Functional Connectivity Patterns in Monolingual and Bilingual Infants

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fNIRS 2018, Tokyo

Motivation I: Early bilingual exposure

- Experience-related effects in brain structure and function.
- Evidence for **bilingual adaptation**.

Li et al.,, 2014 *Cortex (Review)*

- Bilingual adaptation in **infants.**
  - **Resting state FC?**

Molnar et al., 2014 *Infancy*
Ferjan-Ramirez et al., 2017 *Developmental Sci.*

Costa and Sebastián-Gallés, 2014 *Nature Rev. Neurosci. (Review)*

- Resting state FC in infants.
  - Premature birth
  - Socio-economic status
  - Autism

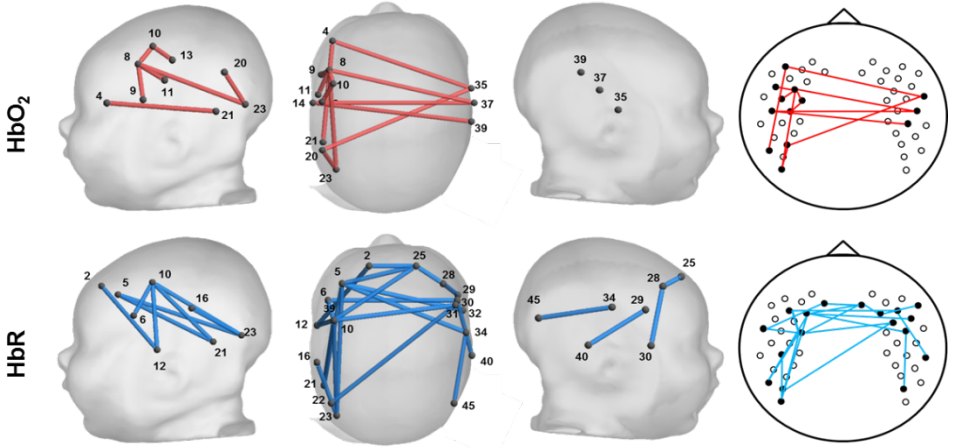
Smyser et al., 2010 *Cereb. Cortex* **(fMRI)**
Gao et al., 2015a *Cereb. Cortex* **(fMRI)**
Keehn et al., 2013 *Front. Hum. Neurosci* **(fNIRS)**

Gao et al., 2017 *Neurocientist (Review)*

Motivation II: Quality assessment (QA)

- Assess the **reliability** of our previous **fNIRS** resting state FC study in **awake** 4-month old monolingual and bilingual infants.

Spanish−Basque Bilinguals > Spanish Monolinguals



- We suspect that these results might be driven by motion artifacts that were not accurately identified and removed.

The current work: Resting state FC in asleep 4-month-old monolingual and bilingual infants

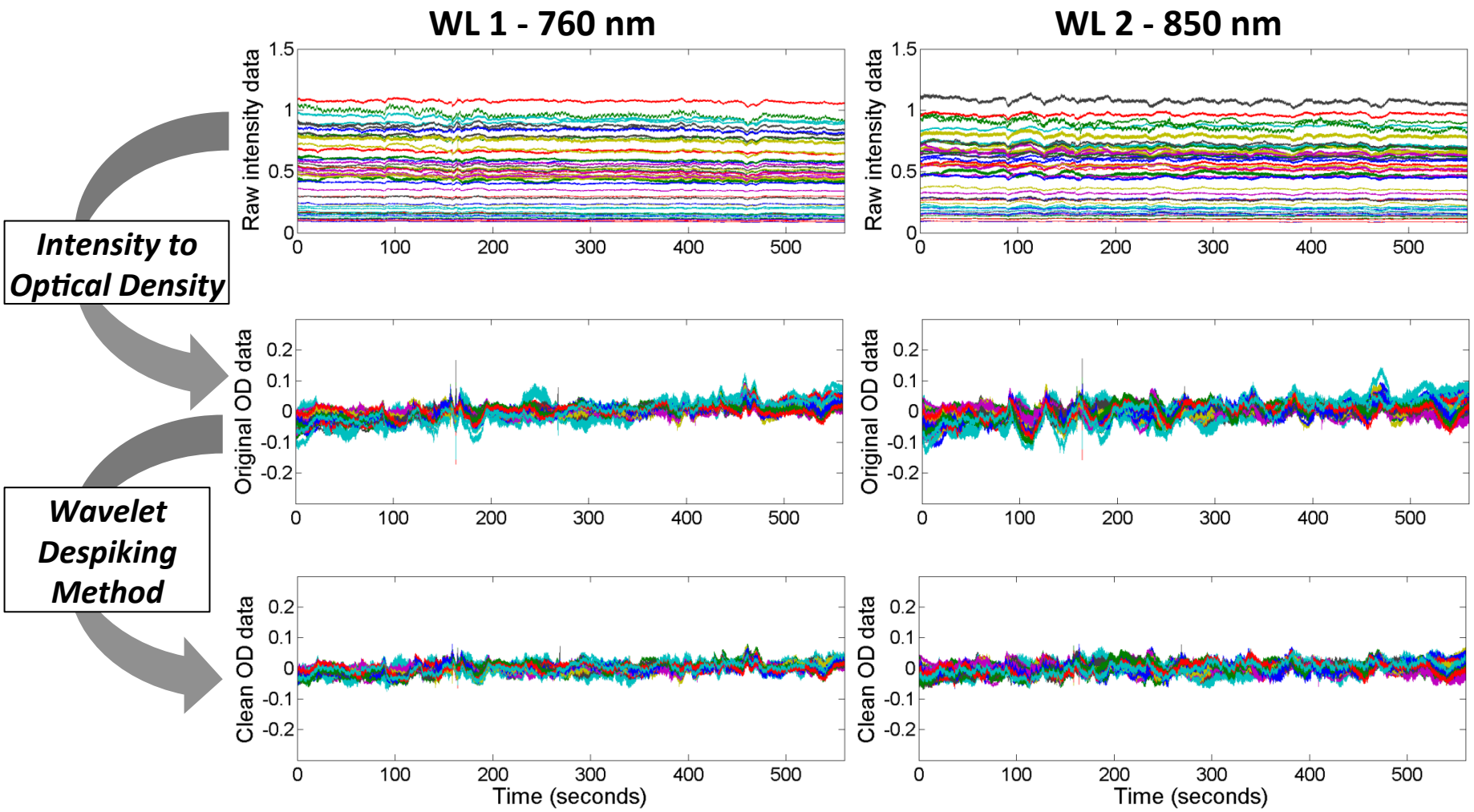
Participants

- 36 **Spanish (SP)-Basque (BQ) bilingual** infants.
- 30 **Spanish monolingual** (>90% exposure to SP) infants
- 33 **Basque monolingual** (>90% exposure to BQ) infants.

Data acquisition

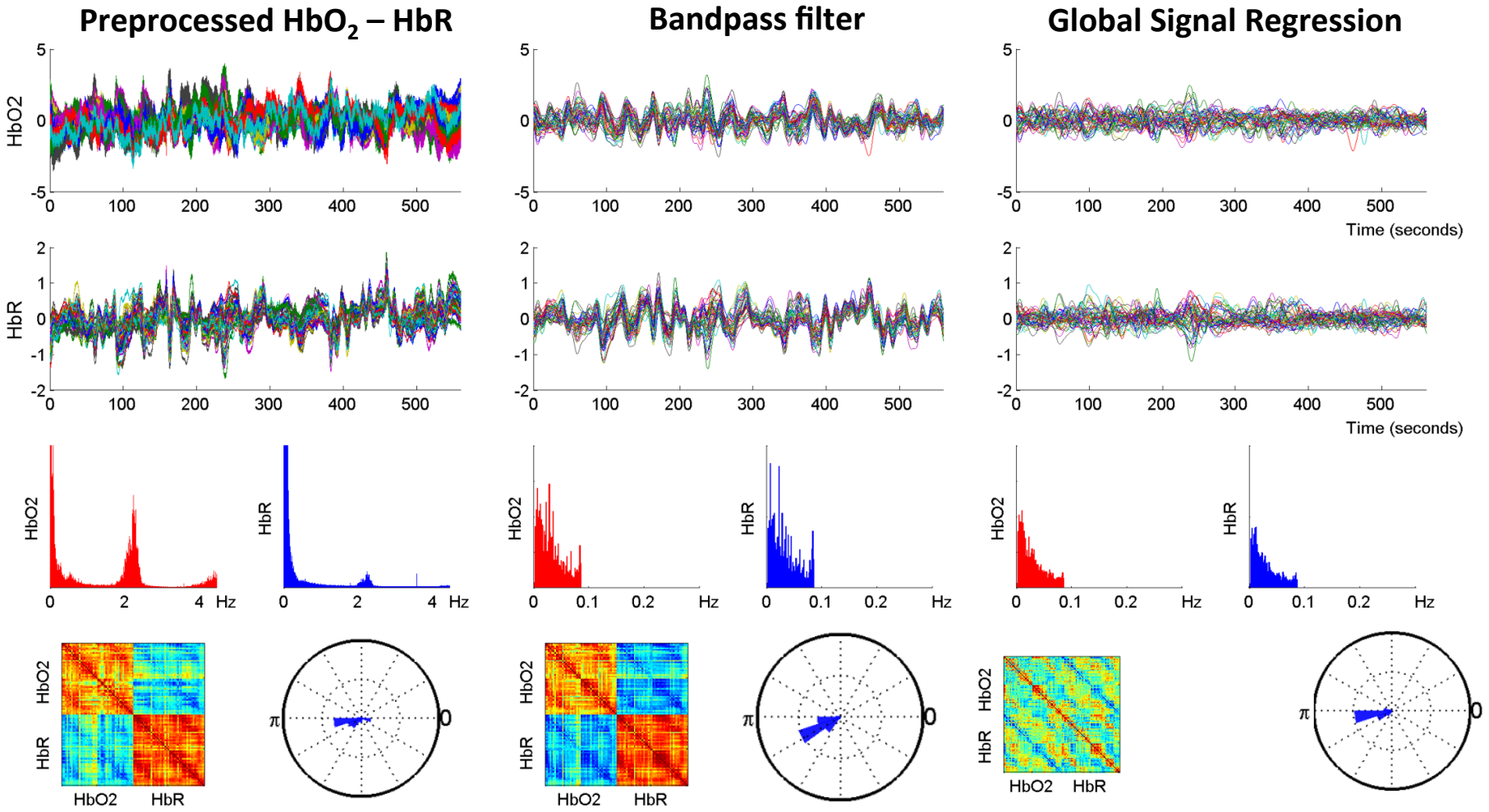
- Spontaneous hemodynamic activity during **natural sleep**.
- NIRx NIRScout system (16 sources – 24 detectors).
- **10 minutes recordings** of continuous data.

