Simultaneous EEG recordings

a BCI application

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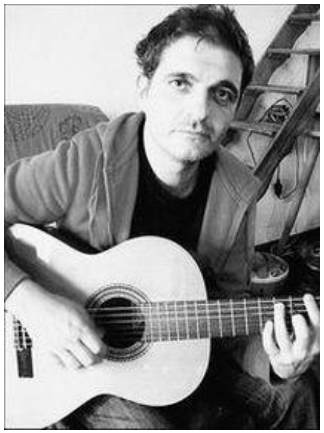
Grenoble | images | parole | signal | automatique | laboratoire

SCCN 8th June 2016

GIPSA-lab - EEG Hyperscanning : Methods

Prof. Christian Jutten



Dr. Marco Congedo

Michael Acquadro
PhD

Paolo Zazini
PhD

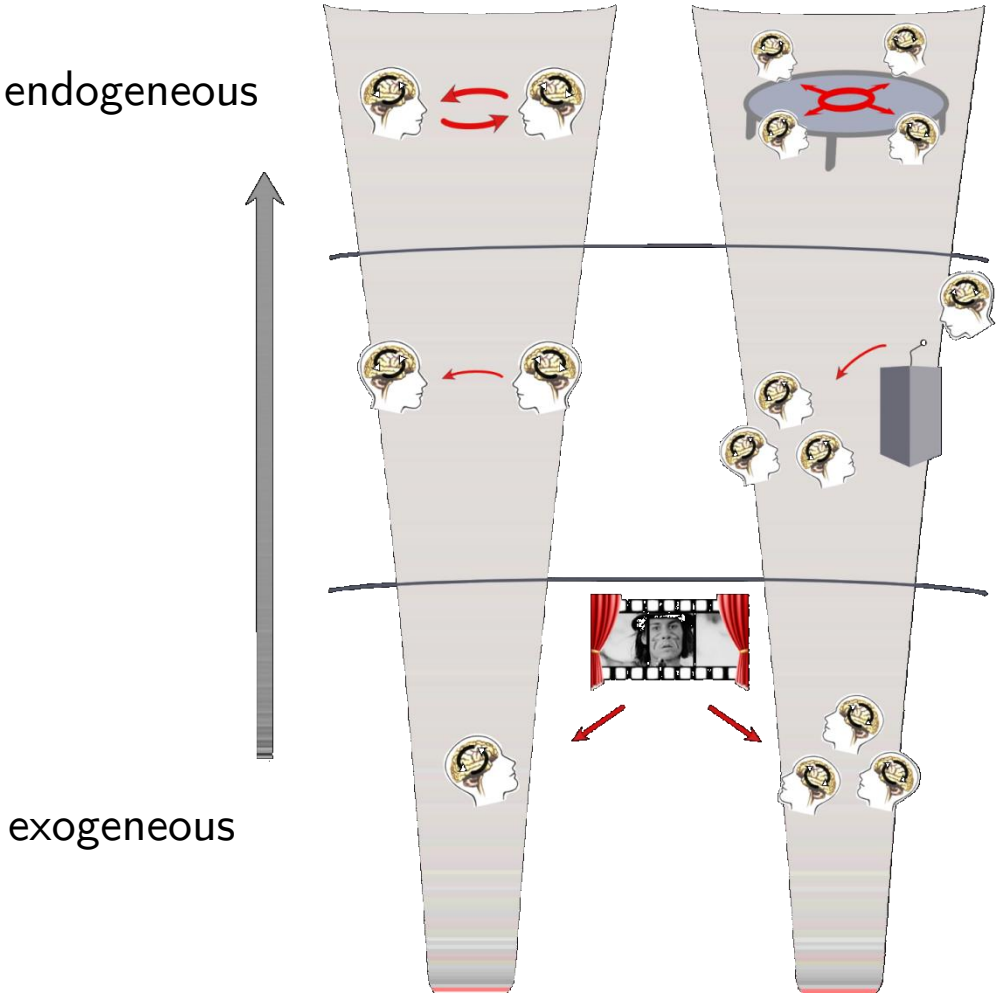
Florent Bouchard

Summary

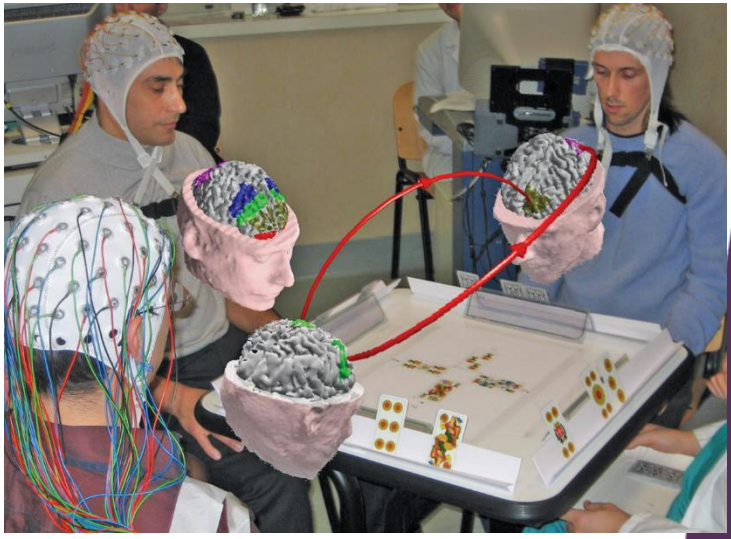
1. Hyperscanning
2. Multi-User BCI
3. ERP sources by AJD
4. Discussion
5. Complementary Materials

Hyperscanning

What are we searching ?

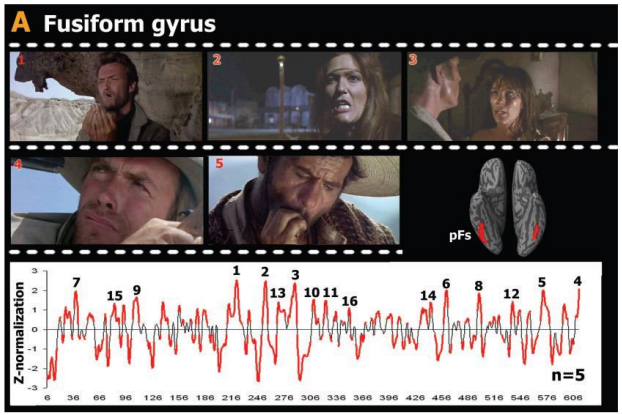


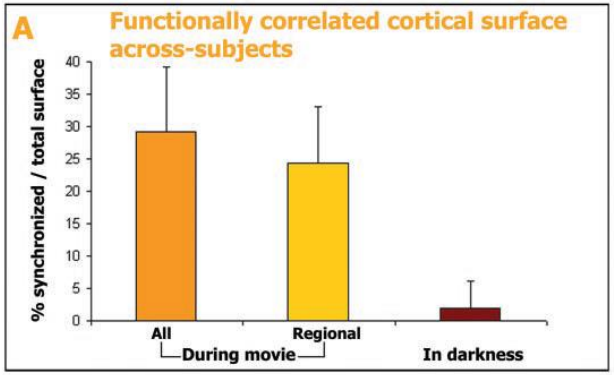
Adapted from Chatel-Golman, et al. 2014 [1]

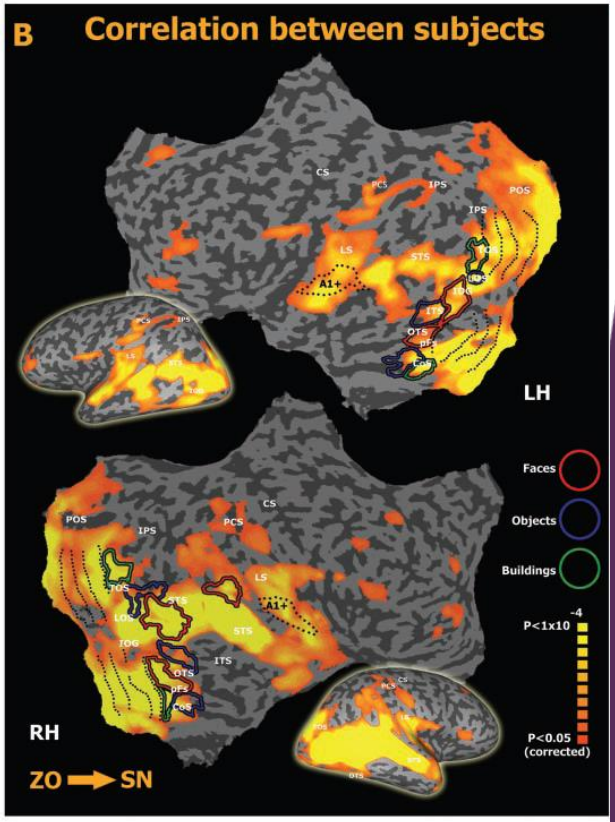


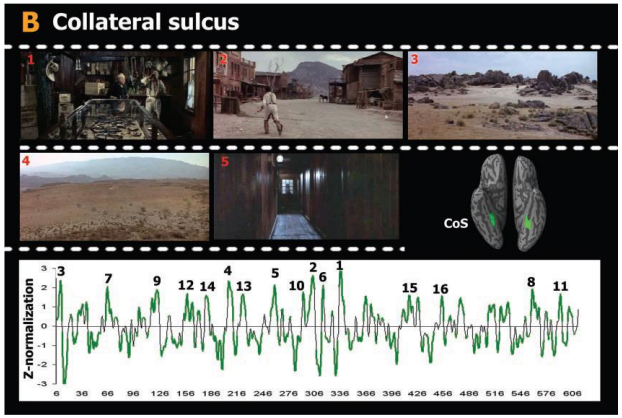
Babiloni et al. 2007 [2]

Stimulus to Brain Coupling







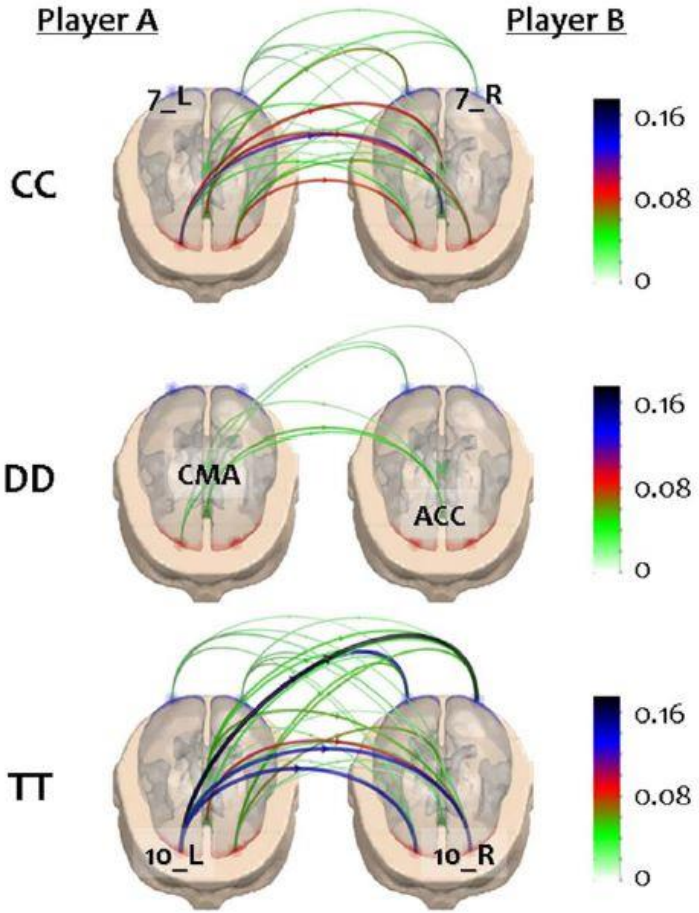


- Cortical Surface :

Almost **30%** functionally correlated

Hasson et al. 2004 [3]

