Signal Processing for Functional Brain Imaging: Applications of ICA and Multimodal Techniques

Dimitri Van De Ville
Medical Image Processing Lab, EPFL/UniGE
dimitri.vandeville@epfl.ch

March 28, 2013
Overview

- Applications of ICA
  - Temporal ICA: application to EEG
  - Spatial ICA: application to resting-state fMRI

- Multimodal techniques
  - Basic principle
  - Combining fMRI with EEG
    - Artefacts identification and removal
    - Asymmetric fusion: EEG-informed fMRI analysis
      - Scoring of EEG (epileptic spikes)
      - Timecourses from ICA on EEG
      - Microstate sequences
    - Symmetric fusion:
      Independent component analysis for multimodal data
Temporal versus spatial ICA

- **Temporal ICA**
  - Observation is mixture of independent temporal sequences
  - Unconstrained images

- **Spatial ICA**
  - Observation is mixture of independent spatial images
  - Unconstrained temporal sequences

[Stone, Independent Component Analysis]
Two-back learning task

[Onton and Makeig, 2006]
Resting-state studies

- But what is baseline?
  - Brain is 2% of body weight but consumes 20% of body’s energy
  - Differences related to tasks explain less than 5% of total brain energy
    - 95% are used to maintain the machine!

- Looking at task-related data is only the tip of the iceberg!
But ICA allows to go further!

- ICA of resting-state (typically 10min) reveals several large-scale grey-matter brain networks!

[Mantini et al, 2007]
Multimodal imaging

- Combination of images
  - From different sources (i.e., instruments)
  - Showing different contrasts (e.g., MRI)

- Why is it useful?
  - Multiple observations of the same phenomenon can lead to a more complete picture!

- Structural imaging
  - Bone, soft tissue (CT, MRI)
  - Fiber tracts (Diffusion MRI)

- Functional imaging
  - Electrical potential (EEG)
  - Blood perfusion, volume, BOLD (MRI, optical)
  - Metabolic information, uptake (PET)
Classical post-hoc fusion (MRI + PET)

- Informative for tumor imaging
  - Specific (molecular origin) signal of PET
  - Combined with good spatial resolution and soft tissue contrast of MRI

[Chen et al, 2007]
Function + structure

- **Function:**
  - Brain regions from resting-state ICA (default-mode)

- **Structure**
  - Tractography on diffusion-weighted MR between DM brain regions

[Damoiseaux, Greicius, 2009]
EEG & FMRI

EEG – high temporal resolution

- 5000 maps / sec
- precisely WHEN in the brain

fMRI – high spatial resolution

- 50.000 voxels / TR
- precisely WHERE in the brain

[Adapted from J. Britz]
EEG & FMRI

- Complementary information!
  - Spatial and temporal properties
  - Nature of the signal
- “Marry the lame and the blind”

[Adapted from J. Britz]
EEG & fMRI: acquisition strategy

- Sequential or simultaneous measurements?
- Time scale of phenomenon w.r.t. acquisition time?
  - Short: degree of synchrony more crucial
    - Single evoked response, epileptic spike, sleep discharge,...
  - Long: degree of synchrony less crucial
    - Effect of aging, tumor, anatomical changes,...
- Not interested in individual events? Averaging OK? Is data of different sessions comparable?
  - Yes: asynchronous acquisition
  - No: need synchronous acquisition
- Two examples in EEG & fMRI
  - Conventional evoked potential: async. OK
  - Interictal epileptic spiking, single trial, resting-state: sync. needed

[Inspired from Lemieux; Debener et al., 2006]
Getting the best of both worlds

- Simultaneous EEG & fMRI acquisition
- Avoid loops of cables to avoid induced current (skin burns!)
- MRI-compatible EEG equipment
  - Non-ferromagnetic, battery-powered amplifiers
  - Fiber-optic transmission of digitized and amplified signals
- Capture both brain signal (tiny, uV) and artefacts (huge, >1’000 larger) without *saturation* and *aliasing*
  - Large dynamic range of amplifiers
  - High sampling rate (5kHz)
- Perfect phase synchronization between amplifier and scanner clock!
Electric currents in magnetic fields