QA: Preprocessing I



Patel et al., 2014 *Neuroimage*

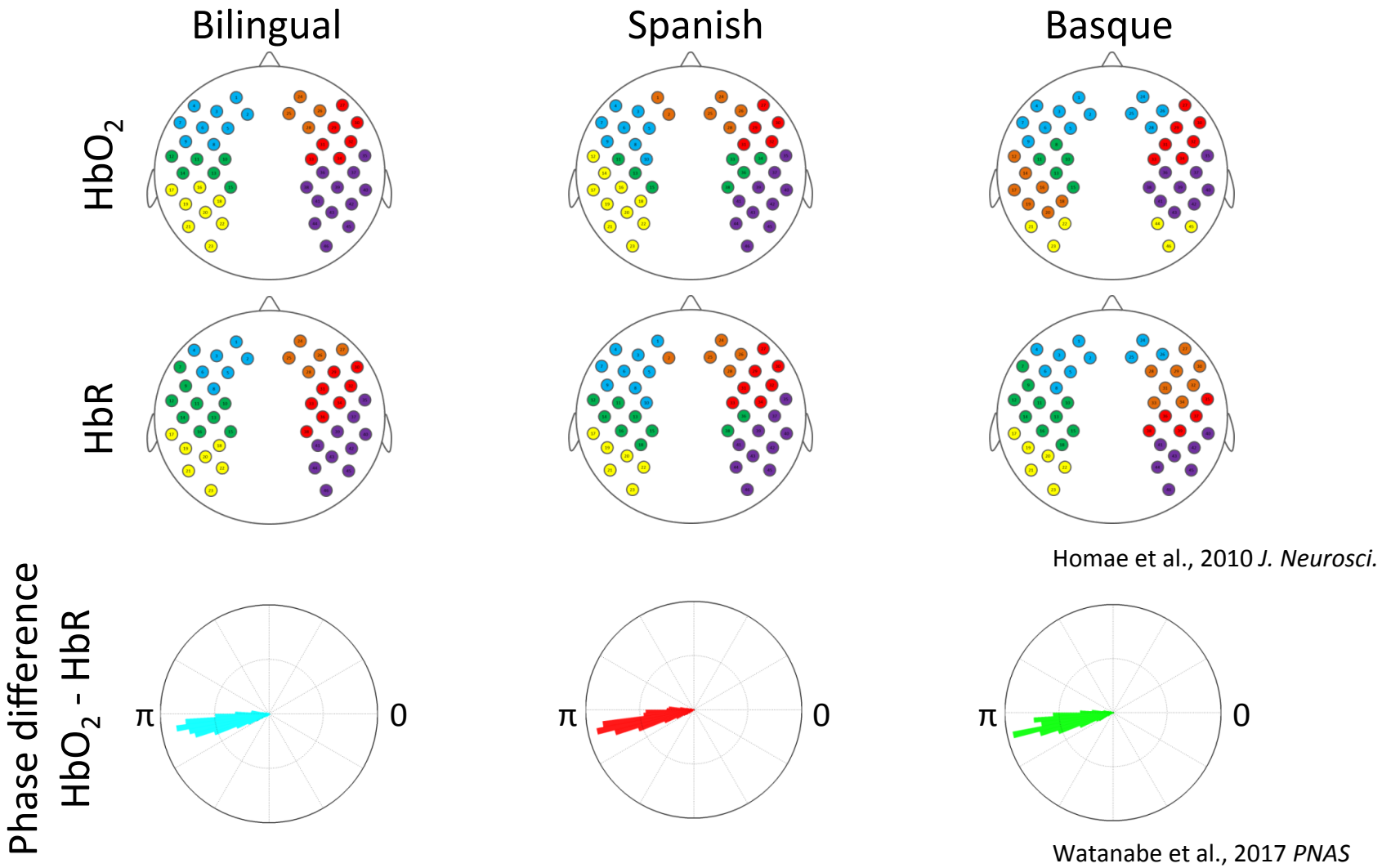
QA: Preprocessing II



Pfeifer et al., 2018 *Front. Hum. Neurosci.*

Santosa et al., 2017 *J. Biomed. Opt.*

QA: Replication of previous studies



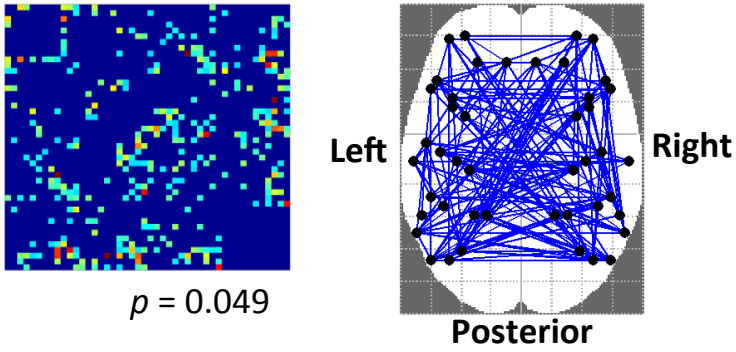
Homae et al., 2010 *J. Neurosci.*

Watanabe et al., 2017 *PNAS*

Group effects I: Network Based Statistics

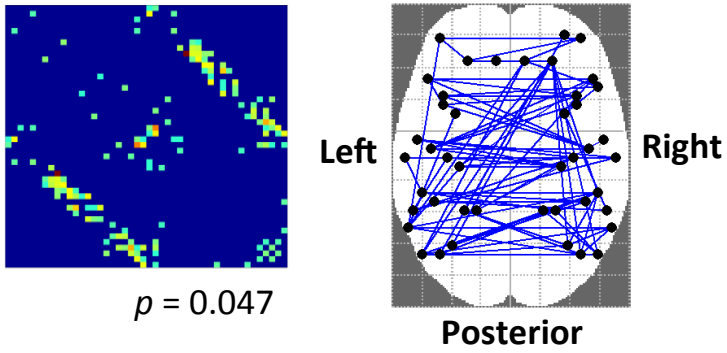
- Identify networks showing differences between groups.
  1. Compute statistics at each edge independently. Keep significant pairs.
  2. Identify networks (i.e., interconnected edges).
  3. Assess the significance of the network based on its size using non-parametric testing with participant permutation.

ANOVA group (HbR)



p = 0.049

SP > BQ Monolinguals (HbR)

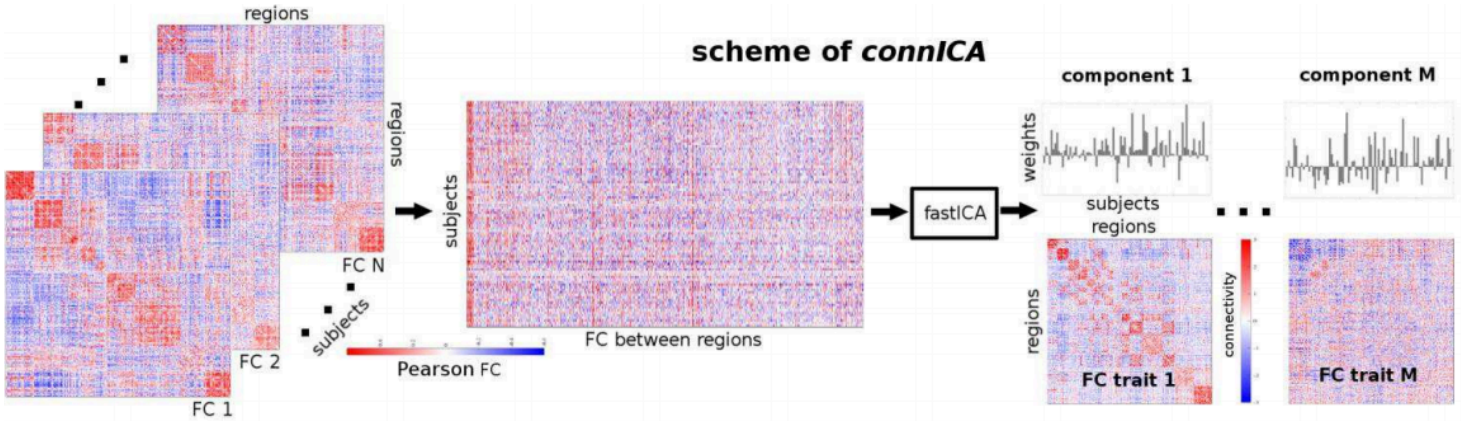


p = 0.047

Zalesky et al., 2010 *Neuroimage*

Group effects II: connICA

- Identify **robust independent FC patterns** in a set of individual FC matrices (i.e., connectomes).



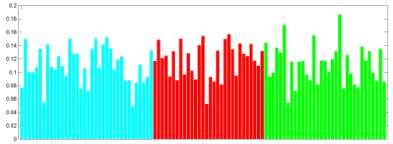
- Associated **weights** quantify the presence of the FC pattern in each participant and can be linked to individual metrics (e.g., clinical outcomes, bilingualism) to assess group differences.

