ICA Decomposition of EEG Data

Virtual EEGLAB Workshop 2021
University of California San Diego

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ICA is a method to recover a version, of the original sources by multiplying the data by a unmixing matrix.
Independent Component Analysis

\[ x = \text{scalp EEG} \quad \text{W} = \text{unmixing matrix} \quad u = \text{sources} \]

\[ W^* x = u \]

\[ x = W^{-1} u \]

\[ W^{-1} \text{(scalp projections)} \]
“Secrets” to a good ICA decomposition

- Garbage in… garbage out (it’s not magic)
- Remove large, non-stereotyped artifacts
- Do you have enough data? (based mostly on time, not frames)
- High-pass filter to remove slow drifts (no low-pass filter needed)
- Remove bad channels
- Data must be in double precision (not single)
- Data must be full rank
Running ICA

Task 1
Run ICA
Task 2
Evaluating ICA Components
Download data at
http://sccn.ucsd.edu/eeglab/download/Workshop21_EEGdata.zip

Load:  data/faces_4.set
# ICA options

<table>
<thead>
<tr>
<th>Option</th>
<th>Default</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘extended’</td>
<td>0</td>
<td>1 is recommended to find sub-gaussians</td>
</tr>
<tr>
<td>‘stop’</td>
<td>1e-7</td>
<td>final weight change → stop</td>
</tr>
<tr>
<td>‘lrate’</td>
<td>determined from data</td>
<td>too small → too long… too large → wts blow up</td>
</tr>
<tr>
<td>‘maxsteps’</td>
<td>512</td>
<td>more channels → more steps</td>
</tr>
<tr>
<td>‘pca’</td>
<td>0 or EEG.nbchan</td>
<td>Decompose only a principal data subspace</td>
</tr>
</tbody>
</table>
Runica progress...

Input data size [33.133175] = 33 channels, 133175 frames/nFinding 33 ICA components using extended ICA. Kurtosis will be calculated initially every 1 blocks using 6000 data points. Decomposing 122 frames per ICA weight ((1089)^2 = 133175 weights, Initial learning rate will be 0.001, block size Learning rate will be multiplied by 0.98 whenever angledelta >= 60 deg. More than 32 channels: default stopping weight change 1E-7 Training will end when wchange < 1e-07 or after 512 steps. Online bias adjustment will be used. Removing mean of each channel ... Final training data range: -171,806 to 179,094 Computing the sphering matrix ... Starting weights are the identity matrix ... Sphering the data ...

Beginning ICA training ... first training step may be slow ...
step 1 - Irate 0.001000, wchange 16.85061324, angledelta 0.0 deg
step 2 - Irate 0.001000, wchange 0.26760405, angledelta 0.0 deg
step 3 - Irate 0.001000, wchange 0.73958323, angledelta 104.0 deg
step 4 - Irate 0.000990, wchange 0.66700331, angledelta 147.2 deg
step 5 - Irate 0.000990, wchange 0.62849071, angledelta 146.5 deg
step 6 - Irate 0.000941, wchange 0.73958355, angledelta 104.7 deg
step 7 - Irate 0.000922, wchange 0.73727229, angledelta 151.6 deg
step 8 - Irate 0.000904, wchange 0.74051387, angledelta 137.9 deg
step 9 - Irate 0.000888, wchange 0.74536137, angledelta 156.0 deg
step 10 - Irate 0.000868, wchange 0.72101402, angledelta 143.7 deg
step 11 - Irate 0.000851, wchange 0.14690114, angledelta 102.5 deg
step 12 - Irate 0.000834, wchange 0.11822200, angledelta 114.3 deg
step 13 - Irate 0.000817, wchange 0.75552966, angledelta 100.6 deg
step 14 - Irate 0.000801, wchange 0.26739750, angledelta 109.1 deg
step 15 - Irate 0.000785, wchange 0.12132351, angledelta 94.2 deg
step 16 - Irate 0.000769, wchange 0.10285606, angledelta 110.7 deg
step 17 - Irate 0.000754, wchange 0.09770439, angledelta 118.6 deg
step 18 - Irate 0.000739, wchange 0.09544428, angledelta 117.1 deg

Sorting components in descending order of mean projected variance ... Permuting the activation wave forms ...
Alternatives to runica

Infomax ICA
binica compiled version; fast
cudaica GPU version


AMICA
Best at extracting dipolar ICs
Multiple-model support
Run AMICA
Run AMICA

AMICA -- pop_runamica()