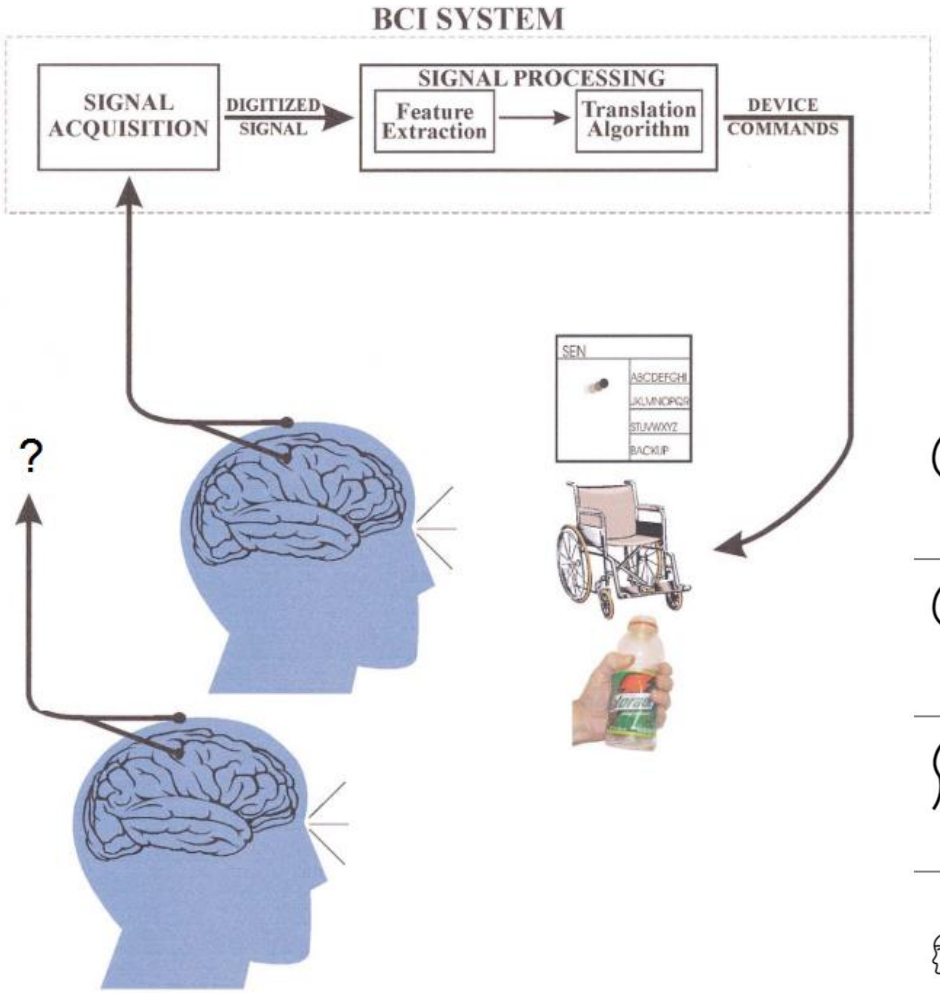
Social interaction induced coupling



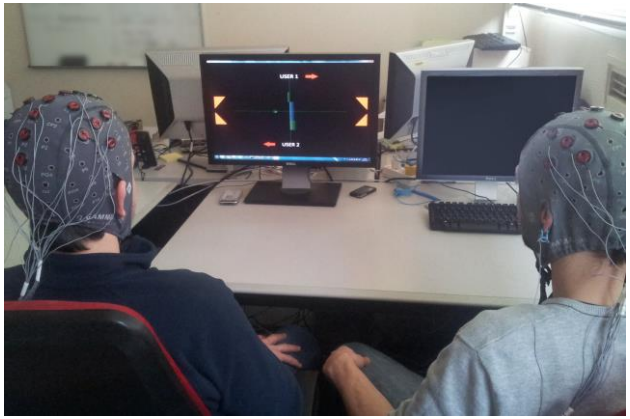
De Vico Fallani et al. 2010 [4]

Multi-user BCI

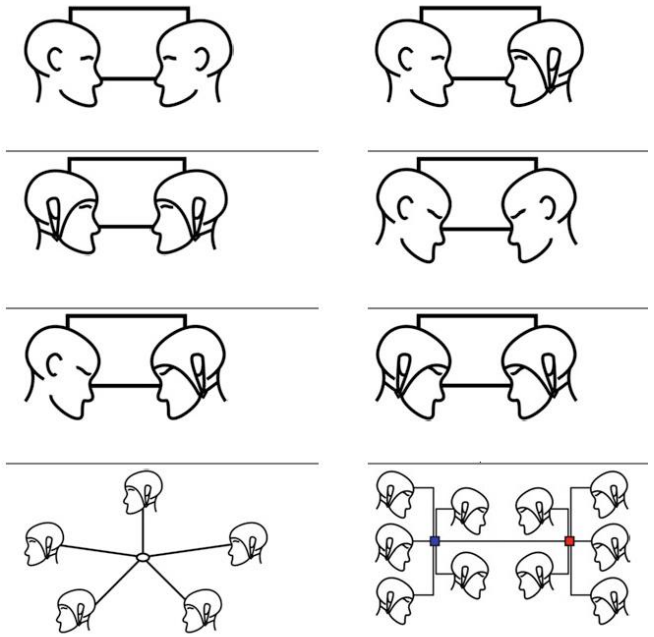
Hyperscanning & BCI



Wolpaw et al. 2002 [5]

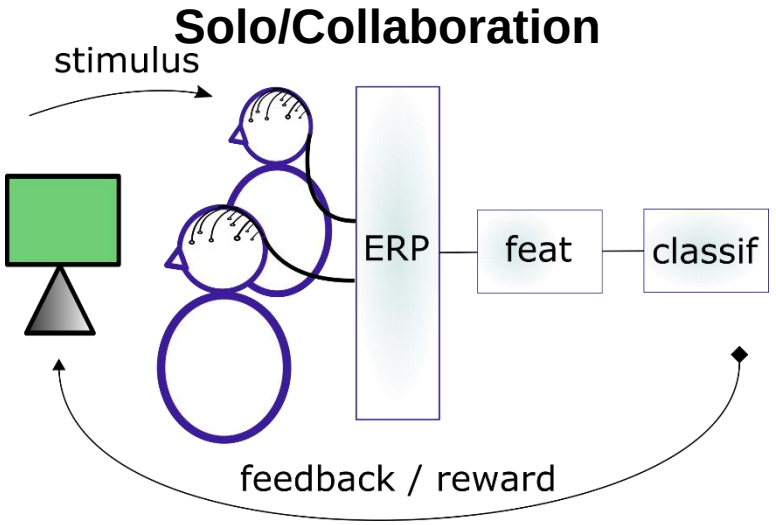


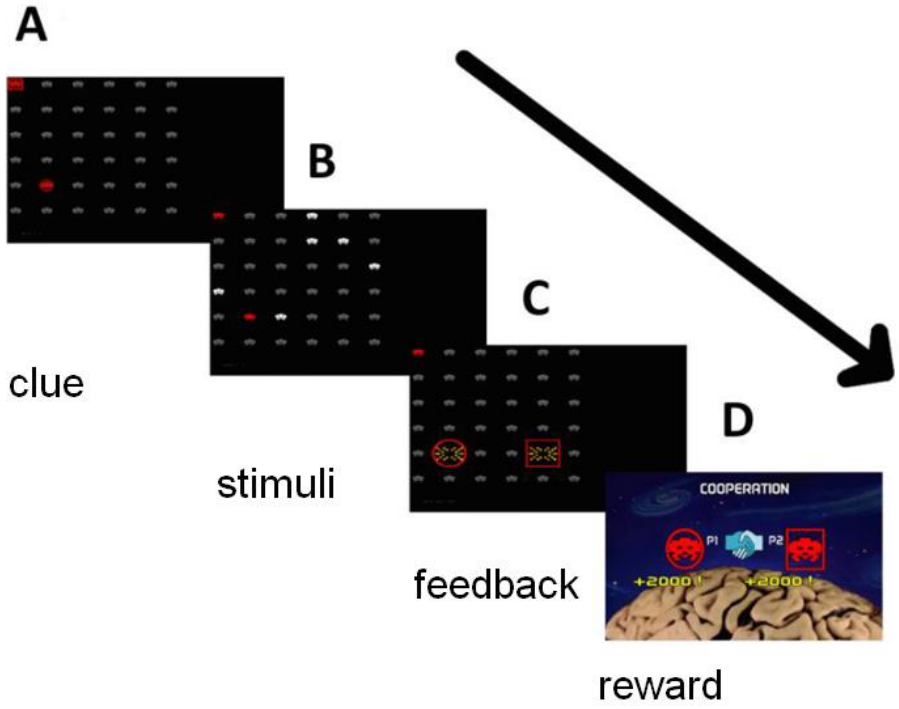
Bonnet et al. 2013 [6]

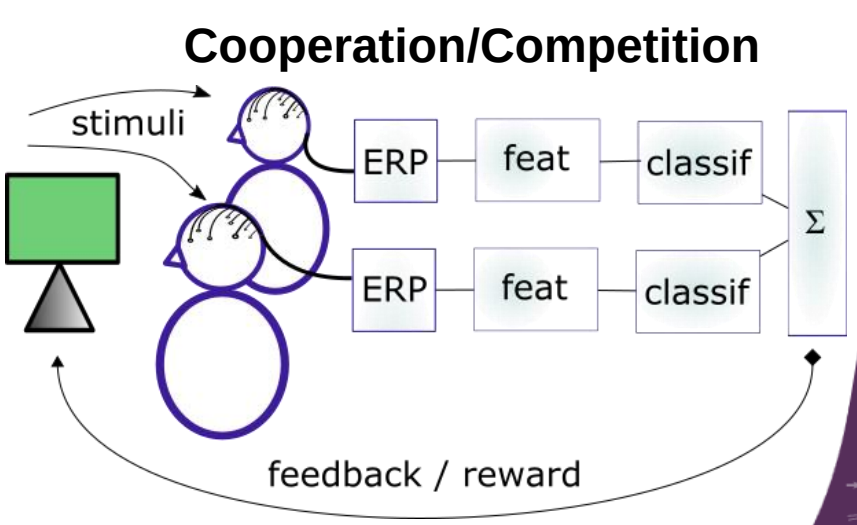


Adapted from Nijholt et al. 2015 [7]

Brain Invaders 2







Korczowski et al. 2016 [8]

Riemannian Geometry for classification

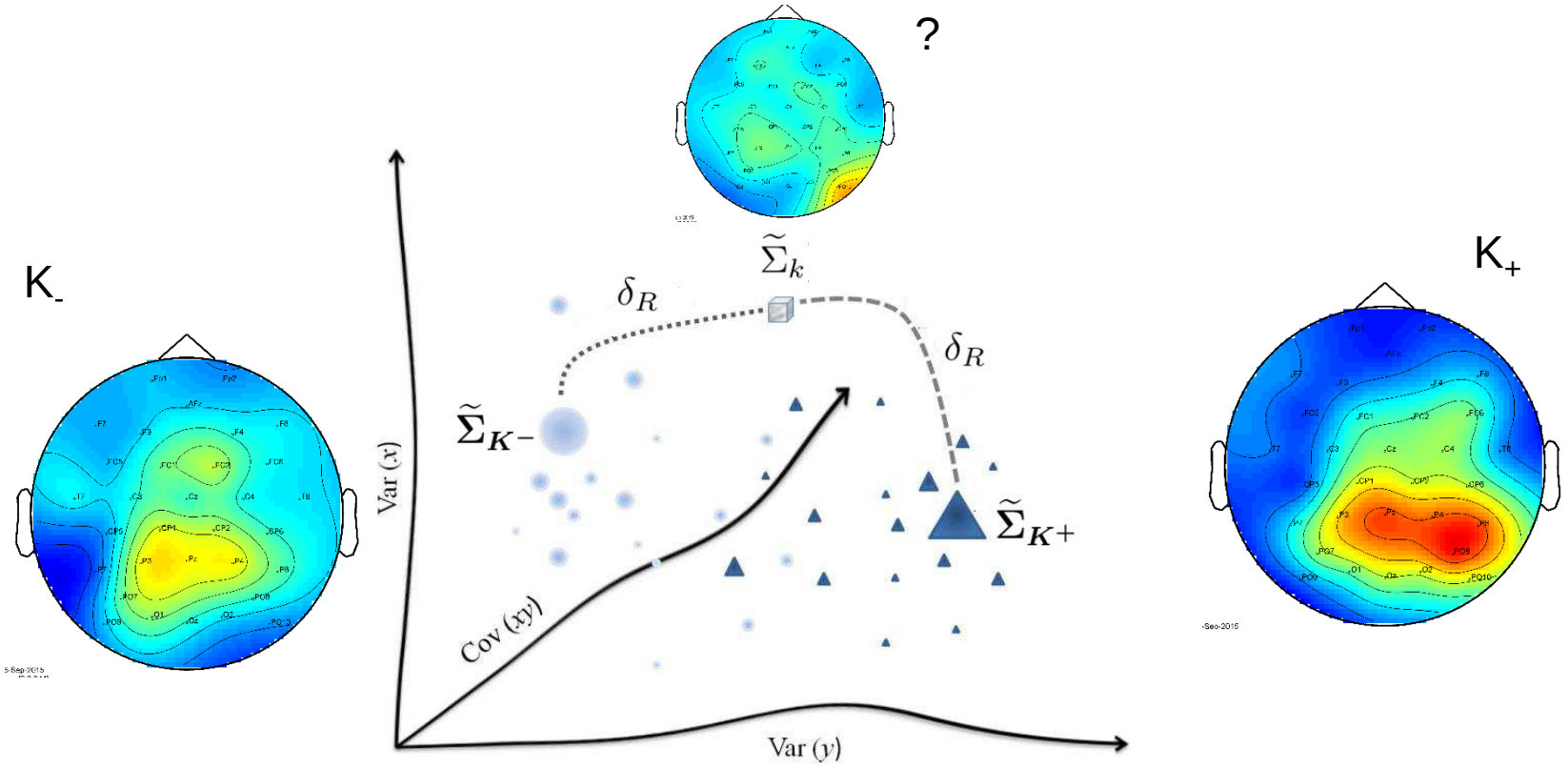
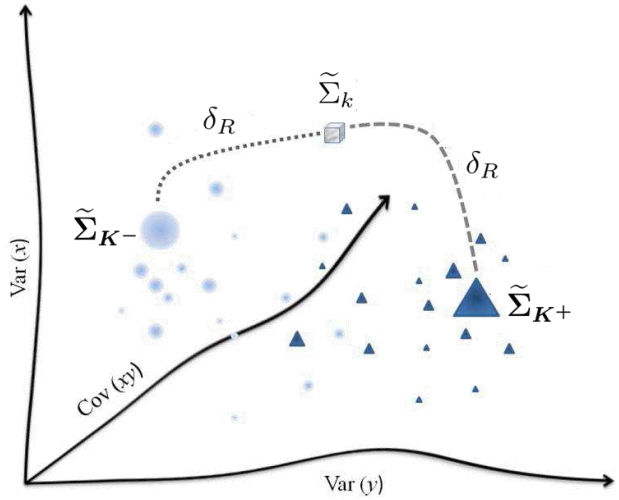


