attention

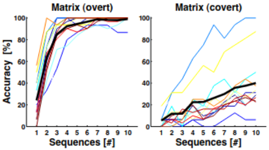


Covert attention decoding performs poorly

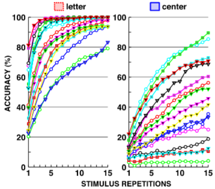
- Multi-target, spatial interfaces
- Long established, not solved
- Accuracy at or below usability threshold of 80%



Brunner et al., 2010



Treder and Blankertz, 2010



Ron2019

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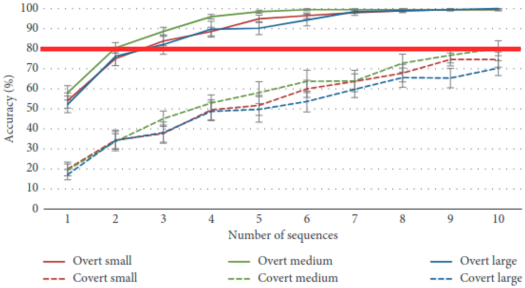

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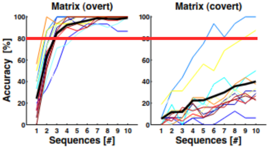

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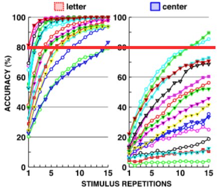


Ron2019

Balance the bandwidth of a **visual ERP BCI** with the needs of individuals with **eye motor impairment** through **improving decoding** of covert attention.

A visual Brain-Computer Interface for gaze-free communication

Introduction

C1: General ERP decoding algorithms

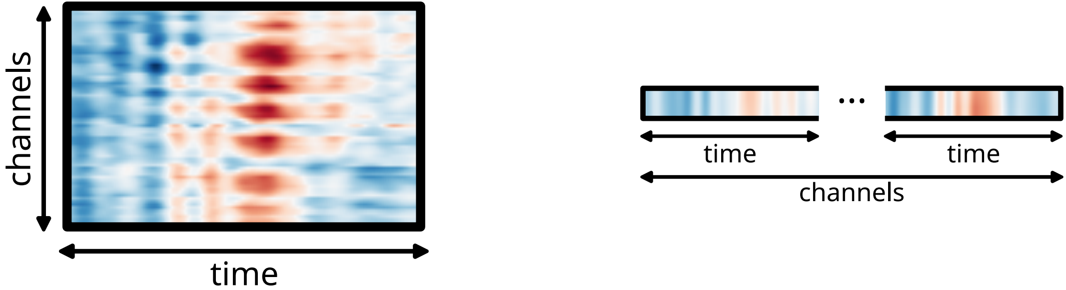
C2: Gaze-independent ERP decoding

C3: End-user case studies

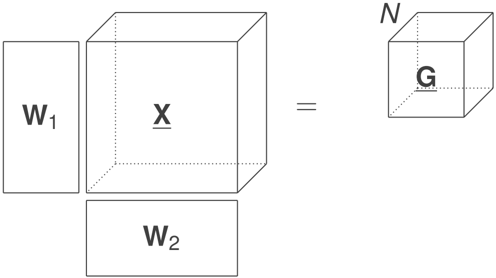
Conclusion

A visual Brain-Computer Interface for gaze-free communication

Exploit channel-time structure of ERP data for regularization



Higher-order discriminant analysis

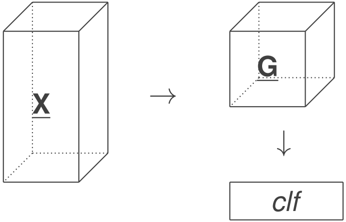


$$\underline{\mathbf{G}} = \underline{\mathbf{X}} \times_1 \mathbf{W}_1 \cdots \times_{K-1} \mathbf{W}_{K-1}$$

s.t. $\underline{\mathbf{G}}$ is maximally **discriminant** between classes.