Amico et al., 2018 *Neuroimage*

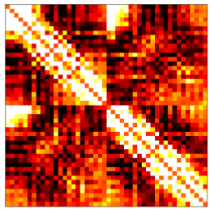
Group effects II: connICA

HbR

Weights



FC pattern

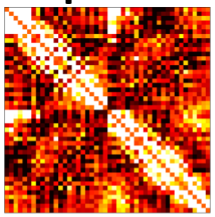


F (2, 96) = 0.86
p = 0.4246

Neighboring channels

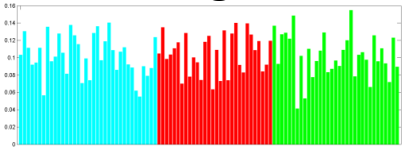
HbO_2

FC pattern

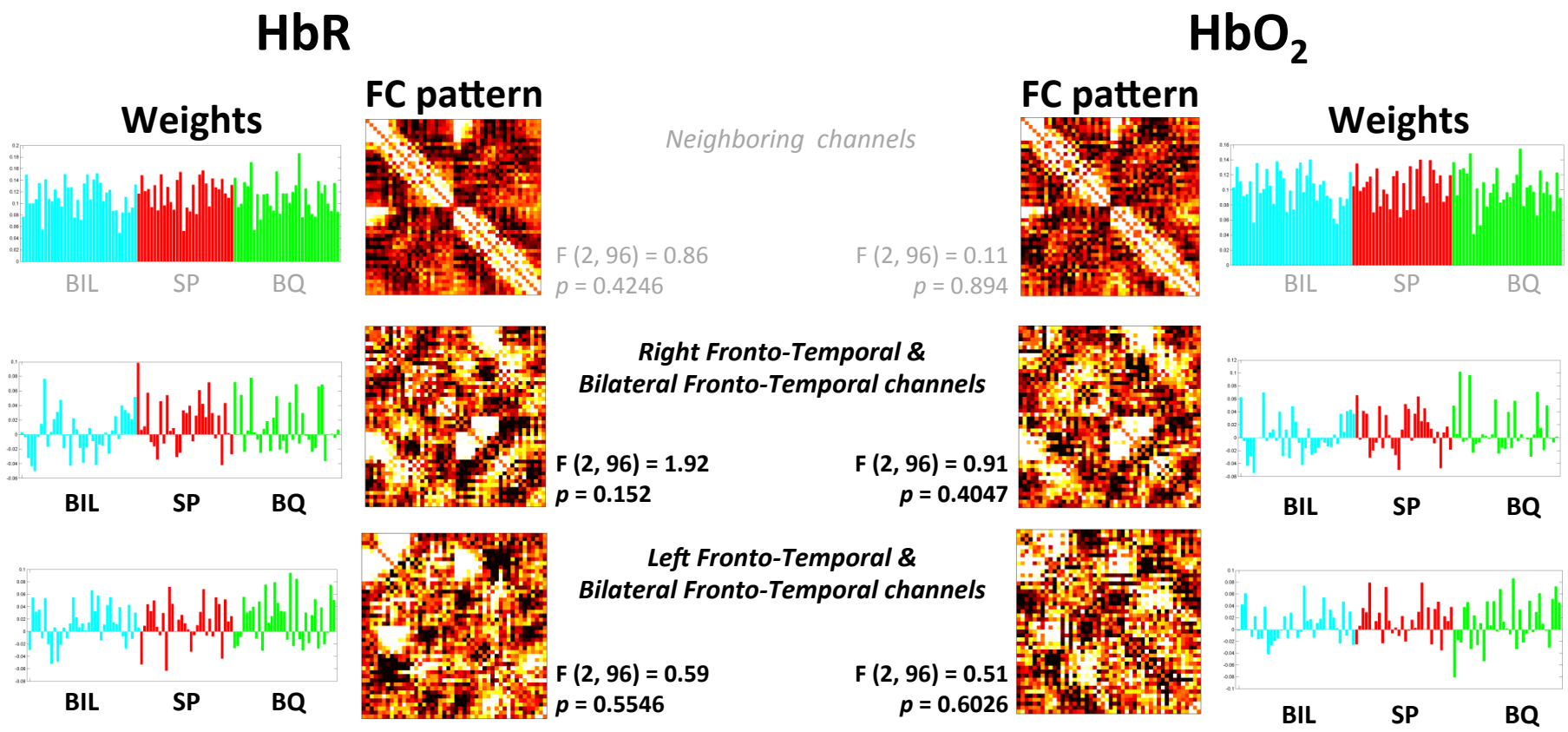


F (2, 96) = 0.11
p = 0.894

Weights



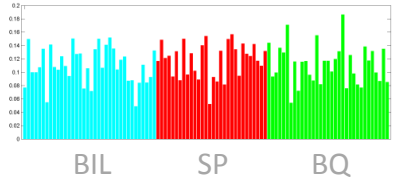
Group effects II: connICA



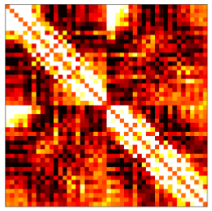
Group effects II: connICA

HbR

Weights

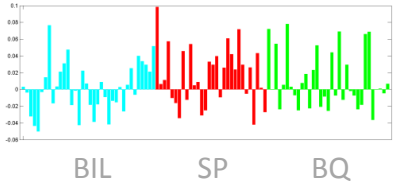


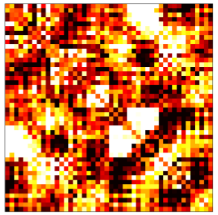
FC pattern



Neighboring channels

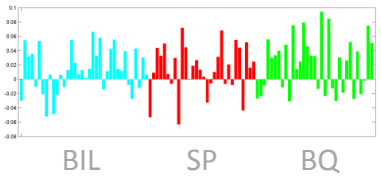
F (2, 96) = 0.86
p = 0.4246

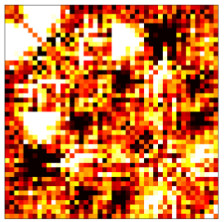




Right Fronto-Temporal & Bilateral Fronto-Temporal channels

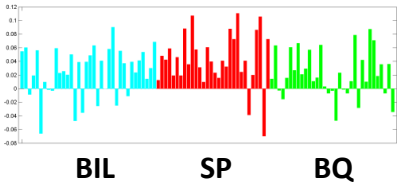
F (2, 96) = 1.92
p = 0.152

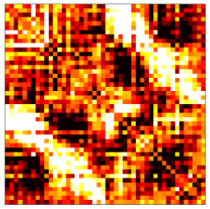




Left Fronto-Temporal & Bilateral Fronto-Temporal channels

F (2, 96) = 0.59
p = 0.5546



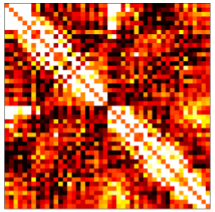


Bilateral-Homotopic channels

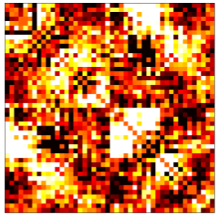
F (2, 96) = 3.26
***p* = 0.0426**
SP > BQ
***p* = 0.0497**

