Clustering Independent Components of EEG Data

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Why cluster independent components across subjects or sessions?

• ICA transforms the data from a channel basis (activity recorded at each channel)
  • to a component basis (activity computed at each IC).
  • Normally, EEG researchers assume that, for example, electrode channel F7 == F7 == F7 ... in each subject – and then ‘cluster‘ their data assuming channel equivalence.
  • This amounts to the simple assumption
  
  "Your Cz is My Cz!“

• But this is only *roughly* correct!
Example: First Subject

Electrode F7

ICs

IC1

IC2

Cortex

IC3

IC4

Scalp
Clustering ICA components by eye

**Left mu**  
- [Images of mu waves for left hemisphere]  

**Right mu**  
- [Images of mu waves for right hemisphere]

Makeig et al., ~2000 *unpublished*
The same problems hold for clustering independent components

Across Ss, components don’t even have “the same” scalp maps!

→ Are “the same” components found across subjects?

• What should define “the same” (i.e., “component equivalence”)?
  • Similar scalp maps?
  • Similar cortical or 3-D equivalent dipole locations?
  • Similar activity power spectra?
  • Similar ERPs?
  • Similar ERSPs?
  • Similar ITCs?
  • Or similar combinations of the above?? …
EEG IC Source Locations
(135,794 IC equivalent dipoles!)

NB: Width of these hotspots gives a lower bound on IC effective source localization accuracy!

Clustering must actually be still tighter, since the actual 'hotspots' are here convolved with 1) a 3-D location blur, 2) head co-registration errors!
Some caveats

In this dipoledensity() assay …

• MR head images were not available → brain co-registration crude.
• Single versus dual-dipole model selection was subjective.
• Different electrode montages → mis-localization effects.
• Electrode locations were not all digitized – some ‘guestimated’!
• Brain geometries differ!
Co-Registration of Electrodes with MR Image

MR + EEG

EEG

Onton & Makeig, 2004
Why should IC clusters have breadth?

Equivalent cortical areas have different scalp maps and dipole locations!

Arthur Tsai et al., *Neurolmage*, 2014
Does the spatial distribution of IC equivalent dipole source locations depend on the task the subject performs?

i.e.

Do “the same” ICs (and IC clusters) appear for every task?

Makeig, 2007
Equivalent dipole density

Sternberg letter memory task

>> dipoledensity()
Equivalent dipole density

Emotion imagery task

>> dipoledensity()
Equivalent dipole density

>> dipoledensity()

Onton et al., 2005

Sternberg letter memory task

Onton et al., ‘05
Equivalent dipole density

Emotion imagery task

>> dipoledensity()
So how to cluster components?

The same problems hold for clustering independent components

Across Ss, components don’t even have “the same” scalp maps!

→ Are “the same” components found across subjects?

• What should define “the same” (i.e., “component equivalence”)?
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  • Similar activity power spectra?
  • Similar ERPs?
  • Similar ERSPs?
  • Similar ITCs?
  • Or similar combinations of the above?? …
  • EEGLAB clustering supports all these possibilities.

Makeig, 2007
Study IC Clustering: Assumptions

- Assumes there are *functionally equivalent* ICs across most subjects.
- Assumes these ICs have *similar responses* to experimental conditions across a set of measures (ERP, ERSP, ITC…)
- Creates *non-overlapping IC partitions* making each IC belong to only one cluster.
EEGLAB Study Clustering strategy

1. Cluster on **multiple measures** *(dipole locations, scalp maps, spectra, ERPs, ITCs, ERSPs, …)* **in one or more conditions.**

2. **Reduce the dimension** of each measure to a principal component subspace.

3. Compose a PCA-reduced **position vector** for each component.

4. **Cluster** the composed component vectors using k-means or other.

5. Use the computed component measures *(not PCA-reduced)* to **visualize the activities and spatial properties** of the clustered components.

6. Compute and visualize the **cluster-mean measures**.

7. Use **clustered Study set data** as input into ‘std_???’ functions.

Makeig, 2007
Study IC Clustering

Sometime clusters are spatially separate AND have distinct responses. In other cases, they may have similar responses or may overlap spatially.

Onton & Makeig, 2007
EEGLAB Study Clustering procedure

1. Identify a set of datasets as an EEGLAB Study.
2. Specify the subject code, subject group, condition and/or session for each dataset in the Study.
3. Identify components to cluster in each Study dataset.
4. Decide on component measures to use in clustering the Study and/or to evaluate the obtained component clusters.
5. Compute the component measures for each Study dataset.
6. Cluster the components on these component measures.
7. Review the obtained clusters (e.g., their scalp maps, dipoles, and activity measures).
8. Edit the clusters (manually remove/shift components, make sub-clusters, merge clusters, re-cluster).
9. Statistically test differences within or between selected clusters.