HODA and the Tucker tensor core model

Tucker model



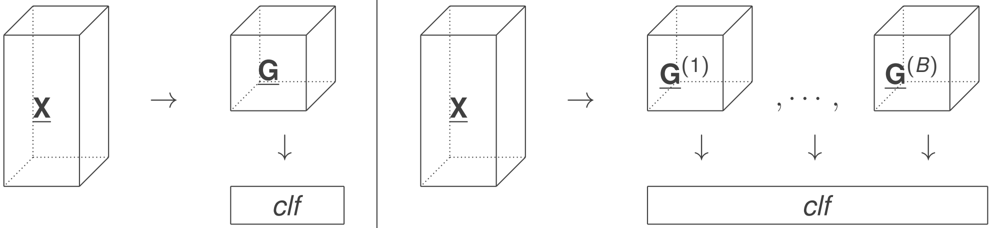
Strong assumptions
on data structure

+ Efficient
+ Regularizing constraints
+ Increased flexibility

– ~~Redundant features~~
– ~~More parameters to tune~~

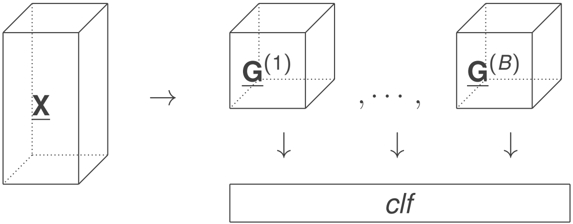
Towards a Block-Term Tensor model

Tucker model | **Block-Term Tensor** model



Block-term Tensor Discriminant Analysis

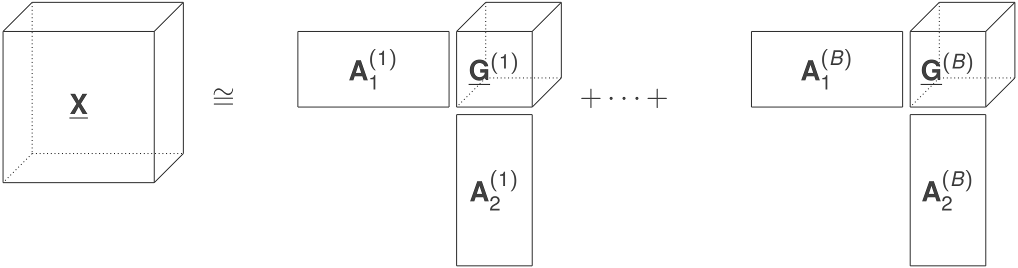
Block-term Tensor model



Weaker assumptions on data structure

- \+ Efficient
- \+ Regularizing constraints
- – ~~Manual rank selection~~
- – ~~Redundant features~~
- – ~~Cannot model full covariance structure~~

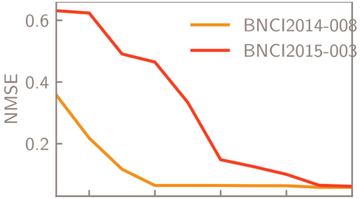
Block-term tensor model through deflation

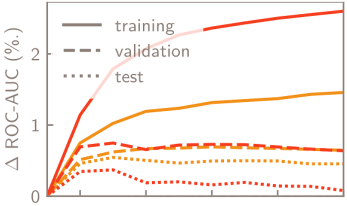


Deflation scheme:

$$\underline{\mathbf{X}}^{(b+1)} = \underline{\mathbf{X}}^{(b)} - \underline{\mathbf{G}}^{(b)} \times_1 \mathbf{A}_1^{(b)} \cdots \times_K \mathbf{A}_K^{(b)}$$