HbO_2

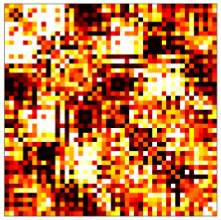
FC pattern



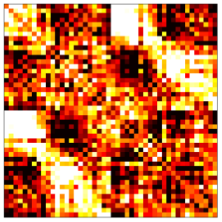
F (2, 96) = 0.11
p = 0.894



F (2, 96) = 0.91
p = 0.4047

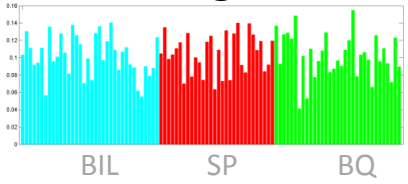


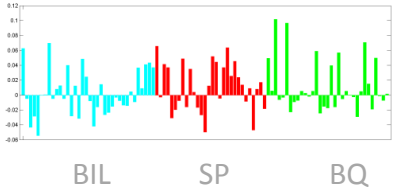
F (2, 96) = 0.51
p = 0.6026

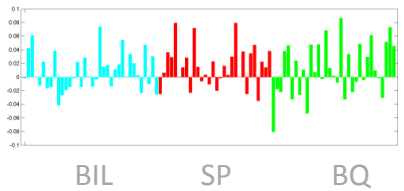


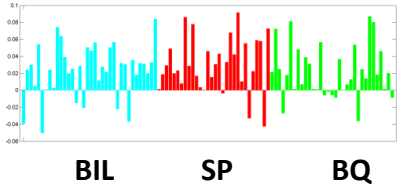
F (2, 96) = 0.8
***p* = 0.4516**

Weights

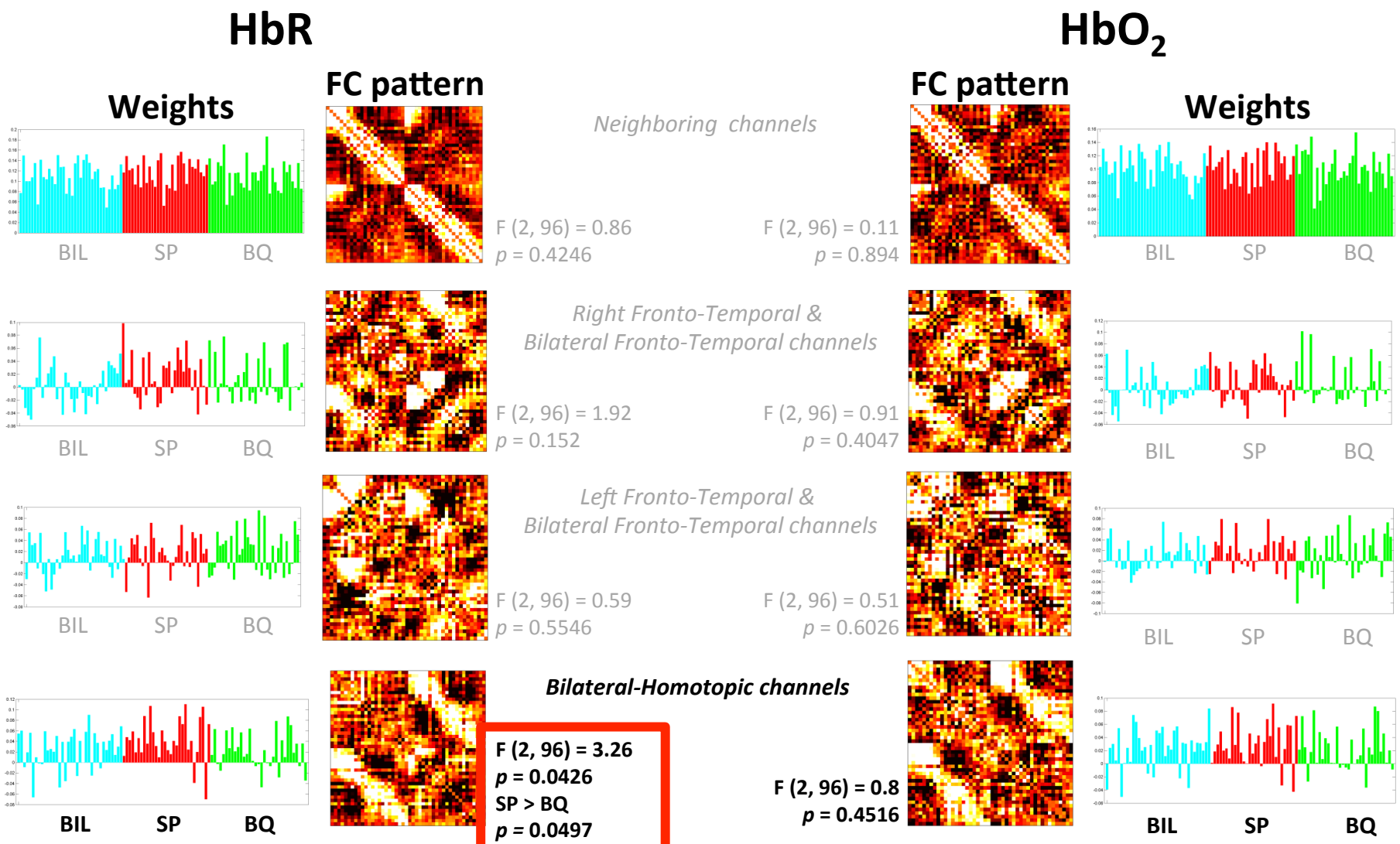








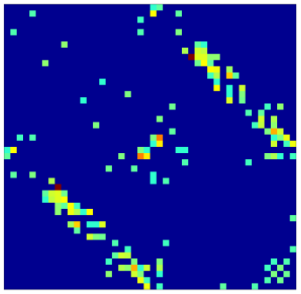
Group effects II: connICA



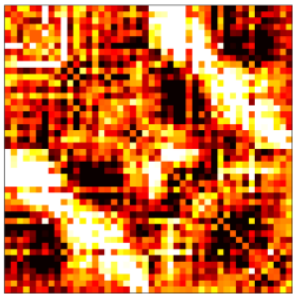
Discussion I: Early bilingual exposure

- **Marginal differences** between groups, but **consistent** results across methods.

SP monolinguals > BQ monolinguals



NBS (HbR)



connICA (HbR)

- Feasibility of **NBS** and **connICA** methods to assess group differences in fNIRS resting state FC studies.

Discussion II: Quality assessment

- Relevance of the current work:
  - Large sample size in three experimental groups.
  - Recording duration and data quality.
  - Replication of previous studies.

https://github.com/borjablanco/fNIRS-2018

- Impact of **data quality** and data **preprocessing** in infant fNIRS resting state FC studies.
- Importance of unified data processing criteria that ensure **consistency** across studies and **replication**.

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AND LANGUAGE

Thank you

https://github.com/borjablanco/fNIRS-2018

Monday October 8th. Poster session III – 66

Effect of prewhitening in resting-state near infrared spectroscopy data.

B. Blanco, M. Molnar and Cesar Caballero-Gaudes

Supplementary information

Early bilingual exposure

- Experience-related effects in brain structure and function (e.g., socioeconomic status, formal education, music training).

- Bilingual language acquisition.
  - **Language processing (bilingual ≠ monolingual).**
  - **Language acquisition (bilingual ≠ monolingual).**

Bialystok et al., 2017 *Psychol. Bull*
Costa and Sebastián-Gallés, 2014 *Nature Rev. Neurosci.*

- Bilingual adaptation in children and adults:
  - **Structural imaging**
  - **Functional task-based imaging**
  - **Resting state FC**

Mohades et al., 2015 *PLoS One;*
Li et al., 2014 *Cortex (Review)*

Arredondo et al., 2016 *Developmental Sci.;*
Abutalebi et al., 2012 *Cereb. cortex*

Berken et al., 2016 *J. Neurosci.;*
Grady et al., *2015 Neuropsychologia*

Early bilingual exposure

- Bilingual adaptation in infants:
  - **Behavioral studies**
  - **Functional task-based imaging**
  - **Resting state FC?**

Kovacs & Mehler, 2009a *PNAS*
Sebastian-Galles et al., 2012 *Psychol. Sci.*
Molnar et al., 2014 *Infancy*

Ferjan-Ramirez et al., 2017 *Developmental Sci.*
Nacar-Garcia et al., 2018 *Sci Rep.*

- Resting state FC in infants:
  - **Premature birth**
  - **Socio-economic status**
  - **Autism**

Smyser et al., 2010 *Cereb. Cortex* **(fMRI)**
Kwon et al., 2015 *Neuroimage* **(fMRI)**

Gao et al., 2015a *Cereb. Cortex* **(fMRI)**

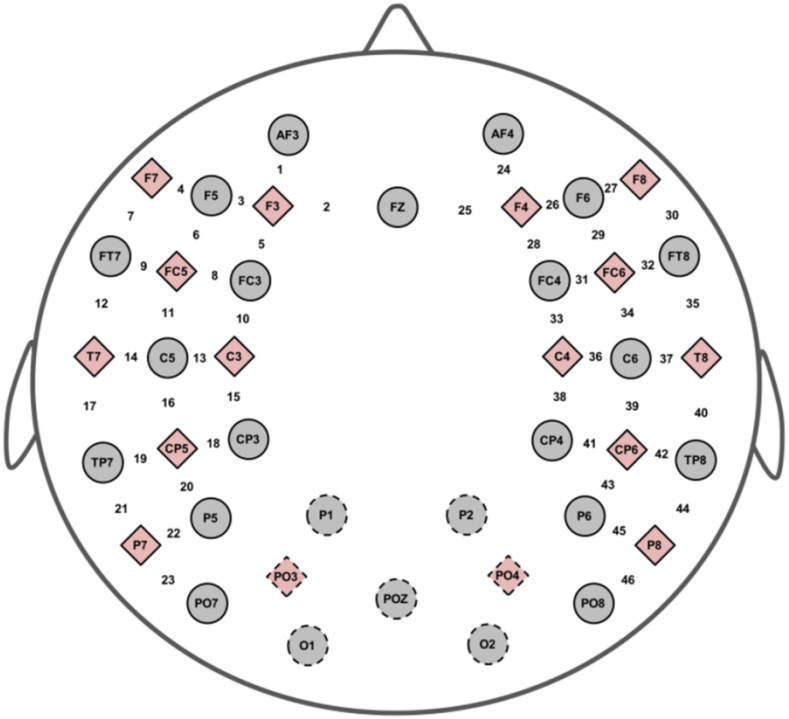
Keehn et al., 2013 *Front. Hum. Neurosci* **(fNIRS)**

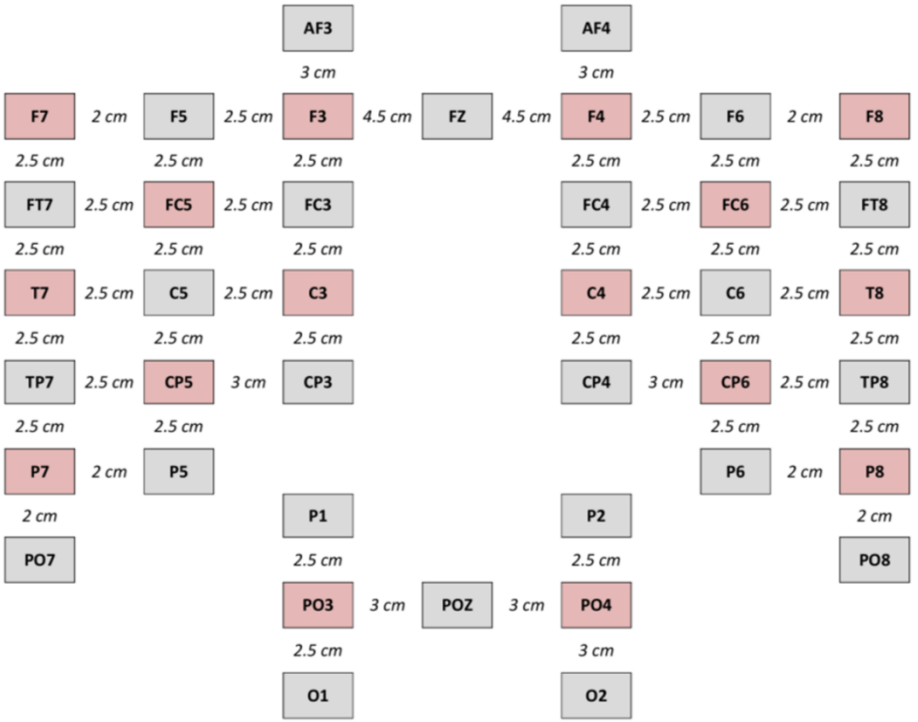
Participants

- **Total:** 123 healthy full-term infants.
- Not able to fall sleep (n = 16).
- Regular exposure to English (n = 1).
- Datasets shorter than 10 minutes (n = 2)
- Low data quality (n = 5).

