Hybrid Eeg-MRI and Simultaneous neuro-FEedback for brain Rehabilitation
HEMISFER Partnership

• Labex team representatives
  • Christian BARILLOT (INSERM Visages U1228, IRISA CNRS 6074)
  • Anatole LECUYER (HYBRID Team, INRIA/IRISA CNRS 6074)
  • Rémi GRIBONVAL (PANAMA Team, INRIA/IRISA CNRS 6074)
  • Isabelle BONAN (PU-PH, INSERM Visages U1228, Rehabilitation Dept. CHU Rennes)

• Collaborator Team representatives
  • Dominique DRAPIER (EA 4712, University of Rennes I, Psychiatric Hospital of Rennes)
  • Maureen CLERC (INRIA ATHENA team, Sophia-Antipolis)
General objectives of HEMISFER

• Make full use of neurofeedback (NF) paradigm for brain self-regulation/stimulation in:
  • rehabilitation (ADHD, Stokes, ...)
  • psychiatric disorders (resistant mood disorders, anxiety, schizophrenia, ....)

• Main Challenges:
  • Learn a coupling model associating functional and metabolic information from simultaneous Magnetic Resonance Imaging (fMRI) and Electro-encephalography (EEG)
  • Enhance the NF paradigm from the coupling model
From Imaging Biomarker to therapeutic process

HEMISFER CONTEXT
General consideration about brain function

- Two views about brain functions [Raichle 2010]:

  - **Event-related activity**
    - Functional ASL/fMRI/EEG
  
  - **Intrinsic brain function**
    - Basal ASL
    - Metabolic activity
    - Perfusion
    - Connectivity
    - Electrical activity
    - dMRI
    - EEG
Biophysical parameters for fMRI (ASL and BOLD)

Neuronal activity

Energy needs of brain tissues

Conversion of glucose (CMR_Glc) & O₂ (CMR_O₂)

Cerebral blood flow and volume (CBF, CBV)

Blood concentration in dHb

Local magnetic perturbation due to dHb

BOLD Signal

\[ \text{BOLD} \propto \left( \frac{\text{CBF}}{\text{CBV} \cdot \text{CMRO}_2} \right) \]

\[ \frac{\text{CBV}}{\text{CBV}_0} = \left( \frac{\text{CBF}}{\text{CBF}_0} \right)^\alpha; \alpha = 0.38 \quad [\text{Grubb} - 74] \]

EEG

ASL

BOLD fMRI
Brain Perfusion as an imaging biomarker in psychiatry

- Perfusion abnormalities in depressions

- Results:
  - Hyper perfusion in right Hippocampal and left Cingulus regions (Apathy > Controls, n=30; p<0.05 FWE cluster level).
  - In line with general models of depression.

- Results (Group level):
  - Hyper perfusion in right striatum: Controls (n=30) < Patients (n=31; p < 0.05 FWE).
  - In line with general models of depression with hyperactivity of limbic and para limbic structures and a lower level of activity in neocortical regions.

Patient CD10 > control group (n=30)

Patient MJG20 > control group (n=30)

"Robert G. et al. 2014"
From imaging biomarkers to new therapeutic solutions: The HEMISFER Project

Acquisition of brain functions (MRI/EEG)

Data Processing
- Pretreatments (artifacts, …)
- Real time data analysis
- Extraction of patterns of interest

Rehabilitation

Production of « feedback »

Brain-state model learning

Brain state undergoing training
HEMISFER project: From imaging biomarker to image-guided therapy

- Joint project with Visages, PANAMA and HYBRID teams and Univ. Hosp. and Psychiatric Hosp. of Rennes
- Applications: Make full use of neurofeedback (NF) paradigm for brain self-regulation/stimulation in:
  - rehabilitation (ADHD, Stokes, ...)
  - psychiatric disorders (resistant mood disorders, anxiety, schizophrenia, ....)
HEMISFER : Experimental scenario
HEMISFER: Major challenges

- Develop new neurofeedback paradigms able to profit from simultaneous EEG/fMRI/fASL recordings
  - We expect these novel paradigms to be able to concentrate the brain metabolism on specific regions of the brain
- Learn models at the signal level able to explain the coupling of EEG and fMRI signals under simple and more advanced brain stimuli (e.g. BOLD fMRI, fASL, basal ASL)
  - Learn both the domain in which brain activity is sparse (e.g., dictionary learning), and adjust parametric models of the acquisition processes
  - Achieve super-resolution in the spatial and frequency domain by expressing the problem as a linear inverse problems regularized with the learned coupled model
  - Use brain connectivity models as prior information (later stage)
- Use the learned coupling models in order to “enhance” the EEG signal while performing the same stimuli and neurofeedback tasks outside MRI
Experimental Environment: The Neurinfo Platform

- 3T Verio by SIEMENS → 3T PRISMA:
  - 60 cm Diameters– Length 198 cm
  - 10 tons,
  - side positioning
  - Field of View: 50 x 50 x 50 cm
  - Gradients 80mT/m @ 200T/m/s, @400µs
  - 128 independent channels
  - Field homogeneity:
    - <0.1 ppm/h
    - 0.1 ppm (@ 40 cm)
    - 0,045ppm (@ 30 cm)
- MR-EEG BrainProducts 64 channels system