Figure: Minimum Distance to Mean (MDM) for P(2) [9]

Barachant and Congedo 2014 [10]

Riemannian Geometry

- Won several competitions
  - *DecMeg2014 – Decoding the Human Brain,*
  - *BCI Challenge@NER 2015,*
  - *Grasp-and-Lift EEG Detection 2015*



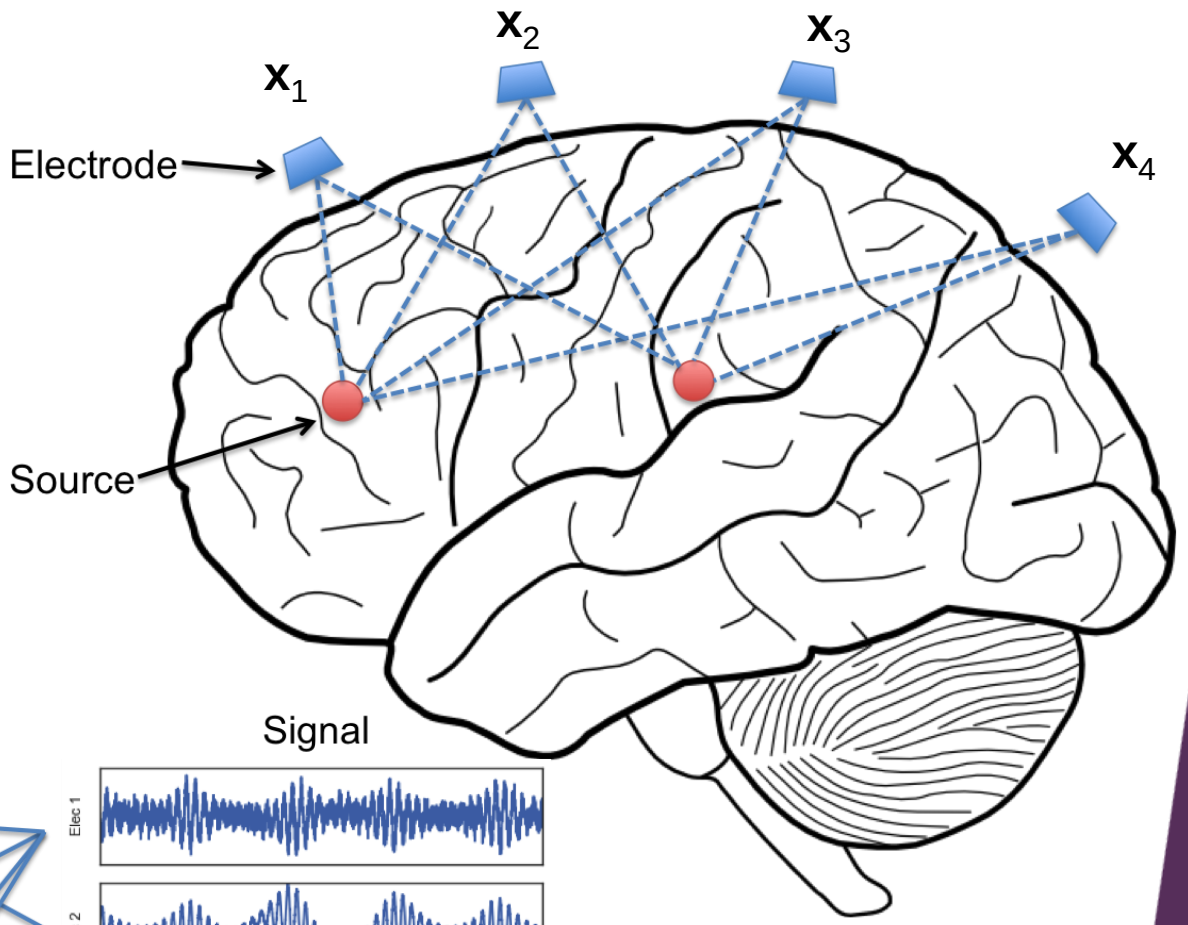
EEG Model

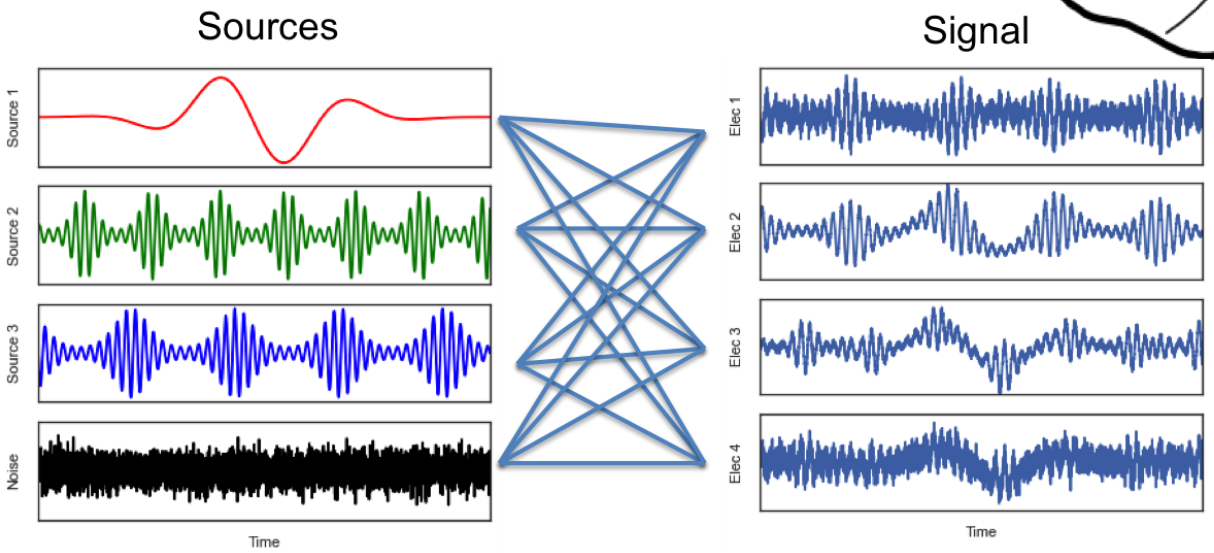
We consider the linear instantaneous mixture model where

$$\boldsymbol{X}_{k,m} = \boldsymbol{A}_m \boldsymbol{S}_{k,m}$$

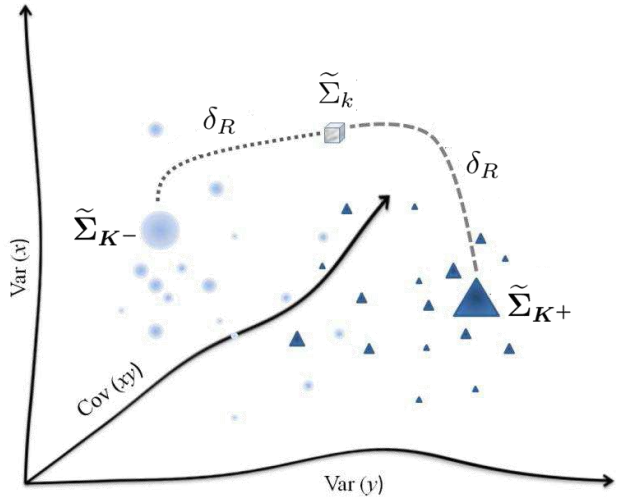
with the mixture matrix

$$\boldsymbol{A}_m \in \mathbb{R}^{N \times N}$$





Riemannian Geometry

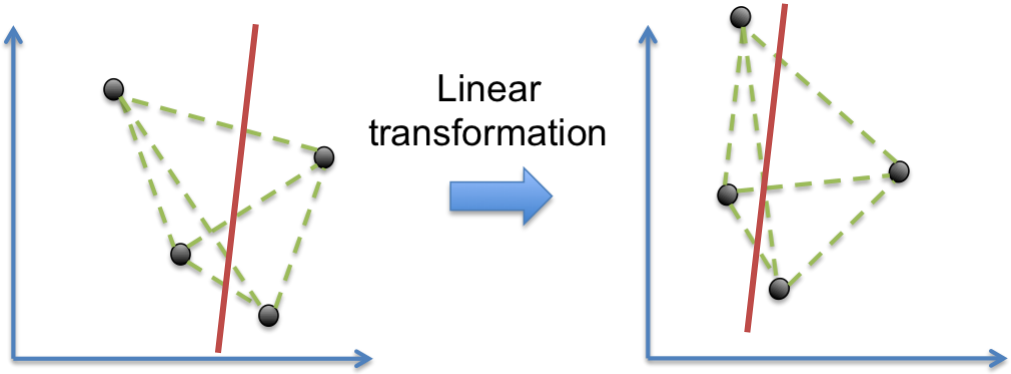


- Won several competitions
  - *DecMeg2014 – Decoding the Human Brain,*
  - *BCI Challenge@NER 2015,*
  - *Grasp-and-Lift EEG Detection 2015*

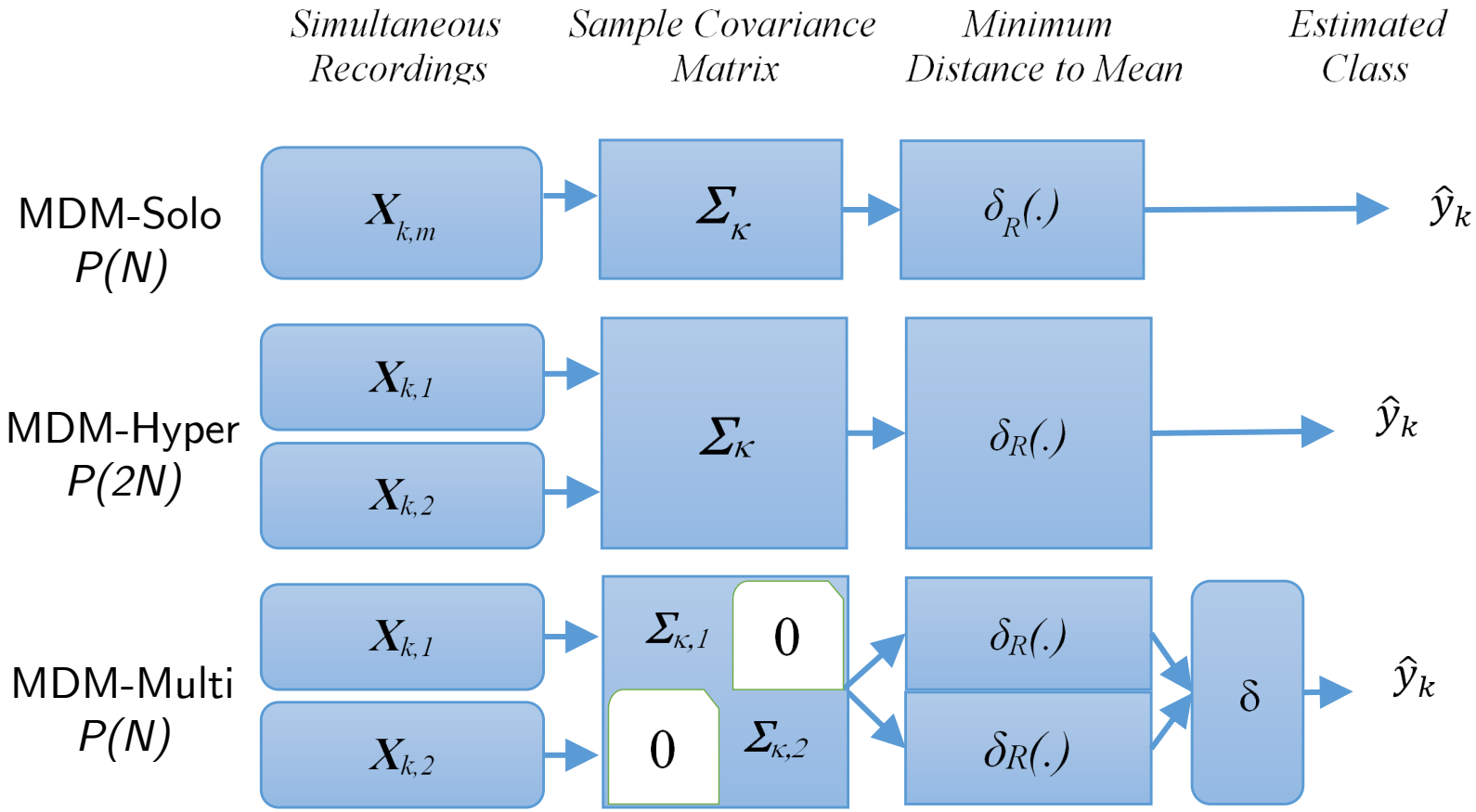
- Congruence invariance

$$\delta_R(\mathbf{W}^T\boldsymbol{\Sigma}_1\mathbf{W}, \mathbf{W}^T\boldsymbol{\Sigma}_2\mathbf{W}) = \delta_R(\boldsymbol{\Sigma}_1, \boldsymbol{\Sigma}_2) \;\forall\; \mathbf{W} \in Gl(N)$$