- Induced current due to Faraday’s law of induction

- Gradient artefact: alternating magnetic field (MR pulse sequence) induces current in a conductor

- Ballistocardiogram artefact: moving conductor (pulsating blood) in magnetic field induces current
Gradient artefact

- **MR pulse sequence**

- **Induced signal in EEG electrodes**

[Adapted from J. Britz]
Gradient artefact

- Large amplitude, but machine-generated!
  - Reproducible down to sub-millisecond

- Algorithm
  - Compute artefact-locked moving average of induced gradient signal
  - Subtract!

[Allen et al., 2000]
Ballistocardiogram artefact

- Several hypotheses
  - Pulsating vessels displace electrodes (temporal poles)
  - Cardiac-pulse driven head rotation

- Slightly reproducible; variability even between cardiac cycles!

- Typical EEG topographies

- Algorithm
  - Identify & remove artefact topographies with ICA
EEG-fMRI for epilepsy

- Pharmacoresistent epileptic patients
  - Presurgical evaluation with battery of tests
  - Determine seizure-inducing zone for brain resection

- Combined EEG-fMRI to localize underlying anatomical networks related to interictal spikes

- Fast phenomena + spontaneous events
  - Simultaneous measurements necessary!
Focal epileptic spikes on scalp EEG

- Focal epileptic interictal spikes
  - Brief (<100ms)
  - Magnitude 10 uV

- Subclinical:
  - No overt behavioral or cognitive expression
  - No movement artefact in EEG or fMRI

- Scoring of scalp EEG by experienced neurologist

[Adapted from Lemieux]
Epileptic spike-triggered fMRI

interictal EEG w/ spikes

time-course of interictal spikes

hemodynamic response function

convolution with HRF

GLM analysis of fMRI data

[Krakow et al., 1999; Lemieux et al., 2001]
Examples of spike-triggered fMRI maps

[Courtesy of Prof. M. Seeck and Dr. F. Lazeyras]
Building fMRI regressors with EEG ICA

[Debener et al., 2006]
**EEG mapping**

- Spatial topography is important

[Lehmann, 1971; Pascual-Marqui et al, 1995; Lehmann et al., 2009]

12 sec recording

spatial clustering (k-means, hierarchical, ...)
cross-validation indicates 4 states
Making the bridge from EEG to fMRI

[Britz, VDV, Michel, NeuroImage, 2010]
Auditory-phonological  Visual  Self-referential  Dorsal attention

Same networks are confirmed by fMRI group ICA analysis (out of 20 ICs)

[Britz, VDV, Michel, NeuroImage, 2010]
Symmetric fusion

- Different features “at same level” in decomposition
  - Joint ICA (blind)
  - Parallel ICA (semi-blind)
Joint ICA

- Combine (non-simultaneously acquired) EEG & fMRI
  - Auditory oddball experiment

Data
- For each subject
  - fMRI feature = peak of “target”-locked fMRI map
  - EEG feature = electrode Cz of “target”-locked EEG signal

[Calhoun et al., 2006]
Joint ICA: Input

- Group average of fMRI peak map & ERP

[Calhoun et al., 2006]
[Calhoun et al., 2006]
Components with ERP load

[Calhoun et al., 2006]
Maps at specific ERP timepoints

- N1 - primary auditory cortex
- N2 - sensory integration, secondary aud. cortex
- P3a - frontal and parietal lobes

[Calhoun et al., 2006]
ERPs at specific positions in the brain

[Calhoun et al., 2006]
Conclusion

- Multimodal imaging
  - Combining different modalities can improve our knowledge
    - $1+1=3$

- Overview of acquisition strategy: synchronized or not?

<table>
<thead>
<tr>
<th>Protocol feature</th>
<th>Separate</th>
<th>Simultaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal signal quality</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Possibility to optimize design</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Avoidance of order effects</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Identical sensory stimulation</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Identical subjective experience</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Identical behavior</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Direct temporal correlation of EEG and fMRI signals</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

[Debener et al., 2006]