BTTDA oupterforms HODA on benchmark datasets





Pipelines	BNCI2014-008	BNCI2015-003
ERPCov+MDM	74.30±9.77	76.79±10.95
ERPCovSVD+MDM	75.42±9.91	76.93±11.26
XDAWNCov+MDM	77.62±9.81	83.08±7.55
XDAWN+LDA	82.24±5.26	78.62±7.19
XDAWNCov+TS+SVM	85.61±4.43	82.95±8.57
HODA+LDA	83.25±6.25	82.57±7.52
PARAFACDA+LDA	86.19±4.62	84.85±7.93
BTTDA+LDA	**86.43±4.51**	**85.08±7.36**

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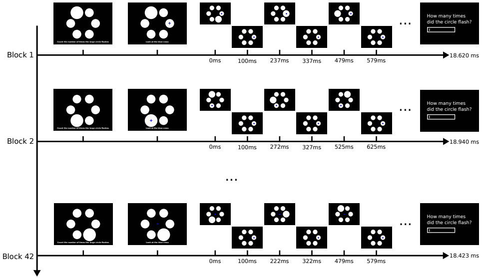
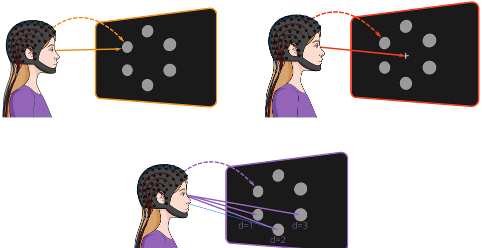
Covert attention ERP data collection



CVSA-ERP dataset

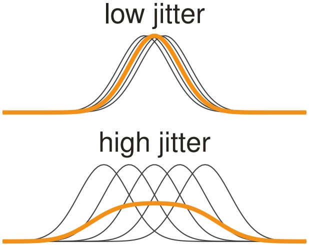
- $N = 15$
- ISI=300 $\pm$ 100 ms
- $\pm$11,25h recoded stimulation,
- 3 conditions based on gaze and attention cue

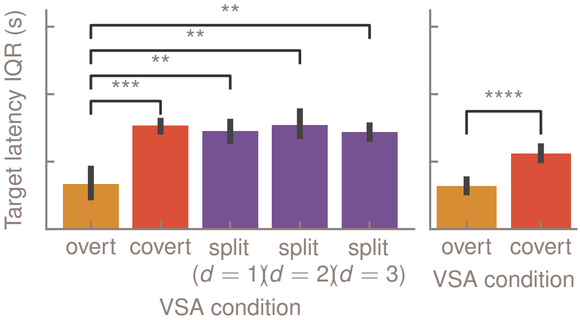


Grand average ERPs

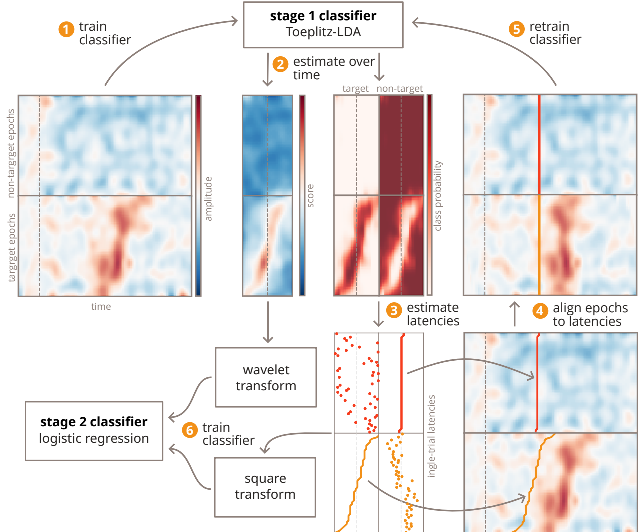
TODO: grand average ERPs and F-scores

Latency jitter decreases performance in covert and split attention Aricò et al., 2014





Classifier-based Latency Estimation with Woody iterations



Aligned vs. non-aligned simulated data

Increase in gaze-independent decoding accuracy

A visual Brain-Computer Interface for gaze-free communication

Experimental setup

- show setup
- list participants

Impaired visual skills

show table

Gaze tracking analysis

highlight specific gaze case

Usability

how many achieved higher than chance?