1. Any linear transformation is a rotation in the Riemannian Space
2. Features in Riemannian space are more robust versus euclidian
3. In practice, we can avoid to estimate spatial filter or find the unmixing matrix, that are poorly compatible between sessions and across subjects



Classification methods



Korczowski et al. 2015 [11]

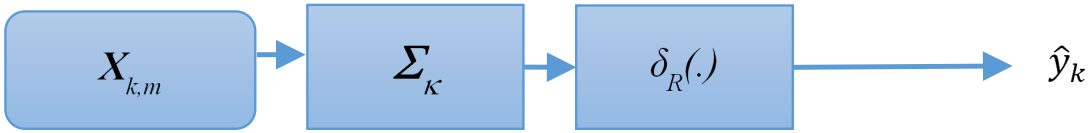
Classifier comparison

- **-solo** / **-multi** / **-hyper**
- **Offline** Cross Validation (100 leave-p-out cross validation)
- Area Under the Receiver Operating Characteristic Curve (AUC)
- Preprocessing minimal
  - 1-20Hz zero phase distorsion bandpass filter

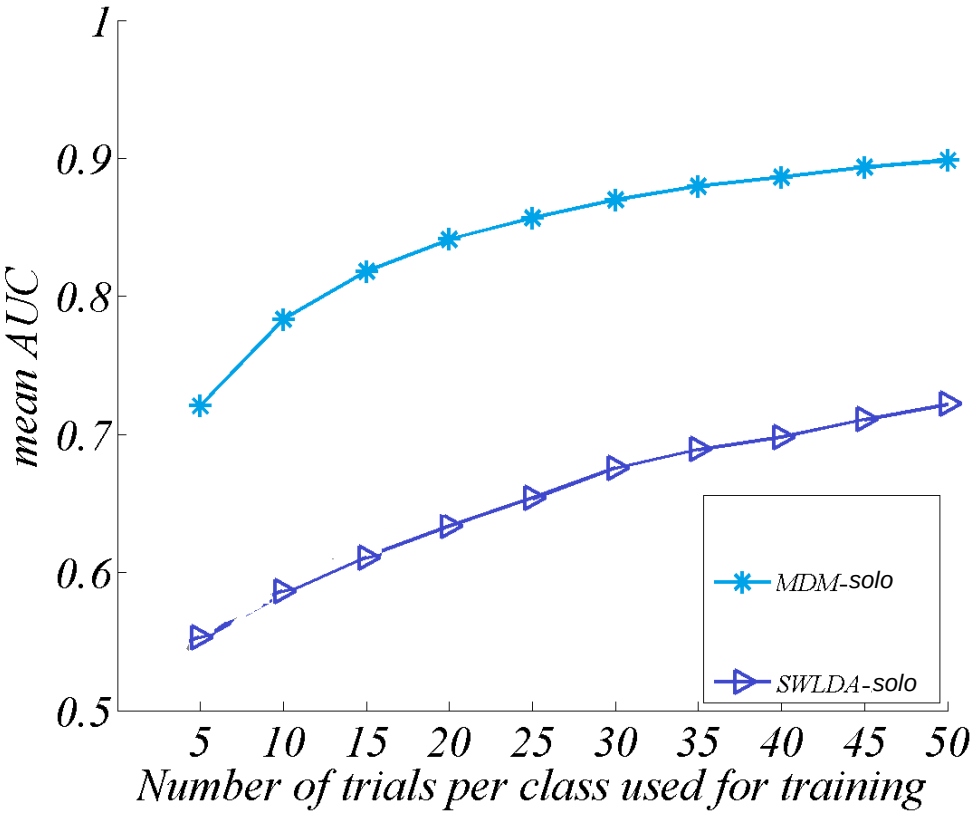
- MDM (Minimum Distance to Mean using Fisher Metric)
  versus
  SWLDA (Step Wise Linear Discriminant Analysis)

Performance -solo

offline



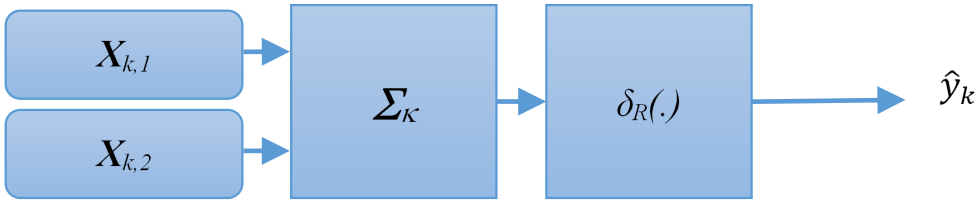
- MDM>SWLDA

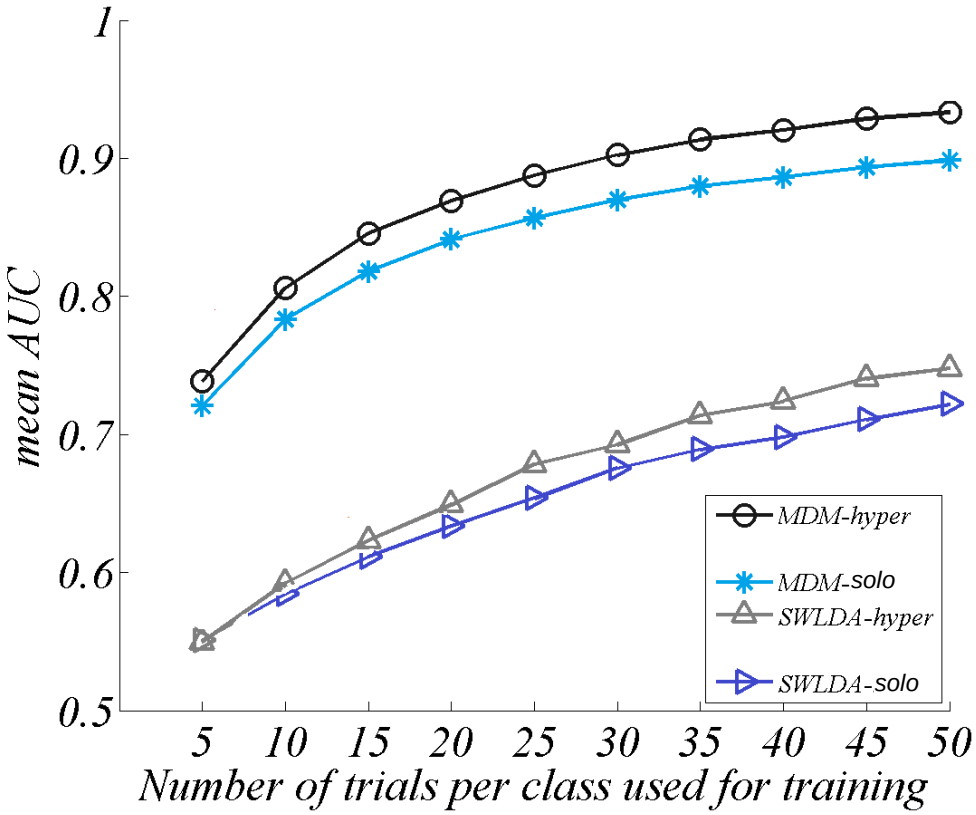


Korczowski et al. 2015 [11]

Performance -hyper

offline



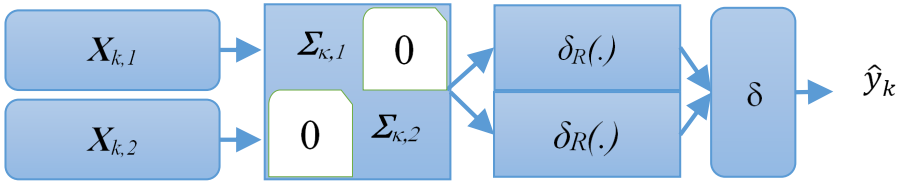


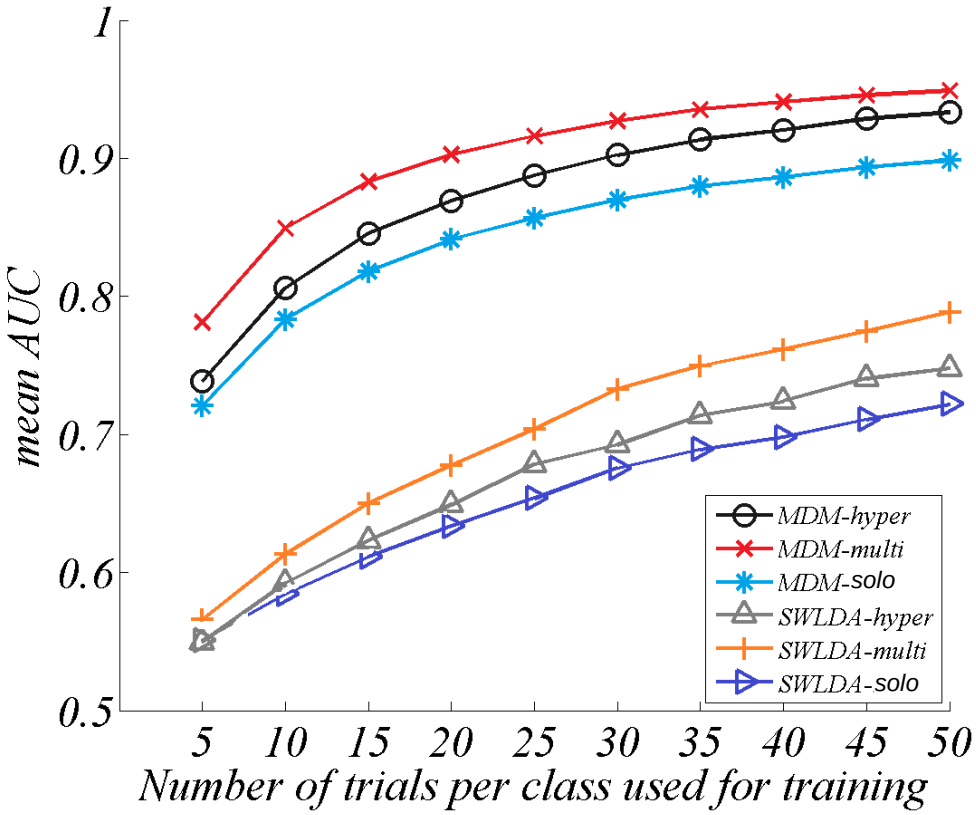
- MDM>SWLDA
- MDM-hyper > MDM-solo
  p-value : t(16)<1e-4

Korczowski et al. 2015 [11]