In File: /Volumes/ExtremeSSD/eeglab_workshop/EEG_data/data/

Out Directory: /Volumes/ExtremeSSD/eeglab_workshop/EEG_data/data/amicaout

# of Channels: 33
# of Models: 1
# of Threads: 2

PCA Dims.: 33
Models...
Sphering...
Generalized Gaussian
Block Sizes...
Lrates, Etc. ...
Load AMICA weights
Load AMICA weights
Results of ICA Decomposition in EEG struct
Source activation = unmixing * Channel data

Channel data = mixing (topo) * Source activation

EEG.icaact = (EEG.icaweights*EEG.icasphere) * EEG.data

EEG.data = EEG.icawinv * EEG.icaact
Now what…?

Part 1
Getting an overview of your ICs

Part 2
Classifying/Evaluating ICs

Part 3
Detailed look at IC properties
  ERP
  Spectrum
  ERP images
  ERSP
Evaluating ICA Components

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Load: data/faces_4.set

Tools → Extract Epochs

Subtract Baseline [-200 0]
Edit → Dataset Info → Enter Comments

Edit comments of current dataset

Parent dataset: faces_4 continuous

Parent dataset "faces_4 continuous":  ---------
Data acquired by: Stefan Debener
Data acquired on: Oct 15, 2005

Data:
33 channel EEG
nose-tip reference
sampling rate: 250 Hz
filtered: .5 - 100 Hz
16 bit, BrainAmps

Task:
speeded discrimination between objects and faces
500 ms presentation duration
ISI: 500-1900 ms
362 trials
Now what…?

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- Spectrum
- ERP images
- ERSP
A convenient ‘trick’…

Use ‘Reject components by map’ to survey components

NB: A new plugin "viewprops" is available!
An interactive overview of ICs
Step 0: Quality of Decomposition
Examining IC Properties

[Diagram of IC properties with images of brain activity and power spectrum]
IC Properties

IC Topography

topoplot()

ERP Image
&
ERP

erpimage()

Power Spectrum

spectopo()
Many plot panels in EEGLAB will expand when clicked on!
Part 1
Getting an overview of your ICs

Part 2
Classifying/Evaluating ICs
  Eye Artifacts
  Muscle Artifacts
  Other Artifacts
  Brain ICs

Part 3
Detailed look at IC properties
  ERP
  Spectrum
  ERP images
  ERSP
Evaluating ICs

Over time, most EEGLAB users develop a *heuristic* sense of which ICs might be brain vs. artifact.

Heuristics are generally based on:

- Topography
- Component Activities (scroll)
- ERP
- Power Spectrum

IC Classification can be used to ‘clean’ data—study likely brain activity without artifacts

*There are new efforts to automate this process, but doing it by hand is a good place to start to build intuition – IC Label plugin*
Topography
IC 4 – eyeblink

Classic frontal eye-blink topography

Sporadic large biphasic pulses

That may yet be task related!

But: highly variable (erpalpha=0.01)
Plot → Component Activations (scroll)
IC 4 Activation – eyeblink

Sporadic large biphasic pulses
IC 9 – lateral eye movement

Classic frontal eye-movement topography
IC 9 Activation – lateral eye movement
Narrowly spaced dipolar topography (consistent with superficial source)

Noisy ERP/ERP Image

High frequencies dominate power spectrum
IC 12, 18 Activation – Muscle
IC 17, 25 – Bad channels

Punctate topography (single channel)

Sporadic epoch activity (sometimes just a single large spike)
IC 2, 7 – Cardiac

Unusual, peaky spectrum (often peaks ~5, 10 Hz)

Periodic spikes (~1 / sec)

Cardiac-like topographies:
Shallow gradient = extremely distant source
Artifacts

Eye
Muscle
Cardiac
Badchan
Brain ICs

Classic occipital topography

Strongly task-related ERP Image & ERP

10 Hz Alpha peak
Dipole orientation matters
Brain ICs

Classic radial-dipole source topography

Strongly task-related ERP Image & ERP
Brain ICs

Classic tangential-dipole source topography
two peaks, not as closely spaced as muscle: deeper

Task-related ERP Image & ERP
IC Classification...so far

Eye
Muscle
Cardiac
Badchan
Brain
Now what…?