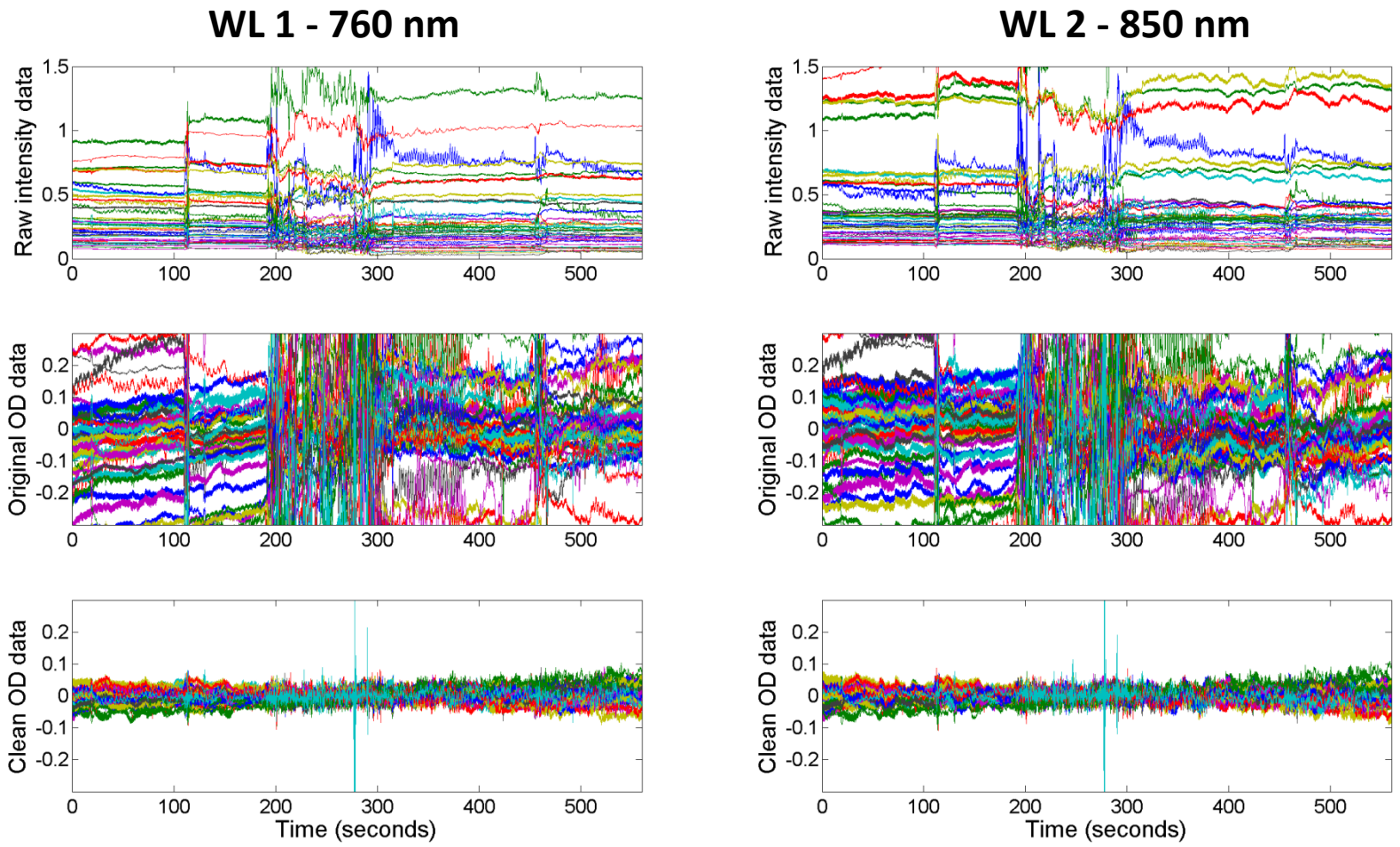
- **Final sample:** 99 healthy full term infants
- Bilinguals (n = 36, 21 girls).
- Spanish (n = 30, 13 girls).
- Basque (n = 33, 17 girls).

Optical probe



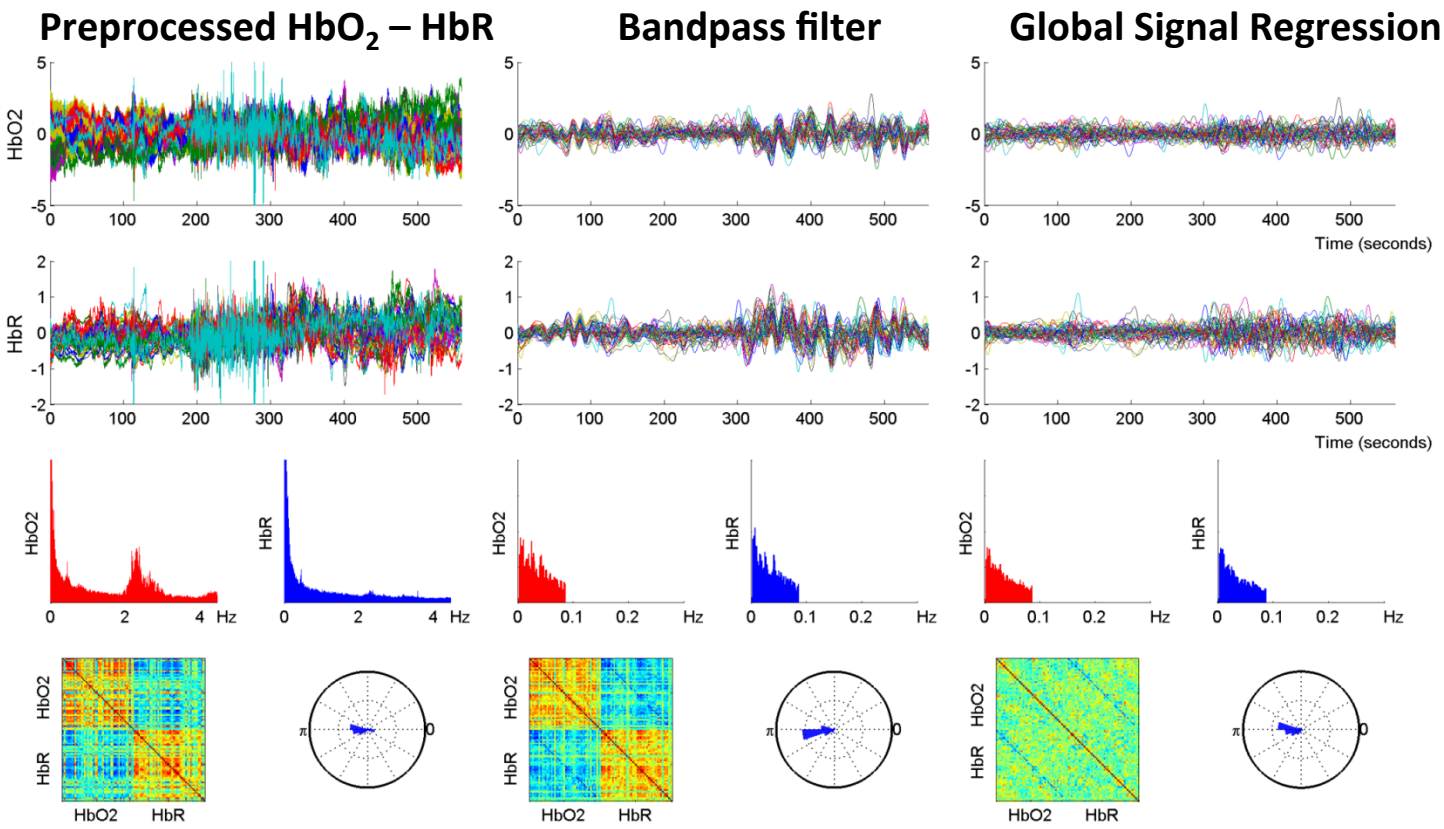


Example of a rejected participant



https://github.com/borjablanco/fNIRS-2018

Example of a rejected participant



https://github.com/borjablanco/fNIRS-2018

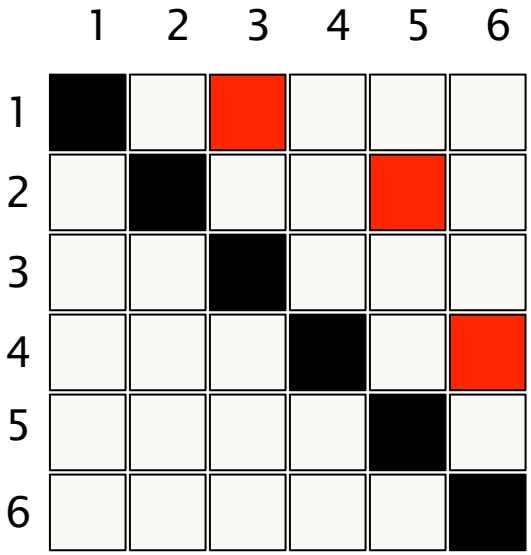
Network Based Statistics

1. Compute statistics for every pair of channels obtaining a matrix of F or T-values (i.e., equivalent to a F-test or a two-sample *t*-test at each channel pair).
2. Retain statistics of significant connections higher than a pre-specified threshold.
3. Identify clusters of connections *(networks)* among the connections exceeding the threshold (i.e., interconnected edges), and compute the size of the network.

   Two different measures of size: Extent (number of connections)
   Intensity (strength of the connections)
4. Compute significance of the network based on permutation testing where participants are randomly interchanged between the groups. Repeat the previous steps for each permutation.
5. The size of the networks found in each permutation is stored to construct the null distribution of the *p*-values.
6. NBS offers higher sensitivity than standard pairwise testing approaches maintaining strict control of false positives at the network level (FWER).