Performance -multi

offline

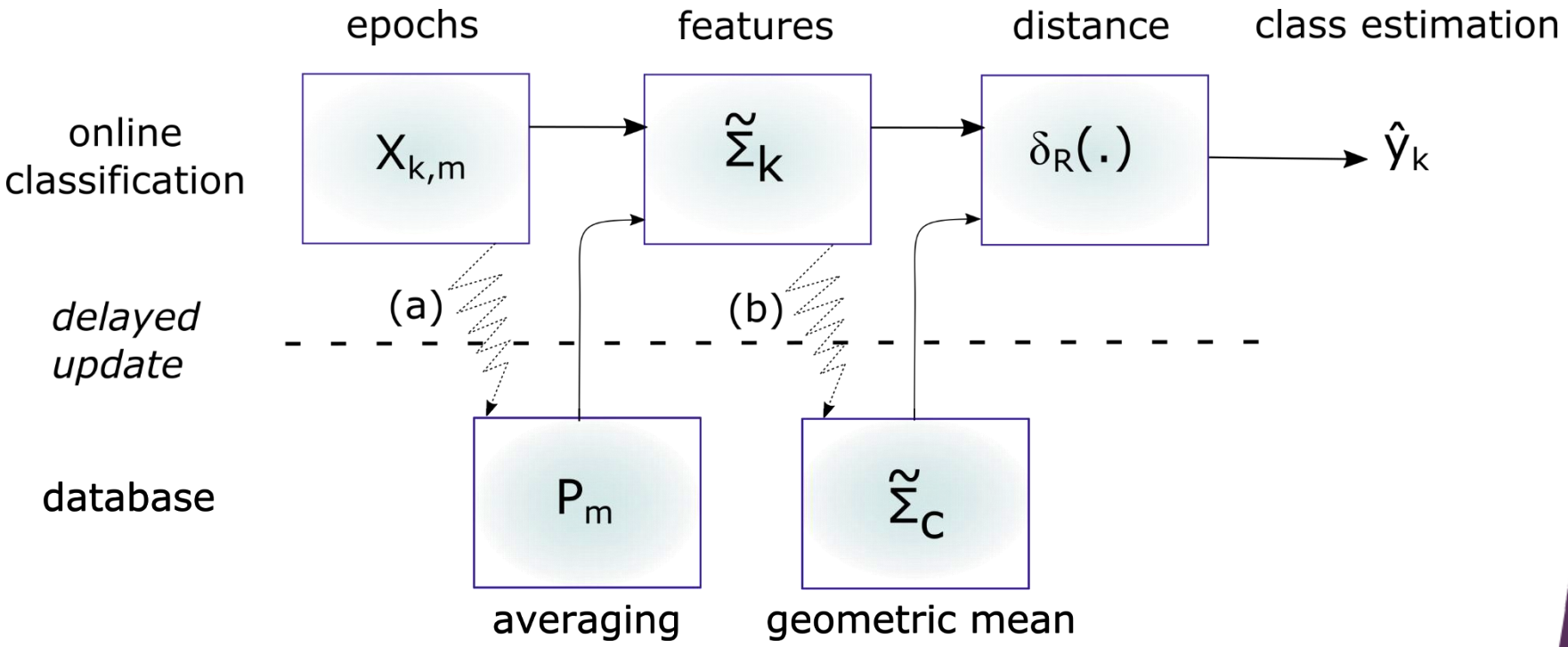




- MDM>SWLDA
- MDM-hyper > MDM-solo
  p-value : t(16)<1e-4
- MDM-multi > MDM-hyper

Korczowski et al. 2015 [11]

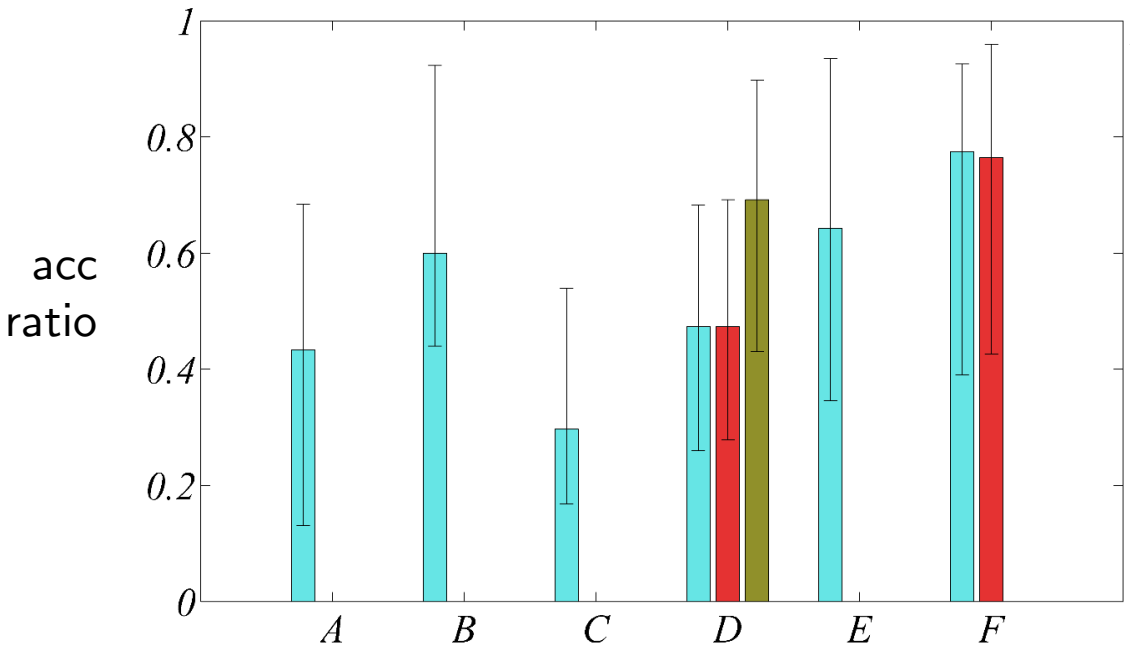
Brain Invaders 2
online



Barachant and Congedo 2014 [10]
Korczowski et al. 2016 [8]

Brain Invaders 2

online – results 6 experiments – 250+ subjects



A – 26 solo
B – 24 solo
C – 71 solo
D – 38 solo1-solo2-collaboration
E – 50 solo
F – 44 cooperation-competition

Median, 0,1 and 0,9 quantile of the ratio of successful classification during the online experiments

Korczowski et al. 2016 [8]

Brain-to-Brain Coupling

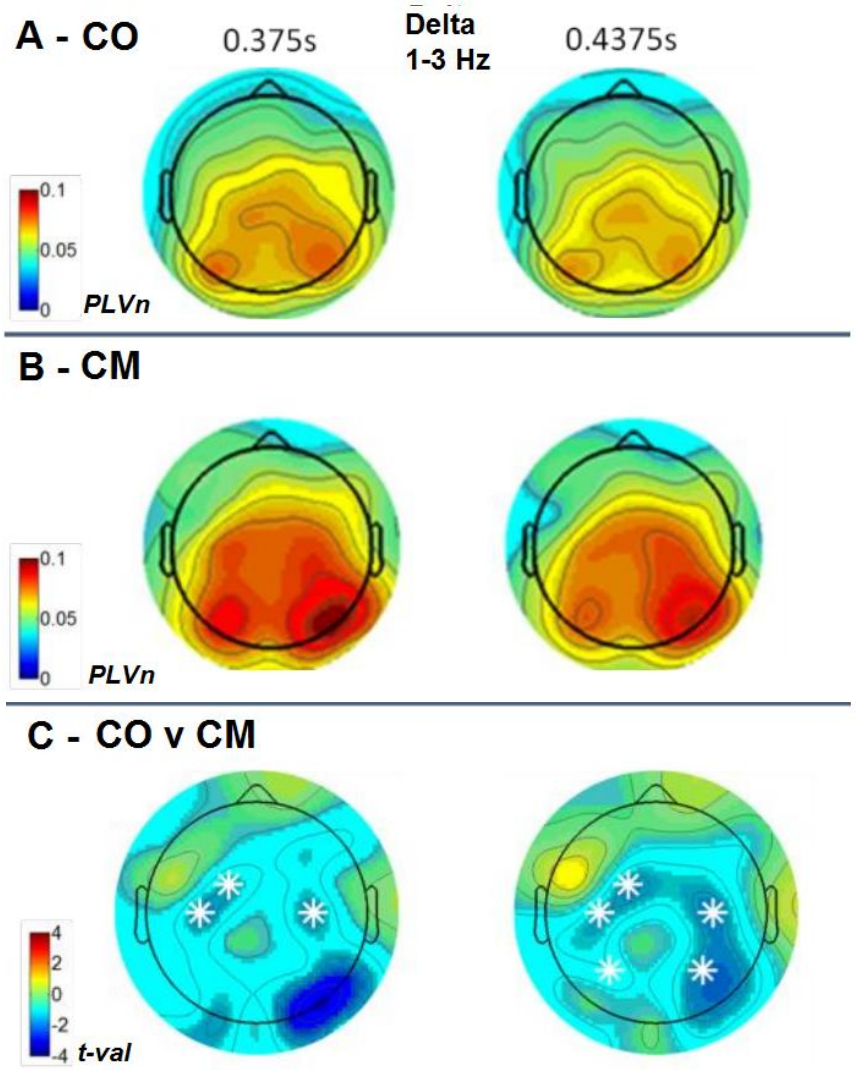
- **Intertrial phase variability**

Phase-Locking Value
(Lachaux et. al 1999 [12])

$$PLV_t = \frac{1}{N}\left|\sum_{n=1}^{N} \exp\left(j\theta(t,n)\right)\right|$$

with $\theta(t,n)=\varphi_1(t,n)-\varphi_2(t,n)$

- **Cluster-based permutation test**



Take-away ideas

- Riemannian Geometry with Extended ERP covariance
  a. Natural transfer learning properties
  b. Adaptive
  c. Straightforward to compute
  d. Compatible to more fancy ML methods

- Multi-user BCI
  a. Benchmarking hyperscanning methods with well studied exogeneous coupling
  b. Possible endogeneous induced coupling by the social paradigm

Approximate Joint Diagonalization

(some) BSS problem

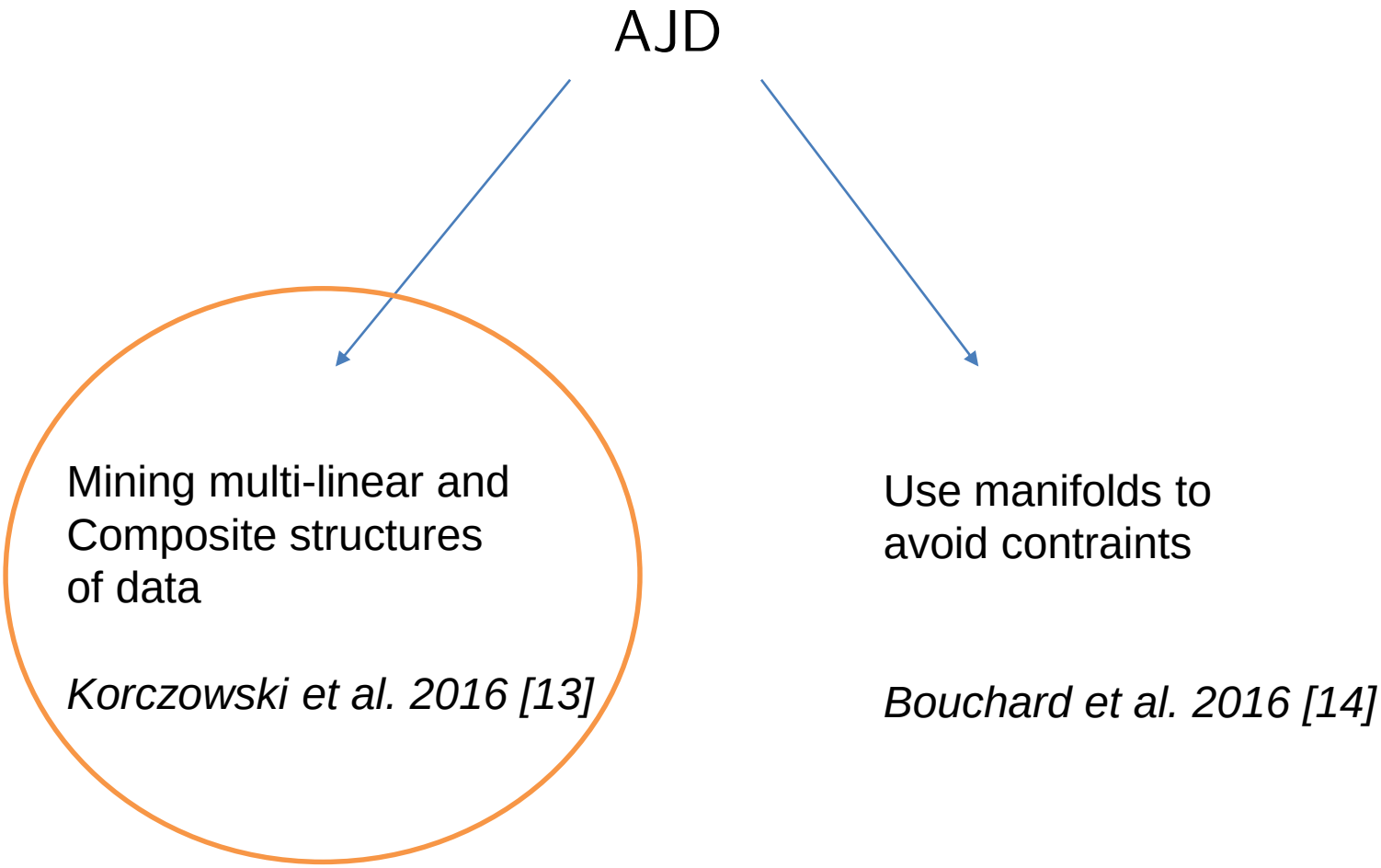
Temporal structure is not taken into account