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  ERSP
Component ERPs
Definition: The data envelope

Data (all channels)

Data envelope (max/min traces)
Definition: IC Envelope

IC 10 Topography

Data Envelope

IC Envelope

IC 10 Activation ERP
back-projected to channels
Key: Scalp ERP peaks are often the sum of multiple independent source processes.

% Variance Accounted For (PVAF)

The variance of scalp EEG accounted for by this component

*ppaf

This component accounts for all of the negative scalp ERP peak at ~150 ms, but only some of other ERP peaks.

Net PVAF: 37%
Component ERP envelope
IC contributions to ERP envelope
Component contribution to the dataset ERP

Artifact Components

Largest ERP components of faces_4 epochs

Potential (μV) vs. Time (s)
IC ERP difference between two conditions

faces

objects
Now what...?

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Detailed look at IC properties
  ERP
  Spectrum (see John’s time-frequency lecture)
  ERP images
  ERSP
Plot component power spectrum

By default, plots topographies for frequency of largest peak
Now what…?

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ERP
Spectrum
ERP images
ERSP
Component ERP image
ERP Image basics

ERP Image

by default, sorted by time-on-task
(1\textsuperscript{st} trial, 2\textsuperscript{nd} trial, ...)

Trial 1

Trial 2

Trial 3

Trial 4
ERP Image basics

Trial 1:

Trial 2:

No Smoothing

Smoothed across 10 Trials
ERP Images: smoothing across trials

![Graphs showing moving averages across trials](image)
Evoked response in ERP Image follows the time of the button press.

This can be obscured in the ERP because reaction times are variable over trials.
Component ERP Images: Sort by phase

<table>
<thead>
<tr>
<th>Component(s)</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project to channel #</td>
<td></td>
</tr>
<tr>
<td>Smoothing</td>
<td></td>
</tr>
<tr>
<td>Downsampling</td>
<td></td>
</tr>
<tr>
<td>Time limits (ms)</td>
<td></td>
</tr>
</tbody>
</table>

Sort/align trials by epoch event values

- Epoch-sorting field
- Event type

Sort trials by phase

- Frequency (Hz | min Hz, max Hz)
- Phase

Inter-trial coherence options

- Frequency (Hz | min Hz, max Hz)

Other options

- Plot spectrum (min Hz, max Hz)

Phase-sorted image

Alpha phase is initially random

After the stimulus, the phase is reset.

This phase alignment yields the ERP!
Component ERP Images: ITC

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Project to channel #</td>
<td></td>
</tr>
<tr>
<td>Smoothing</td>
<td>10</td>
</tr>
<tr>
<td>Downsampling</td>
<td>1</td>
</tr>
<tr>
<td>Time limits (ms)</td>
<td>-800 1000</td>
</tr>
</tbody>
</table>

Sort/align trials by epoch event values
- Epoch-sorting field
- Event type(s)

Sort trials by phase
- Frequency (Hz): 10 12
- Percent low-amp. trials: |

Inter-trial coherence options
- Frequency (Hz): 10 12
- Signif. level (<0.25): 0.01

Other options
- Plot spectrum (minHz maxHz): |
- Baseline ampl. (dB): |

Figure title
- ERP limits
- Color limits (see Help)

Phase-sorted alpha power

ERSP

ITC

Phase-sorted Trials

ERSP

ITC

10.99 Hz

-0.3381 dB
Component ERP Images: Sort by amplitude

Phase-sorted alpha power

Same data: Sorted by alpha amplitude

'ampsrot' = [center_ms, prcnt, freq, maxfreq] Sort epochs by amplitude.
Component ERP Images: Amplitude vs. Activations

Same sorting order: Plotting Amplitude vs. Activations
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ERSP (see John’s time-frequency lecture)
Plot IC ERSP

Time points lost at beginning and end of epoch
Practicum

- Download then load faces_4.set, epoch on face

- **Novice, Intermediate**
  - From the GUI, open the ‘Reject component by map’ interface
  - Explore and classify several additional ICs: muscle, channel, brain
    - Justify your classification
  - Redo the "Plot → Component ERPs → With component maps” excluding your additional artifacts. What change do you observe?
  - Pick a brain IC. Plot an ERP Image
    - Try sorting by phase, is there any relationship to the IC activation pattern? What about power in a frequency band of choice?

- **Intermediate**
  - Plot ERP Image sorted by response latency
    - Figure out how to realign trials to response latency instead (Hint ‘Align’)
  - Plot ERSPs for selected ICs
    - Explore parameter options. Why is each useful?