Zalesky et al., 2010 - *Neuroimage*

Network Based Statistics



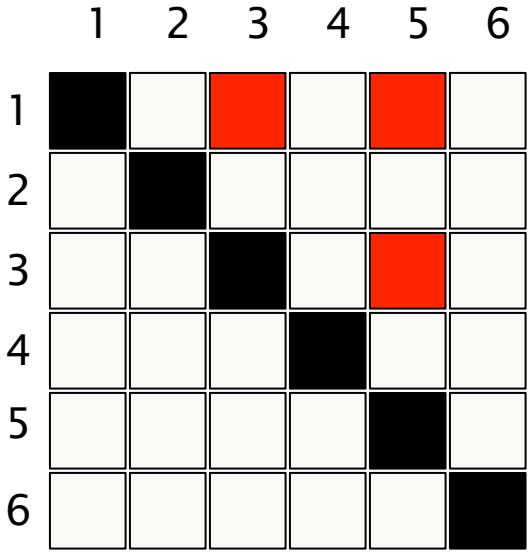
Connections higher than the prespecified threshold but not interconnected edges:

CH1 – CH3

CH2 – CH5

CH4 – CH6

NBS ✗



Connections higher than the prespecified threshold and interconnected edges:

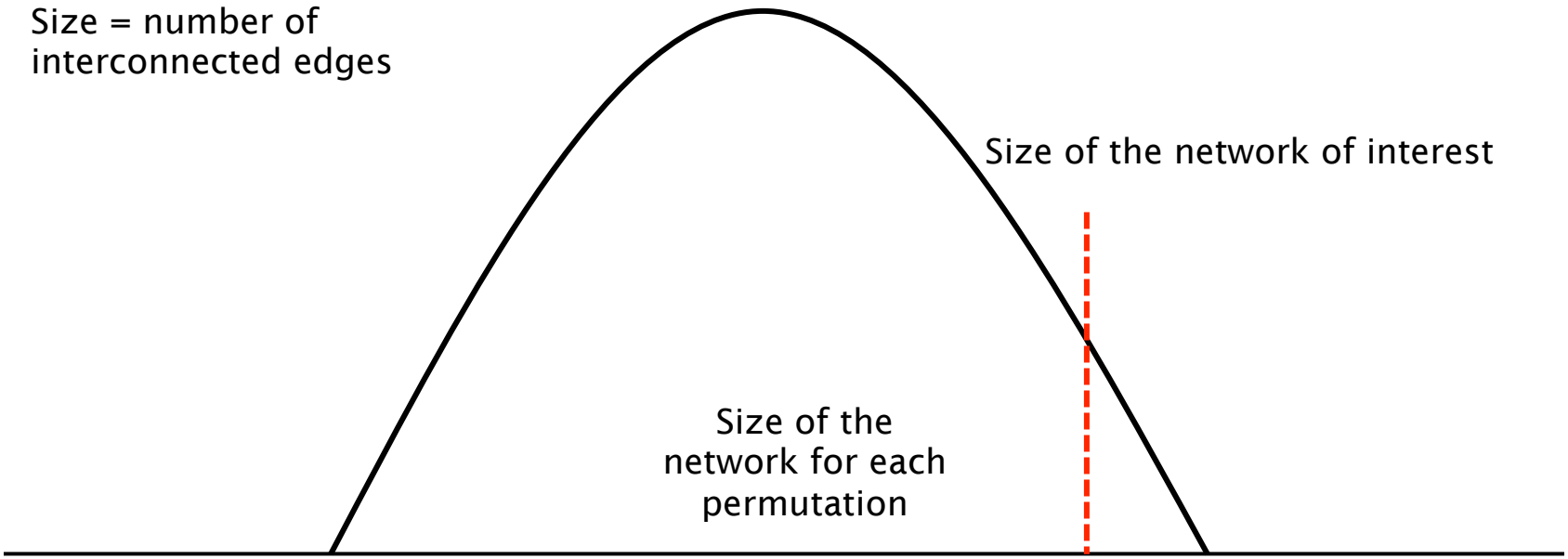
CH1 – CH3

CH1 – CH5

CH3 – CH5

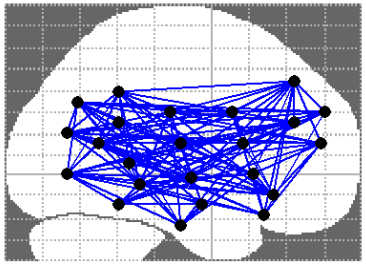
NBS ✓

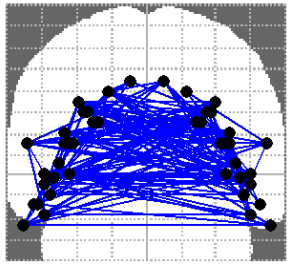
Network Based Statistics

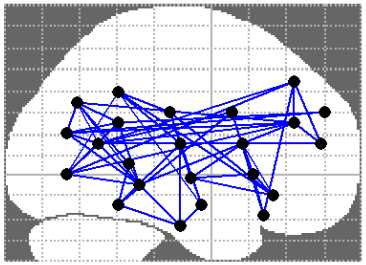


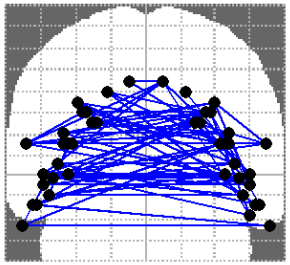
$$\text{P value} = \frac{\text{Number of networks larger than the network of interest}}{\text{Number of permutations}}$$

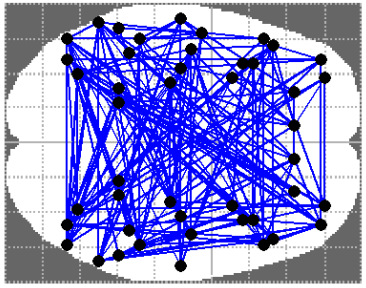
NBS: results



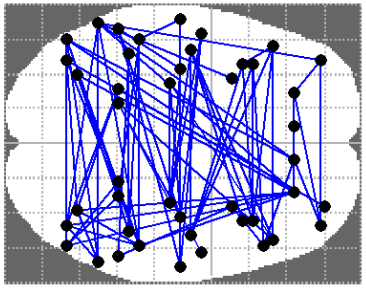








Displaying network 1 of 1
p-value: 0.049
Number of edges: 163
Number of nodes: 45
Click on a node or edge...

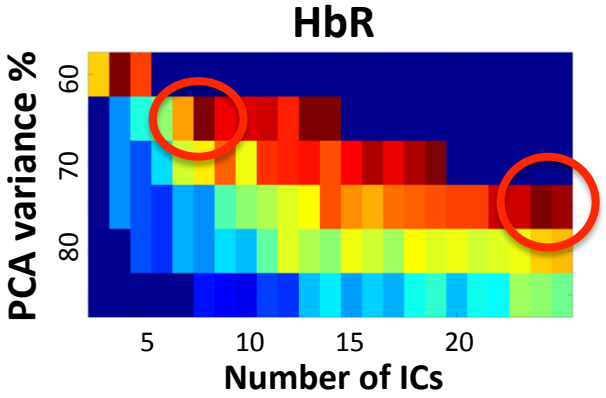


Displaying network 1 of 1
p-value: 0.047
Number of edges: 78
Number of nodes: 44
Click on a node or edge...

Parameters: connICA

- Two sets of parameters for explained variance (PCA) and number of ICs. **PCA 65% - number of ICs 8:** *global components*

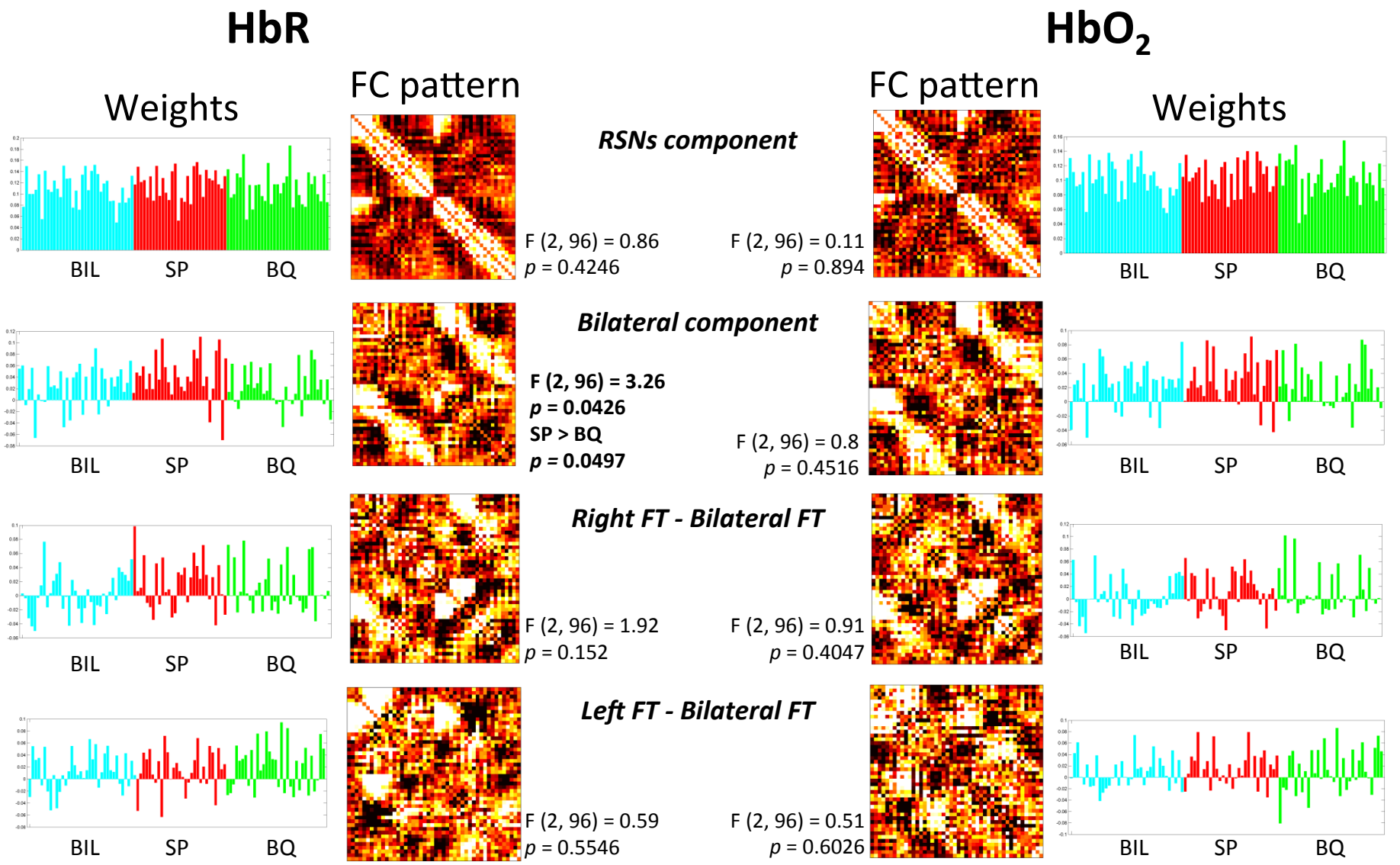
  PCA 75% - number of ICs 24: *focal components*



