Independent Component Analysis of Electrophysiological Data

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Blind EEG Source Separation by Independent Component Analysis

ICA can find distinct EEG source activities -- and their ‘simple’ scalp maps!
ICA Assumptions

- Mixing is linear at electrodes
- Propagation delays are negligible
- Component locations are fixed
- Component time courses are independent
- \# components \leq \# scalp channels

Contribution to EEG

# Scalp channels

# Effective sources

\[ \text{Contribution to EEG} \]

\[ \text{\# Scalp channels} \]

\[ \text{\# Effective sources} \]
Are EEG effective source signals independent?

Independent Domains of Local Synchrony

Cortex

Thalamus

Freeman - phase cones
Plenz - avalanches

S. Makeig (2007)
Properties of EEG Independent Components

- Maximally Temporally Independent
- Concurrently Active and Spatially Overlapping
- Dipolar Scalp Maps
- Functionally Distinct
- Between-Subject Similarity / Complexity
ICA vs. PCA

PCA simply decorrelates the outputs using an **orthogonal mixing matrix**.

PCA makes each successive component account for as much **variance** in the data as possible.

ICA makes each component account for as much **temporally independent information** in the data as possible, with no constraints on the mixing matrix.

**PCA lumps – ICA splits!**
ICA in practice
A P300’ visual target response at electrode Cz (vertex)

Average ERP

No net scalp response in these trials … Why not?

What sources contribute to these potentials?

Sorted trials

Sorted by potential
75-150 ms post-response

μV


erpimage()
The response (at Cz) sums 238 independent sources.

Scalp EEG signals are strong mixtures of brain sources. In this sense scalp channel signals are epiphenomena. Source signals are the EEG phenomena of real interest! No more than ~30% of any scalp channel variance is produced by any one brain source!
Classifying ICs

Non-brain sources

Effective brain sources

EOG

EMG

Brain

Brain
ICA finds Non-Brain Independent Component (IC) Processes...

...separates them from the remainder of the data...
Independent muscle signals

S. Makeig, J. Onton 2005
... and also separates cortical brain IC processes

Equivalent dipoles

Single dipole component

Dual-symmetric dipole component
Single Session - Two Maximally Independent Alpha Processes
ICA is a linear data decomposition method

$$\text{Act} = W \ast \text{Data}$$

$$\text{Data} = W^{-1} \ast \text{Act}$$

$$\text{Data} = W^{-1} \ast (W \ast \text{Data})$$

Makeig & Onton, 2011
Infomax ICA learning approach

How to make the outputs statistical independent?
Minimize their redundancy or mutual information.

Consider the joint entropy of two components,

\[
H(y_1, y_2) = H(y_1) + H(y_2) - I(y_1, y_2).
\]

Maximizing \( H(y_1, y_2) \)
\[\implies\]
Minimizing \( I(y_1, y_2) \).

The learning rule:
\[
\Delta W \propto \frac{\partial H(y)}{\partial W} W^T W
\]

Infomax

Is 0 if the two variables are independent

Natural gradient normalization (Amari)
Historical Remarks

• Herault & Jutten ("Space or time adaptive signal processing by neural network models", *Neural Nets for Computing Meeting*, Snowbird, Utah, 1986): Seminal paper

• Bell & Sejnowski (1995): Information maximization (Infomax)

• Makeig, Bell, Jung, Sejnowski (1996); ICA decomposition of EEG

• Amari et al. (1996): Natural gradient learning

• Cardoso (1996): Joint approximate diagonalization (JADE)

• Hyvarinen (1999): (fastICA)

• Lee/Girolami (1999): Mixture model ICA (Extended Infomax)

• Palmer (2006): Adaptive mixture ICA (AMICA)

Applications of ICA to biomedical signals

– EEG/ERP analysis (Makeig, Bell, Jung & Sejnowski, *NIPS* 1996)

– fMRI analysis (McKeown et al., 1998)

– Fetal/mother ECG separation (Cardoso, 1998)

– Electrocorticography (ECoG) (Whitmer, 2010)
Important Recent Result (2012)

Those linear decompositions of multi-channel EEG data that find ICs whose time courses are more temporally independent …

Also find more ICs whose scalp maps are highly ‘dipolar’ – i.e., ICs compatible with the spatial projection of a single local cortical (or non-brain, artifactual) source process – whose location can be accurately estimated.

More independent time courses $\leftrightarrow$ Larger number of dipolar ICs

Hypothesis: Dipolar ICs = Localized cortical source processes

Delorme et al., *PLOS One*, 2012
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Dipolar ICs = Localized cortical source processes

Delorme et al., *PLOS One*, 2012
Are locations of EEG effective source signals similar across tasks?

Are source locations within task similar across participants?
Effective Source Density

Visual Working Memory

dipoledensity()
Effective Source Density
Eyes-closed emotion imagination

>> dipoledensity()
Effective Source Density

Letter twoback with feedback

Onton & Makeig, 2005
Effective Source Density

Auditory novelty oddball

Onton & Makeig, 2005
Effective Source Density

A. Old/new word memory
Effective Source Density

B. Visually cued selective response

Onton & Makeig, 2005
Are source dynamics similar across participants?
Example: frontal midline theta cluster
Goal: To cluster equivalent ICs across subjects

<table>
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<th>Frequency (Hz)</th>
<th>Correct</th>
<th>Wrong</th>
<th>Difference</th>
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J. Onton, 2005

![Image of brain with Independent Component Clusters]
ERP image of 9.6-Hz alpha power

Onton, Delorme & Makeig, 2005.
Why analyze sources instead of channel activities?

ERSP

ITC

Channel of interest

J. Onton & S. Makeig, 2005
1. Record single-subject 68-channel EEG data

2. Decompose single-subject data with AMICA

3. Estimate IC equivalent dipole locations

4a. Identify & remove non-brain artifact ICs

4b. Compute artifact-removed channel ERPs

5. Cluster brain ICs across subjects based on

6a. Compute IC cluster ERPs

6b. Compute grand-average channel ERPs

Nonpsychiatric Comparison Subjects (NCS)

Schizophrenia Patients (SZ)

Deviant

Standard

MMN P3a RON

MMN P3a RON

P3a

MMN RON
The deepest mental trap in electrophysiology lurks in the word “THE” !!!
## PEAK AMPLITUDES

<table>
<thead>
<tr>
<th>Scalp Electrode (Fz)</th>
<th>ERP</th>
<th>r²</th>
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<tbody>
<tr>
<td>Verbal IQ (WRAT)</td>
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<th>Medial Orbitofrontal</th>
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Why don’t all subjects contribute to every IC cluster?
Subject differences?

Significant ITC differences (by bootstrap) between the LOC and fLOC clusters immediately follow Probe presentation (5-11 Hz).
Subject differences?
Subject differences?
Properties of EEG Independent Components

• Maximally Temporally Independent
• Concurrently Active and Spatially Overlapping
• Dipolar Scalp Maps
• Functionally Distinct
• Between-Subject Similarity / Complexity
But …

NB: Sleep spindles are *not* spatially stationary
More ...