-> invariance by temporal shuffling

Sensible to degenerate solution

-> contraints or « hard »-whitening

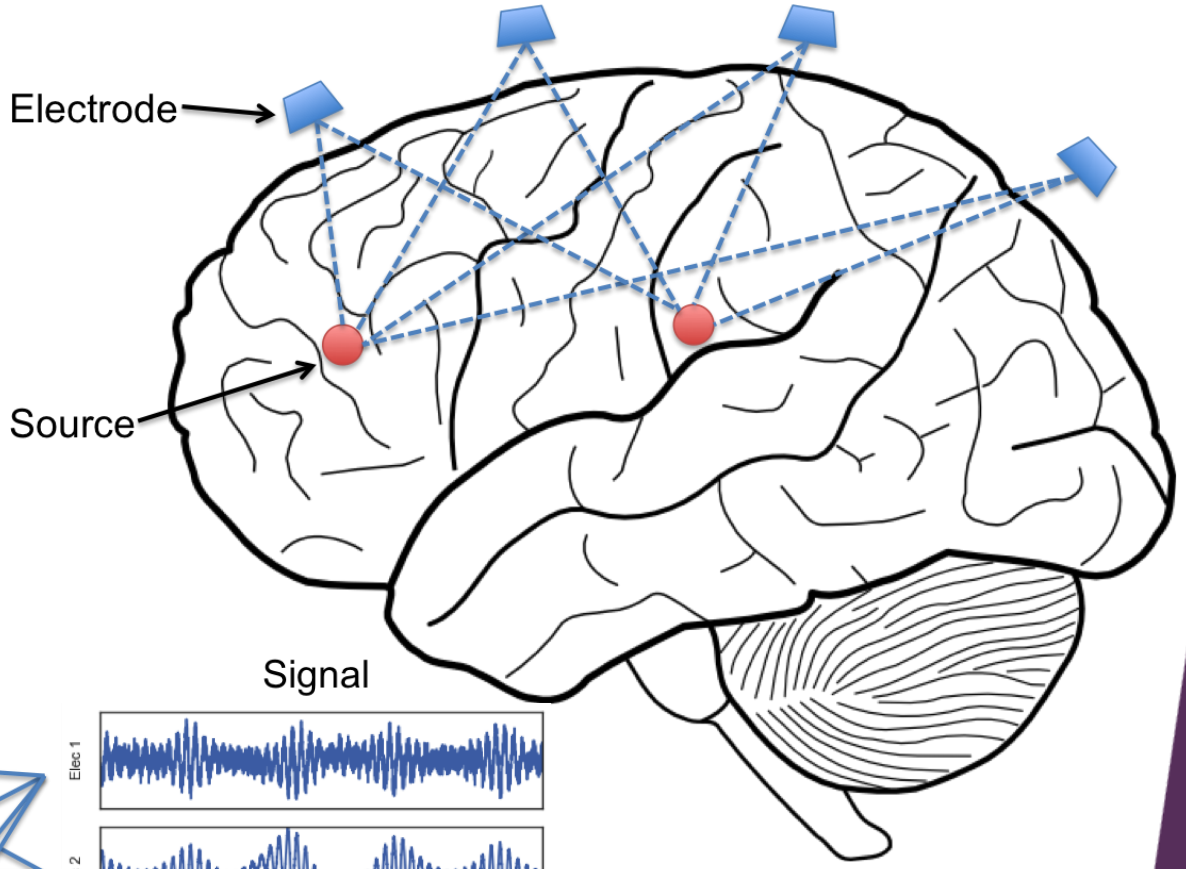
(some) BSS problem

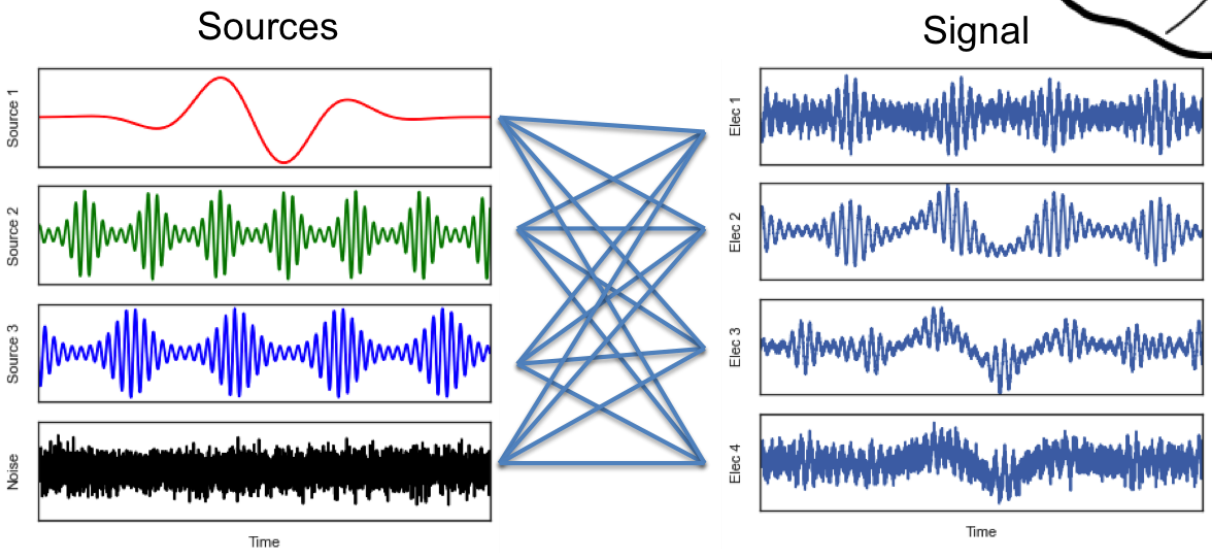


AJD

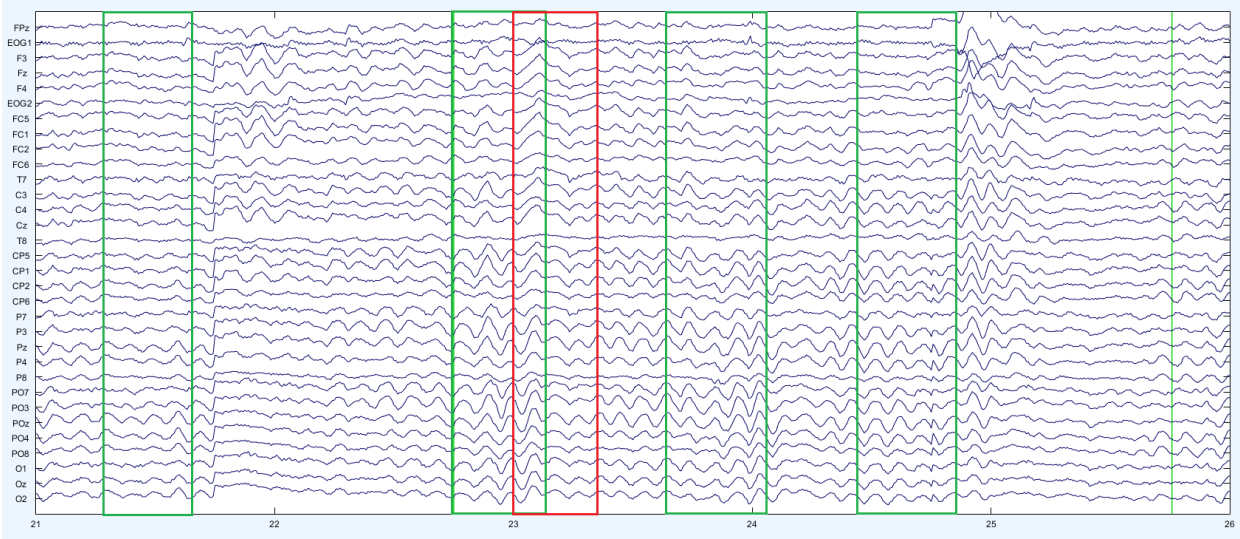
BSS model

$$x(t) = As(t) + n(t)$$





AJD



BSS model

$$\boldsymbol{x}(t) = \boldsymbol{A}\boldsymbol{s}(t) + \boldsymbol{n}(t)$$

We want to find B such as

$$\boldsymbol{R}_{\hat{s}}(l) = \boldsymbol{B}^T \boldsymbol{R}_x(l) \boldsymbol{B} \quad \forall\, l \in \{1, ..., L\} \qquad (1)$$

$\boldsymbol{R}_x$

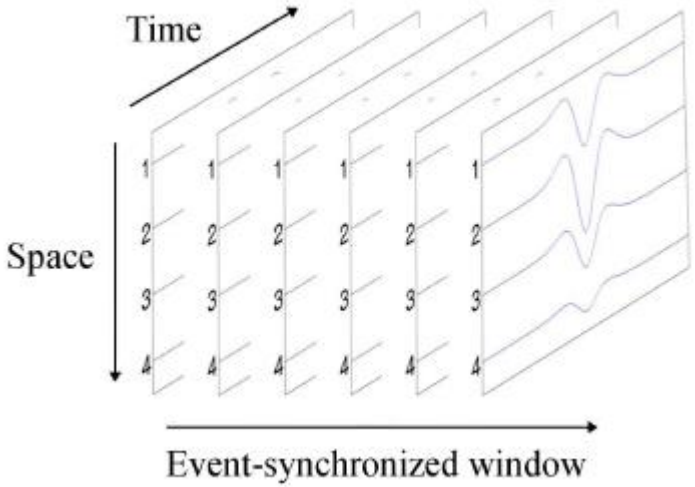
- Non-stationary
  - covariances
- Spectral coloration
  - Time-Lagged covariances
  - Smoothed co-spectral matrices (Bartlett)

Using both diversity Congedo et al. 2014 [15]

A solution is to minimize

$$\mathrm{f}(\boldsymbol{B}) = \sum_{l=1}^{L} \left\| \mathrm{off}(\boldsymbol{B}^T \boldsymbol{R}_x(l) \boldsymbol{B}) \right\|_F^2 \qquad (2)$$

Bilinear AJD



Niknazar et al. 2014 [16]

Model CANDECOMP/PARAFAC

$$\boldsymbol{X}_k = \boldsymbol{A}\boldsymbol{S}_k\boldsymbol{E}^T + \boldsymbol{N}_k \quad (3)$$

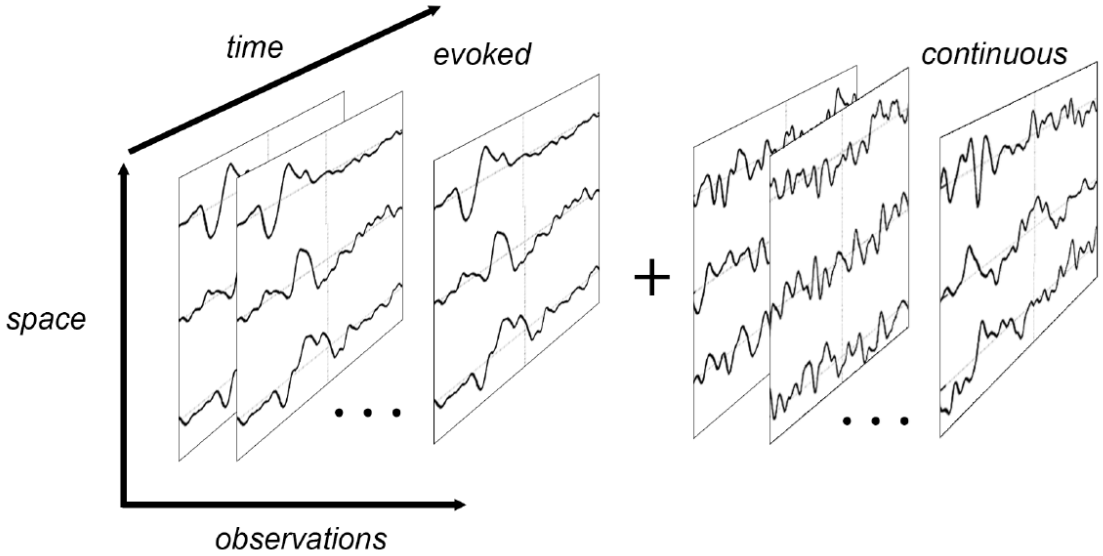
We want to find B and D

$$\hat{\boldsymbol{S}}_k = \boldsymbol{B}^T\boldsymbol{X}_k\boldsymbol{D} \quad (4)$$

A solution can be to minimize the cost function

$$\mathrm{f}_b(\boldsymbol{B},\boldsymbol{D}) = \sum_{k=1}^{K} \left\| \mathrm{off}(\boldsymbol{B}^T\boldsymbol{X}_k\boldsymbol{D}) \right\|_F^2 \quad (5)$$

Composite AJD



Korczowski et al. 2016 [13]