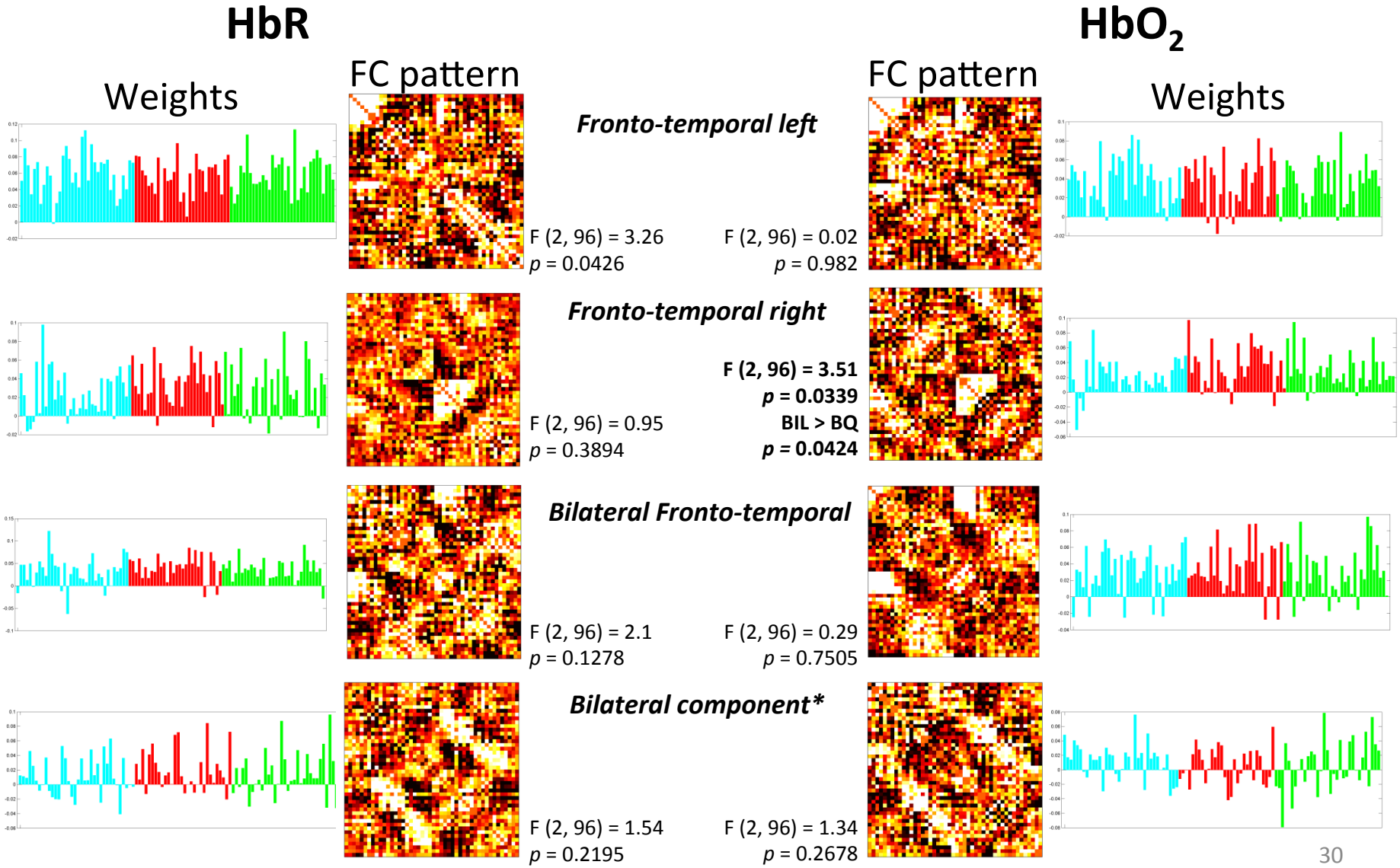
- Assess only FC patterns that appear across HbO_2 and HbR.
- Use the associated weights to test differences between groups.
- ANOVA & multiple comparison of group means (Tukey's HSD).