HARDWARE CONFIGURATION

Preliminary study: Safety issues for hybrid EEG/ASL

Accepted to ISMRM 2015 & SFRMBM 2015

On the feasibility and specificity of simultaneous EEG and ASL MRI at 3T

Elise Bannier1,2, Marsel Mano2,3, Robert Stroemer4, Isabelle Corouge2, Lorraine Perronnet2,3, Jussi T. Lindgren3, Anatole Lecuyer3, and Christian Barillot2

1Radiology, University Hospital of Rennes, Rennes, France, 2Unite VISAGES U746 INSERM-INRIA, IRISA UMR CNRS 6074, University of Rennes, Rennes, France, 3Unite HYBRID INRIA, IRISA UMR CNRS 6074, Rennes, France, 4Brainproducs GmbH, Gilching, Germany

<table>
<thead>
<tr>
<th>Start Time</th>
<th>Sequence</th>
<th>Duration (min)</th>
<th>TR (ms)</th>
<th>Slices</th>
<th>Dynamics</th>
<th>Flip Angle(°)</th>
<th>SAR (W/kg)</th>
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<tbody>
<tr>
<td>11:25:19</td>
<td>3D MPRAGE</td>
<td>08:08</td>
<td>1900</td>
<td>176</td>
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<td>9</td>
<td>0.046</td>
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Table1: Sequence parameters and SAR Values

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Project means

- BCI and rtfMRI (Hybrid, Visages)
  - 2 PhD Students
    - Lorraine Perronnet (Cominabs)
      - With Athena and coll. F. Lotte
      - Started 01-14, Defended 07-17
    - Mathis Fleury (FRM)
      - Started 11-17
- Real-time platform & Software integration (Hybrid, Visages)
  - 2 Research Engineers (PhDs)
    - Marsel Mano (Cominabs)
      - Started 06-14, Ended 09-17
    - Giulia Lioi (Cominabs + FRM)
      - Started 11-17
- Additional means (self funded)
  - MS/PhD in psychiatry (PI D. Drapier)
  - MS/PhD in Rehabilitation (PI I. Bonan)

- Coupling model between MRI and EEG (Panama, Visages)
  - 4 post-docs (Cominabs)
    - Thomas Oberlin (01/14 - 08/14)
    - Nicolas Raillard (02/15 - 03/15)
    - Saman Norzade (10/15 - 03/17)
    - Claire Cury (10/17 - ...)

- Grants:
  - Comin Labs:
    - Hemisfer (phase I)
    - Hemisfer-Clinical
  - FRM

- Experiments:
  - 100h of MRI experiments

- Additional means (self funded)
  - MR-compatible EEG system
  - Computing (GPU, ...)
  - Travelling
General Organization

Simultaneous EEG-fMRI data acquisition

Off-MRI EEG data acquisition

Learned EEG-MRI coupling model

Model Update

Coupling Model

Giulia LIOI

Claire CURY

Magnis FLEURY
Added value of collaboration

- Signal & image processing and machine learning
- BCI and EEG processing
- Real-time processing of fMRI (BOLD and ASL)
- Clinical Research

- PANAMA team along with VISAGES and ATHENA teams
- HYBRID, Visages and ATHENA teams
- Visages U1228 and Hybrid Teams along with Neurinfo
- Visages U1228, Hybrid and EA 4712 teams

- Potential industrial collaboration (*long term*):
  - Clinical research: Biotrial
  - BCI and software integration: Mensia Tech.
Hemisfer: Current Summary

- Project actually started on Jan 2014
- Major Originalities:
  - The “theragnostic” concept: translate imaging sensors to therapeutic systems
  - Hemisfer paradigm never addressed before
  - Joint fMRI/EEG for Neurofeedback addressed only very recently by one team in 2014 *(not afterwards)*
  - EEG/fMRI coupling model from machine learning and sparse representation has never been addressed before
- Major opportunities:
  - High integration of the work between the Hemisfer partners (from information processing, brain
computer interface to clinical medicine)
  - Two major clinical applications: same generic technology applied to two very different clinical
rehabilitation domains
  - Ancillary opportunity: *observe the pathological brain under evolution*
- High efficiency of the collaboration:
  - All dedicated people are shared between at least two teams
  - Effective cross-fertilization between different domains (signal & image processing, VR & Virtual
interfaces, medicine)
- Actual outcomes
  - Technological aspects:
    - integration of a new MR-compatible EEG system (Brain Product)
    - Integration of real time processing for the EEG/fMRI system (first in-vivo experiments done) *(one patent is under discussion)*
  - One of the first world-wide study for safety compatibility of simultaneous ASL/EEG recording
  [*ISMRM & SFRMBM 2015*]
**Hemisfer: Current Publications**

- **Coupling EEG and fMRI**

- **Platform**

- **Neurofeedback**

- **Misc.**

- **Workshop Neurofeedback and Brain Computer Interfaces (Rennes, Sept. 7th, 2017)**