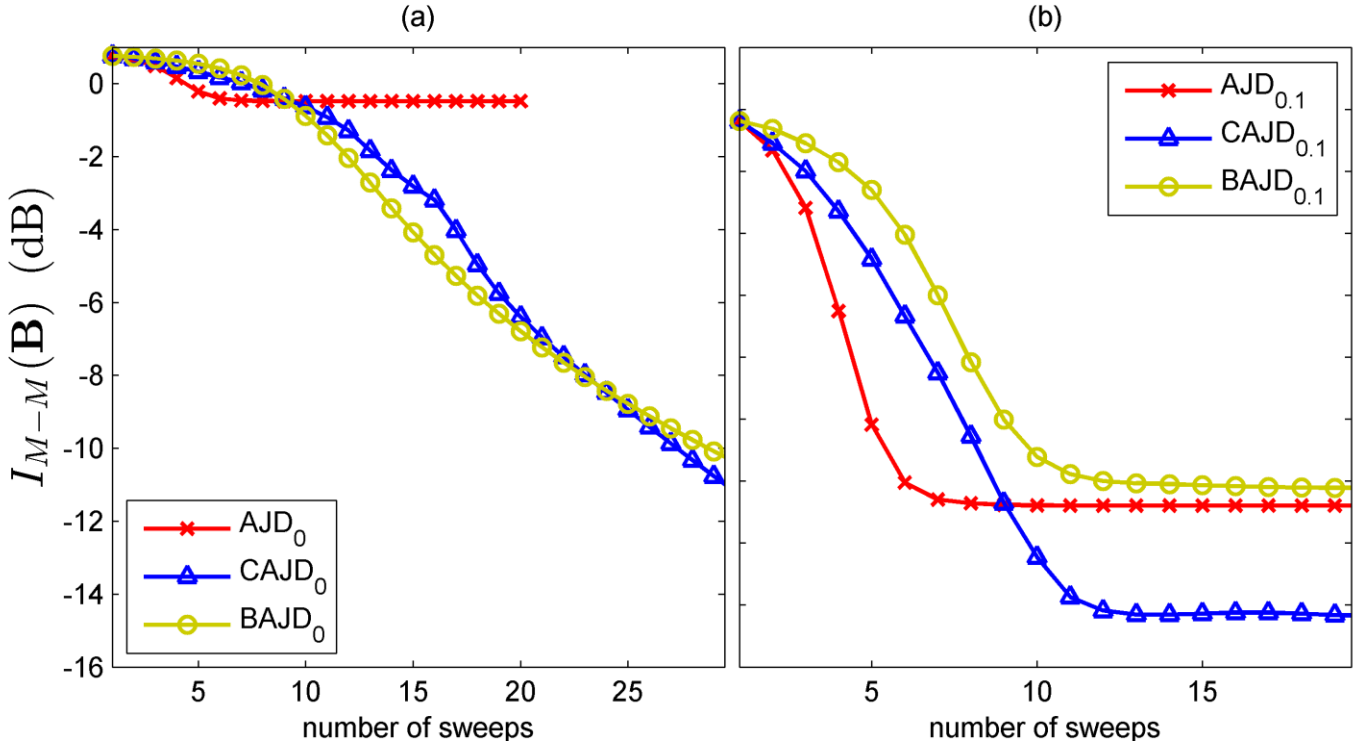
A solution can be to minimize the cost function

$$\mathrm{f}_c(\boldsymbol{B}, \boldsymbol{D}) = \alpha\, \mathrm{f}(\boldsymbol{B}) + (1-\alpha)\mathrm{f}_b(\boldsymbol{B}, \boldsymbol{D}) \quad (6)$$

-> Iterative algorithm proposed by elementary Gauss elimination method (Gauss Planar Transformation)

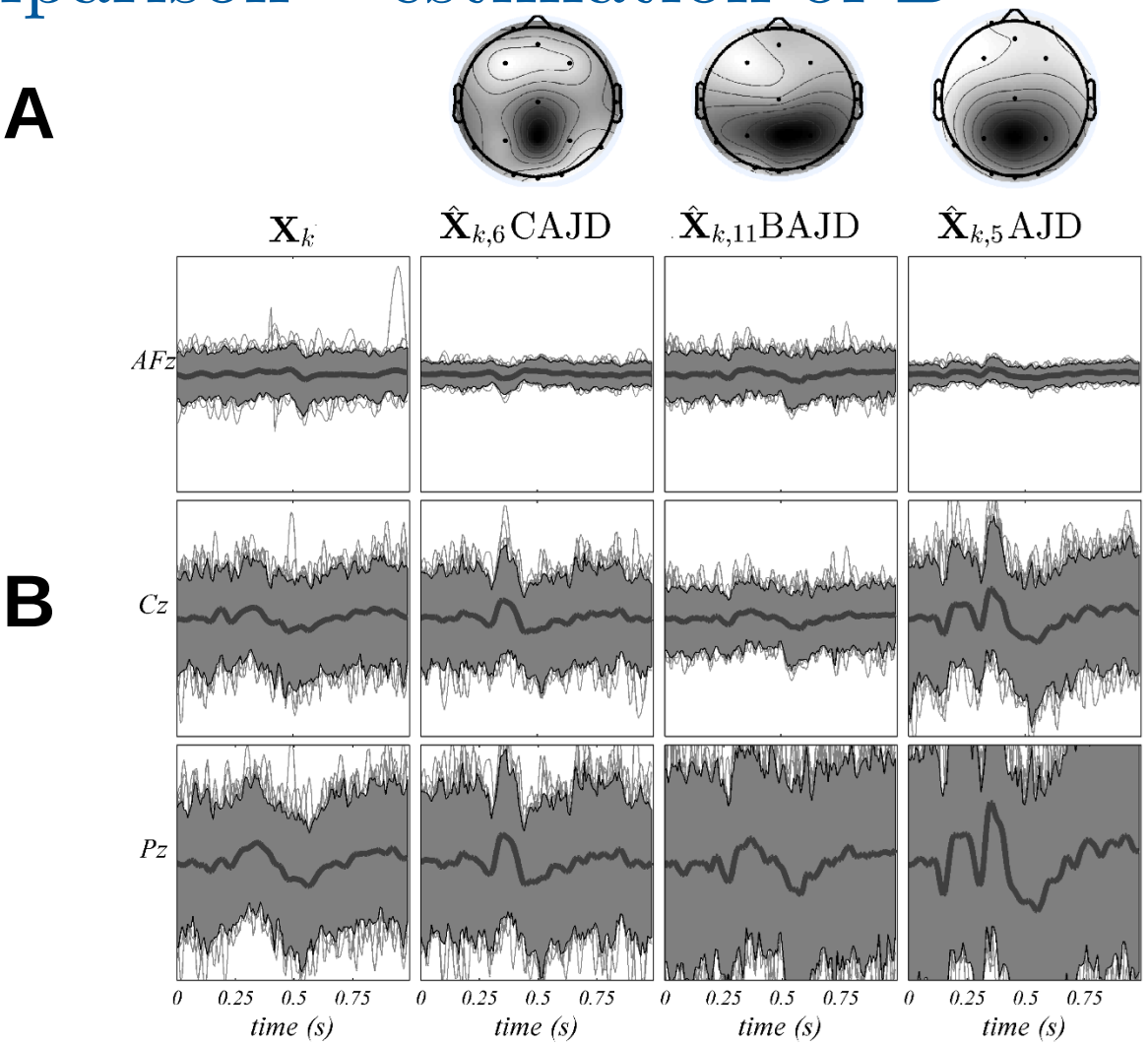
Comparison - simulation

Moreau-Macchi index (Moreau and Macchi 1993 [17])



Average convergence rate for 100 random realization according to a bilinear model. Korczowski et al. 2016 [13]

Comparison – estimation of B



Subject 2

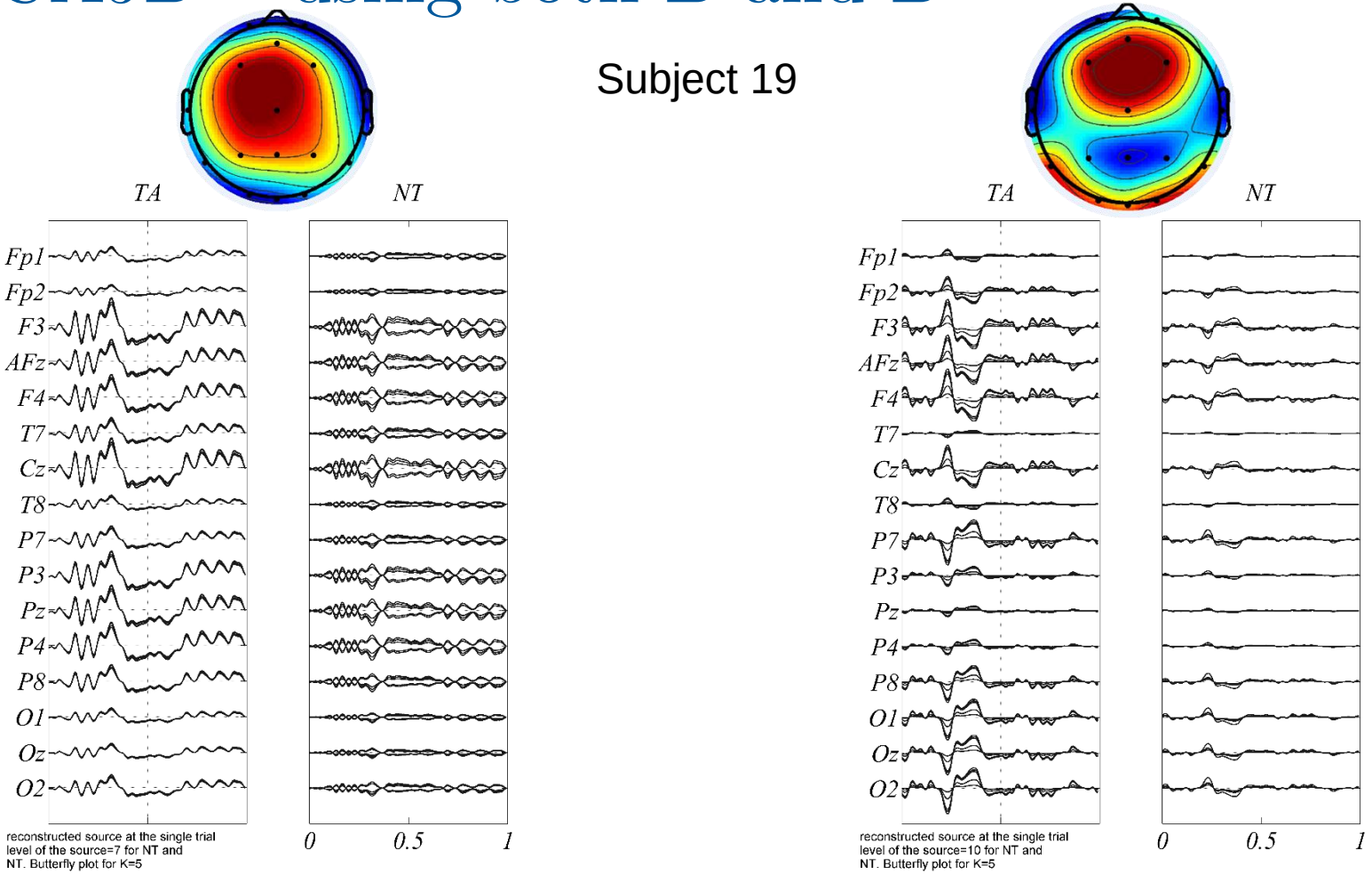
(B) Backprojected sources and (A) their spatial contribution Black : ensemble average. Grey area : 10-90% quantiles.

CAJD – using both B and D

A

B

Subject 19



(B) Backprojected sources and (A) their spatial contribution
Black : butterfly plot, trials (K=5)

Take-away ideas

- Mentionned here
  a. Powerful framework for BSS with weaker assumptions (Common and Jutten 2010)
  b. Can manage several diversities (e.g. coloration and non-stationary) to improve identifiability (Adali et. al 2014)
  c. Go to multi-linear (tensor) and composite AJD (Korczowski et al. 2016, accepted)

- Non-mentionned here
  a. Constraints can be directly embedded in manifolds (Bouchard et al. 2016)
  b. The link between several models can be flexible (Farias et al. 2016, under revision)

Discussion

Discussion

- Study inter-brain connectivity
  a. Multi-user BCI as a benchmarking framework
  b. Need of powerful BSS tools (tailored by data structure)

References (1/2)

[1] Chatel-Goldman, Jonas, Christian Jutten, and Marco Congedo. "Non-Local Mind from the Perspective of Social Cognition." Frontiers in Human Neuroscience 7 (2013): 107. doi:10.3389/fnhum.2013.00107.

[2] Babiloni, F., F. Cincotti, D. Mattia, F. De Vico Fallani, A. Tocci, Luigi Bianchi, S. Salinari, M. G. Marciani, A. Colosimo, and L. Astolfi. "High Resolution EEG Hyperscanning during a Card Game." In Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE, 4957–60. IEEE, 2007. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4353453.

[3] Hasson, Uri, Yuval Nir, Ifat Levy, Galit Fuhrmann, and Rafael Malach. "Intersubject Synchronization of Cortical Activity During Natural Vision." Science 303, no. 5664 (March 12, 2004): 1634–40. doi:10.1126/science.1089506.