Amico et al., 2018 *Neuroimage*

connICA: PCA 65% - number of IC 6



connICA: PCA 75% - number of IC 24



connICA: PCA 75% - number of IC 24

HbR

HbO_2

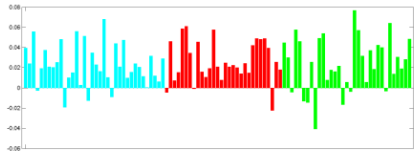
FC pattern

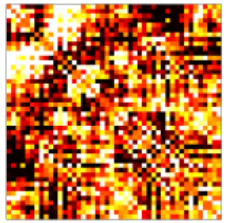
Weights

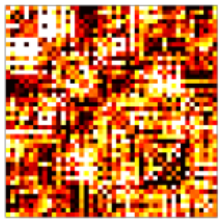
Temporal left

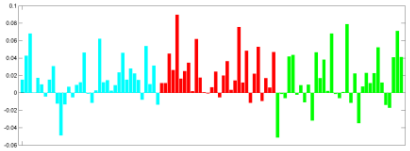
FC pattern

Weights

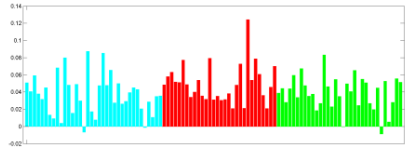


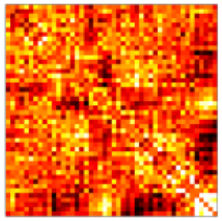


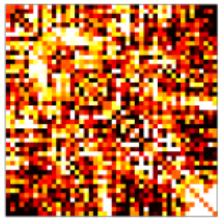


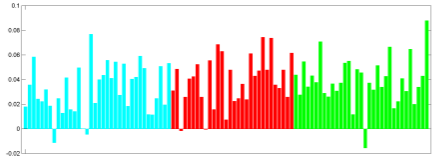


Parietal left

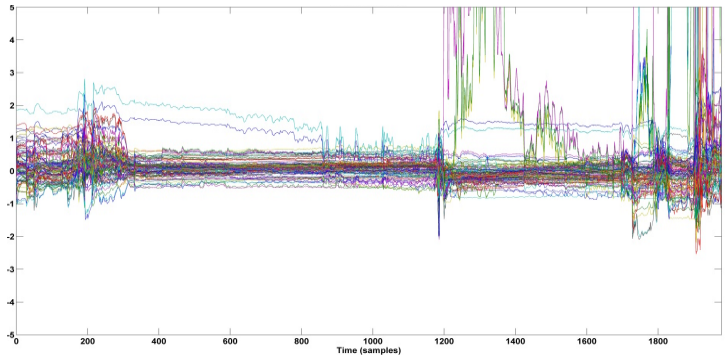


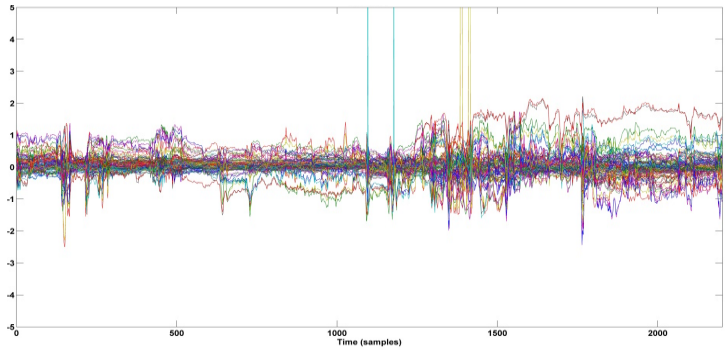


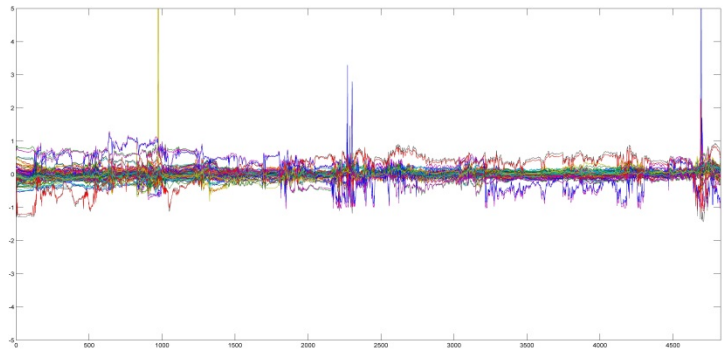




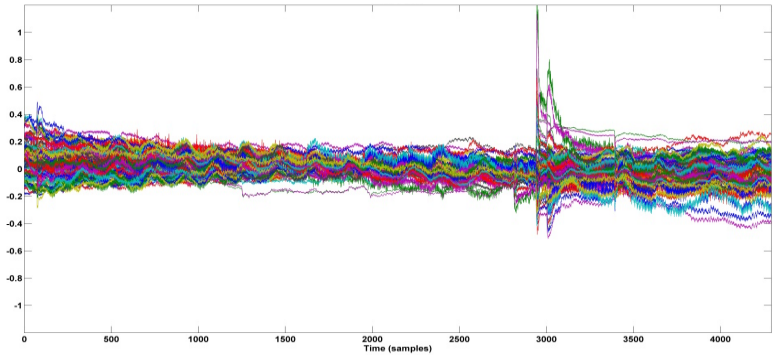
Awake infants

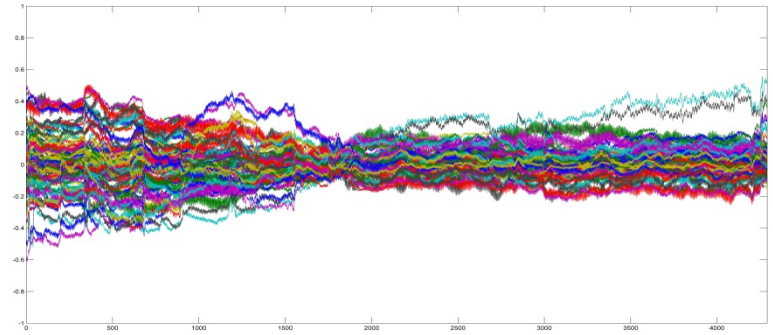


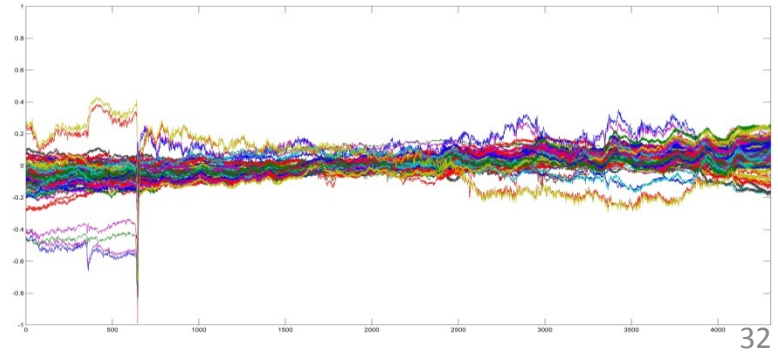




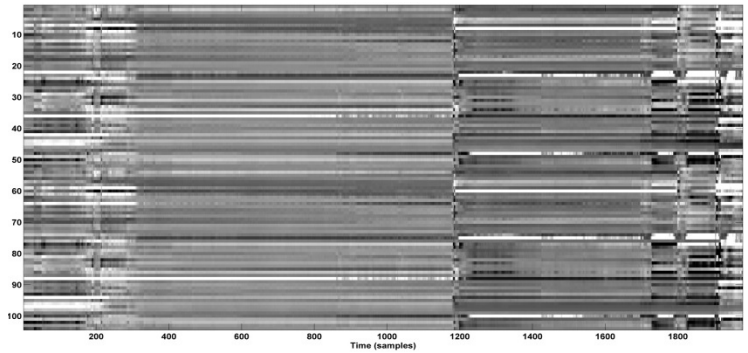
Asleep infants

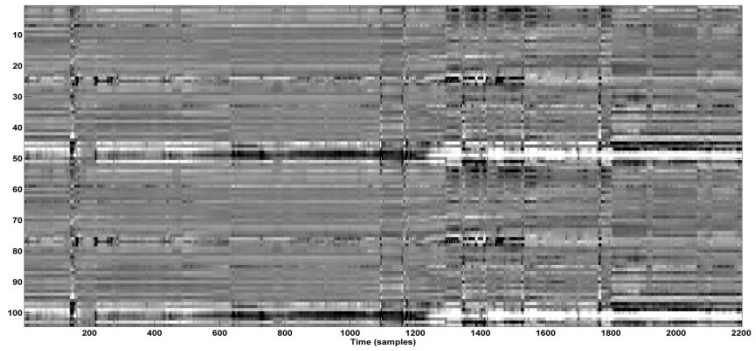


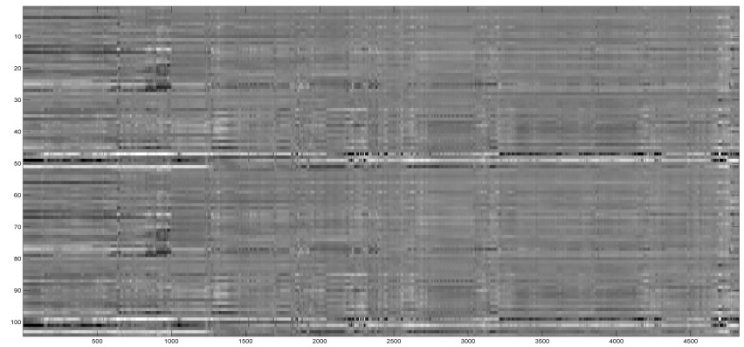




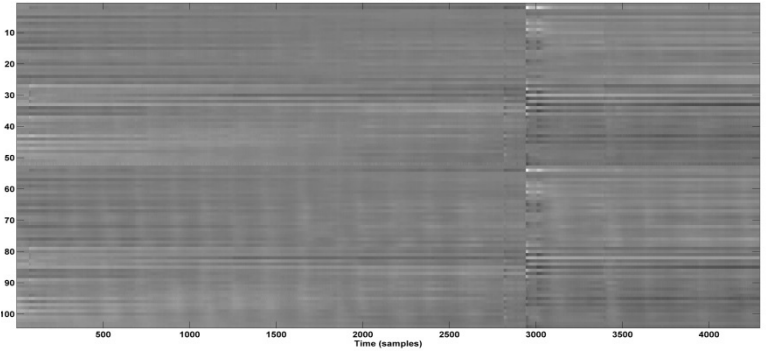
Awake infants

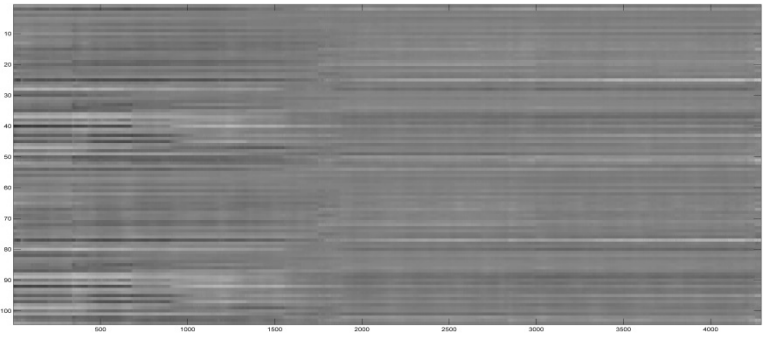


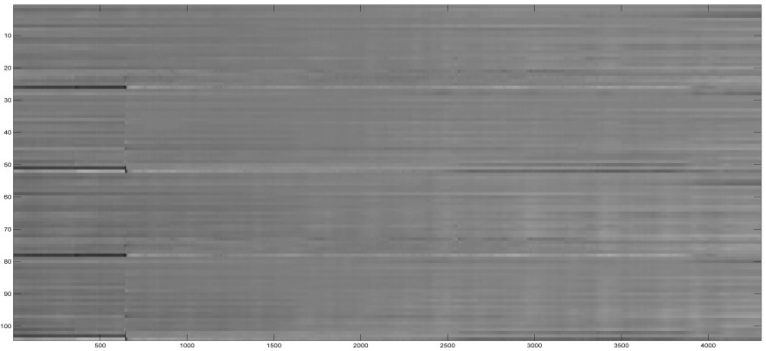




Asleep infants



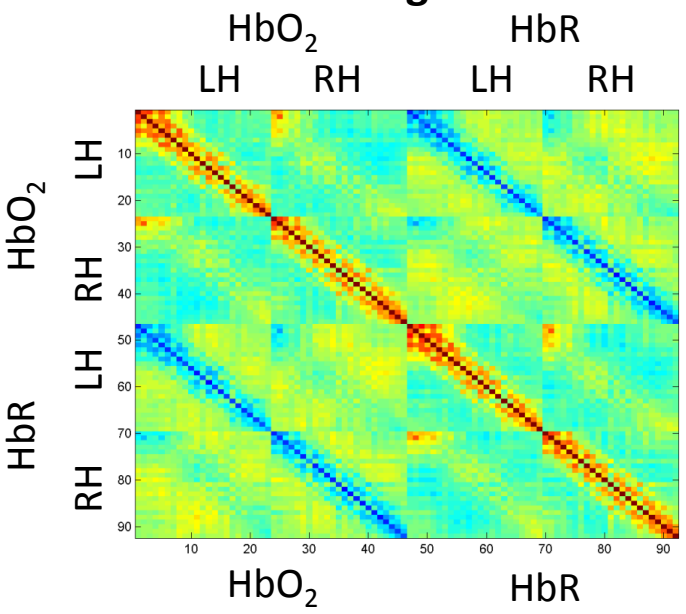




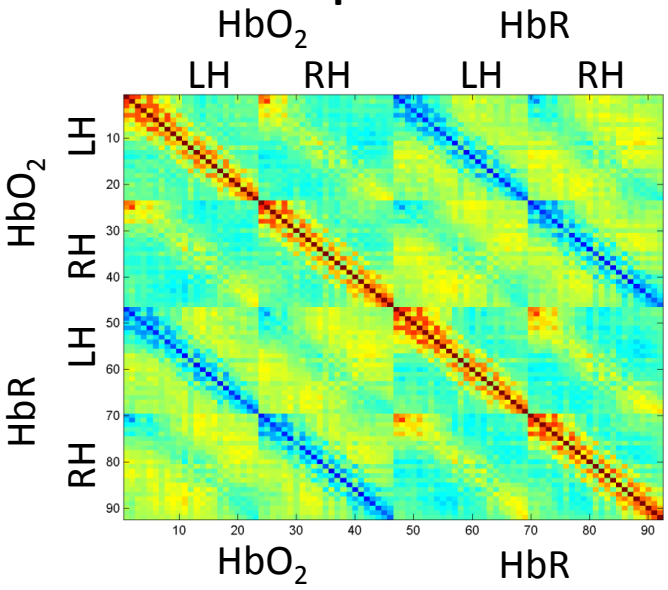
Average functional connectivity matrices in each group for:

- HbO_2
- HbR
- Between HbO_2 and HbR

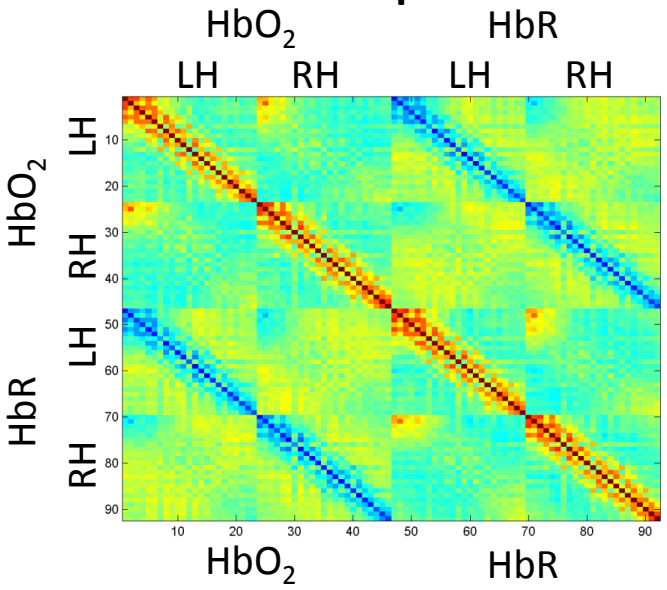
Bilingual



Spanish



Basque



3 clusters

Bilinguals

Spanish

Basque

HbO_2

HbR