[4] De Vico Fallani, Fabrizio, Vincenzo Nicosia, Roberta Sinatra, Laura Astolfi, Febo Cincotti, Donatella Mattia, Christopher Wilke, et al. "Defecting or Not Defecting: How to 'Read' Human Behavior during Cooperative Games by EEG Measurements." PLoS ONE 5, no. 12 (December 1, 2010): e14187. doi:10.1371/journal.pone.0014187.

[5] Wolpaw, Jonathan R, Niels Birbaumer, Dennis J McFarland, Gert Pfurtscheller, and Theresa M Vaughan. "Brain–computer Interfaces for Communication and Control." Clinical Neurophysiology 113, no. 6 (June 2002): 767–91. doi:10.1016/S1388-2457(02)00057-3.

[6] Bonnet, L., F. Lotte, and A. Lecuyer. "Two Brains, One Game: Design and Evaluation of a Multiuser BCI Video Game Based on Motor Imagery." IEEE Transactions on Computational Intelligence and AI in Games 5, no. 2 (2013): 185–98. doi:10.1109/TCIAIG.2012.2237173.

[7] Nijholt, Anton. "Competing and Collaborating Brains: Multi-Brain Computer Interfacing." In Brain-Computer Interfaces, edited by Aboul Ella Hassanien and Ahmad Taher Azar, 313–35. Intelligent Systems Reference Library 74. Springer International Publishing, 2015. http://link.springer.com/chapter/10.1007/978-3-319-10978-7_12.

[8] Korczowski, Louis, Alexandre Barachant, Anton Andreev, Christian Jutten, and Marco Congedo. "' Brain Invaders 2': An Open Source Plug & Play Multi-User BCI Videogame." In 6th International Brain-Computer Interface Meeting, 10–3217, 2016. https://hal.archives-ouvertes.fr/hal-01318726/.

[9] Congedo, Marco. "EEG Source Analysis." HDR Thesis, Université de Grenoble, 2013. https://tel.archives-ouvertes.fr/tel-00880483/document.

[10] Barachant, Alexandre, and Marco Congedo. "A Plug&Play P300 BCI Using Information Geometry." arXiv:1409.0107 [cs, Stat], August 30, 2014. http://arxiv.org/abs/1409.0107.

References (2/2)

[11] Korczowski, L., M. Congedo, and C. Jutten. "Single-Trial Classification of Multi-User P300-Based Brain-Computer Interface Using Riemannian Geometry." In 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 1769–72, 2015. doi:10.1109/EMBC.2015.7318721.

[12] Lachaux, Jean-Philippe, Eugenio Rodriguez, Jacques Martinerie, and Francisco J. Varela. "Measuring Phase Synchrony in Brain Signals." Human Brain Mapping 8, no. 4 (January 1, 1999): 194–208. doi:10.1002/(SICI)1097-0193(1999)8:4<194::AID-HBM4>3.0.CO;2-C.

[13] L. Korczowski, F. Bouchard, C. Jutten, M. Congedo. "Mining the bilinear structure of data with Approximate Joint Diagonalization" (accepted) EUSICO 2016

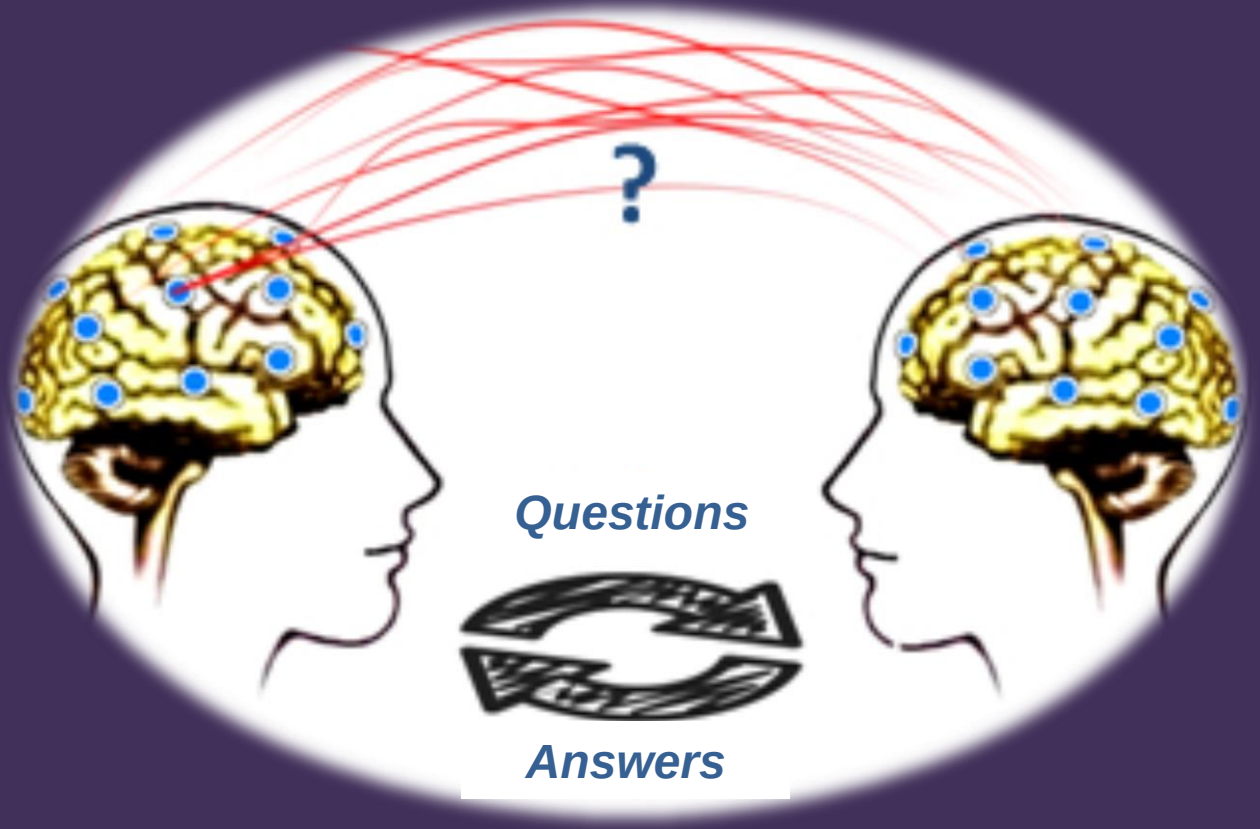
[14] F. Bouchard, L. Korczowski, J. Malick, M. Congedo. "Approximate Joint Diagonalization within the Riemannian Geometry Framework" (accepted) EUSICO 2016

[15] Congedo, Marco, Sandra Rousseau, and Christian Jutten. "An Introduction to EEG Source Analysis with an Illustration of a Study on Error-Related Potentials." In Guide to Brain-Computer Music Interfacing, edited by Eduardo Reck Miranda and Julien Castet, 163–89. Springer London, 2014. http://link.springer.com/chapter/10.1007/978-1-4471-6584-2_8.

[16] M. Niknazar, H. Becker, B. Rivet, C. Jutten, and P. Comon. Blind source separation of underdetermined mixtures of event-related sources. Signal Processing, 101:52–64, August 2014

[17] E. Moreau and O. Macchi. New self-adaptative algorithms for sourceseparation based on contrast functions. In IEEE Signal Processing Workshop on Higher-Order Statistics, 1993, pages 215–219, 1993.

Thank you



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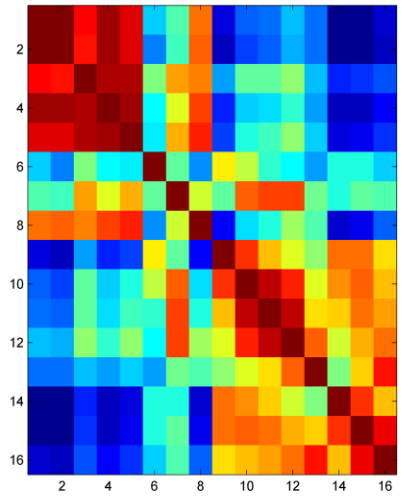
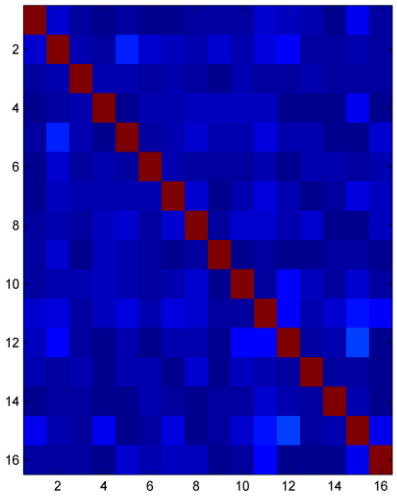
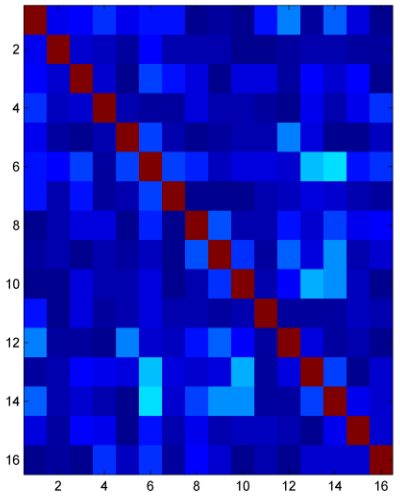
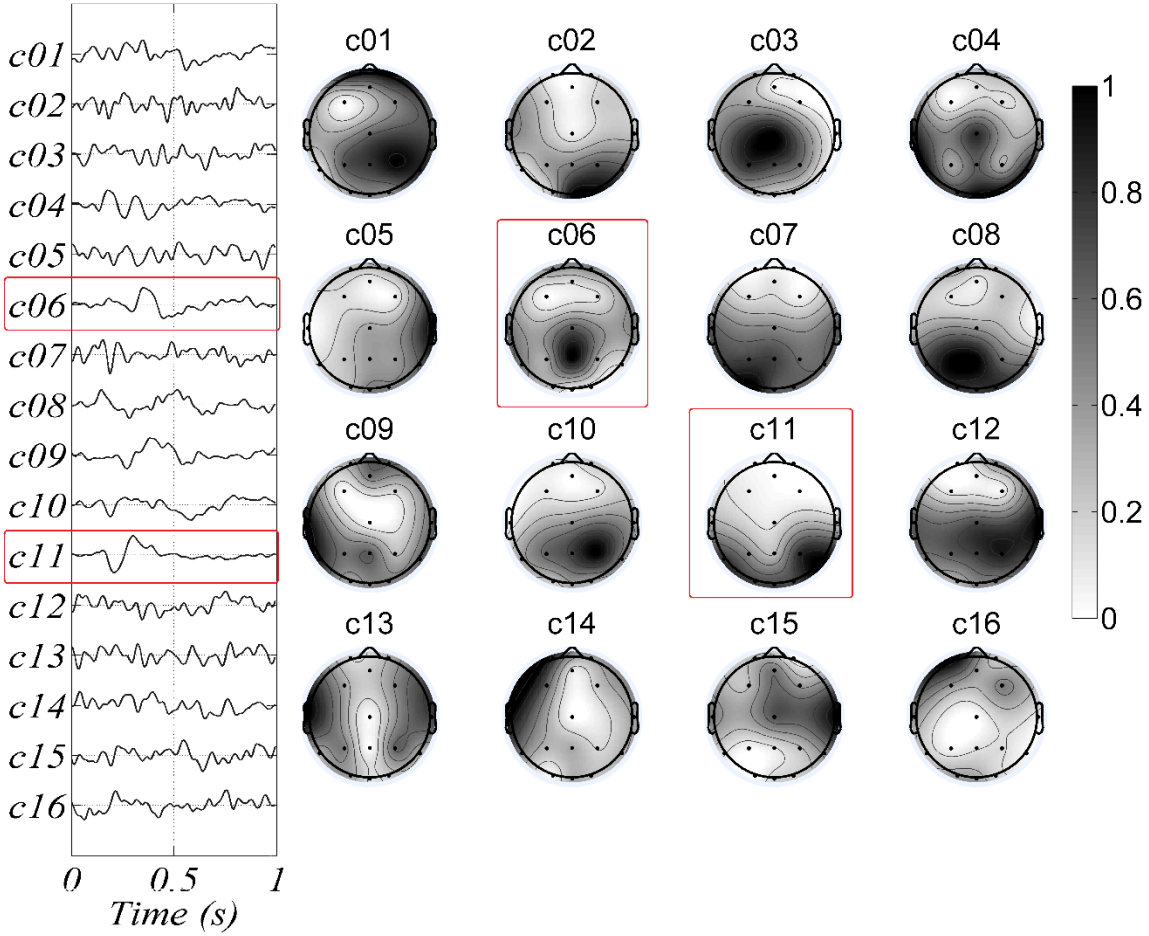
AJD – mean covariance







Source Separation CAJD

Subject 2