Makeig, 2007
Nonpsychiatric Comparison Subjects (NCS)

Schizophrenia Patients (SZ)

Deviant

Standard

MMN  P3a RON

P3a  MMN  RON

RMS

Latency (ms)

0  200  400  600

0  200  400
Auditory Deviance Response

The deepest mental trap in electrophysiology lies in the word “THE”!!!
Nonpsychiatric Comparison Subjects (NCS)  

R Superior Temporal

Dipole Density  

7% δERP pvaf  

x = 40 mm

R Inferior Frontal

Dipole Density  

13%  

40 mm

Ventral Mid Cingulate

Dipole Density  

29%  

0 mm

Anterior Cingulate

Dipole Density  

24%  

0 mm

Medial Orbitofrontal

Dipole Density  

29%  

0 mm

Dorsal Mid Cingulate

Dipole Density  

29%*  

0 mm

(Dev - Std) δERP Envelope

Schizophrenia Patients (SZ)

R Superior Temporal

Dipole Density  

6% δERP pvaf  

x = 40 mm

R Inferior Frontal

Dipole Density  

12%  

40 mm

Ventral Mid Cingulate

Dipole Density  

32%  

0 mm

Anterior Cingulate

Dipole Density  

16%  

0 mm

Medial Orbitofrontal

Dipole Density  

23%  

0 mm

Dorsal Mid Cingulate

Dipole Density  

13%*  

0 mm

Rissling et al., 2014
### PEAK AMPLITUDES

<table>
<thead>
<tr>
<th>Scalp Electrode (Fz)</th>
<th>ERP</th>
<th>r²</th>
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<tr>
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### PEAK LATENCIES

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Should every subject be included in every cluster?

Not all subjects contribute components to each cluster.

Why not?

• Different numbers of artifact components

• Subject differences!? 

• Does my subject group really exhibit a Gaussian cloud of individual differences around ’a mean subject’ in ‘subject space’ ??
Why aren’t all participants in every IC cluster?
Subject differences?

A. Inter-Trial Coherence
   - LOC
   - fLOC

B. Alpha Power
   - LOC
   - fLOC

C. Smoothed Average Trials
   - ERP
   - LOC
   - fLOC

D. ERP
   - LOC
   - fLOC

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

** Cluster ERSPs show significant activity determined by bootstrap statistics within subject and binomial probability between subjects (p < 0.01)

*** Difference ERSP shows significant differences between the two clusters by bootstrap statistics (p < 0.001)
Subject differences?
EEGLAB clustering has ~12 parameters

**STUDY IC Clustering: Practical Problems**

Large parameter space problem: many different clustering solutions can be produced by changing parameters and measure subsets. Which one should we choose?
Problems with multi-measure clustering

In a uniform density distribution,

where are the clusters by location?

N. Bigdely-Shamlo, 2010
Problems with multi-measure clustering

What are the clusters according to location?
Problems with multi-measure clustering

What are the clusters according to size?
Problems with multi-measure clustering

What are the clusters according to location and size?

Well, it depends on how much weight we give each measure...
• With either clustering method, we basically mix together distances for a subset of EEG measures (ERP, ERSP, ITC, mean spectrum, dipole location).

• This may make clustering distance less interpretable.
Study IC Clustering by Measure Projection

• Instead, we can directly work on pair-wise similarity matrices and prevent ICs with similarities less than certain threshold (e.g., ERSP corr. < 0.5) to be clustered together.

• The most important measure is equivalent dipole location.

• Assuming a certain variability estimate for dipole location (due to error in localization and subject variability), one can also estimate an optimum number of clusters.

Measure Projection asks:

1. Where in ‘template brain space’ does our data have evidence that our measure of interest is consistent across nearby ICs?

2. Which such brain space voxel domains show consistent differences?
Project Target ERSPs on Equivalent Dipole Locations
Measure Projection: RSVP Task Example
Questions?
Equivalent dipole density

Auditory oddball plus novel sounds

>> dipoledensity()
Equivalent dipole density Exp I

>> dipoledensity()
Equivalent dipole density Exp II

Onton et al., 2005

>> dipoledensity()

Visually cued button press task

Onton et al., ‘05
Measure Projection: RSVP Example

Rapid Serial Visual Presentation Experiment

- 8 subjects
- 15 Sessions
- Visual target detection
- 257 components with equiv. dipoles inside the brain

1 s
Fixation screen

4.1 s
Burst of 49 clips at 12 Hz
Subject input
Time

Non-target Target Non-target

N. Bigdely-Shamlo, 2010
Measure Projection: RSVP Task Example

Project Target ERSPs on Equivalent Dipole Locations

(p < .0002)
An FM-theta IC cluster
In a working memory task
Complex event-related dynamics produce "the" P300.
Cluster ERP contributions – std_envtopo()
IC clustering of LPC data

• Clustered components from 15 Ss using a IC distance metric incorporating differences between their (weighted) scalp maps, dipole locations, spectra, ERP, ERSP, and ITC patterns.

• Hand-adjusted clusters to remove outliers.

• Determined time/frequency regions of significant ERSP and ITC for each component using permutation-based statistics.

• Used binomial statistics to highlight time/frequency regions significantly active within clusters.
Visual Selective Attention Task

15 subjects

Makeig et al., PLPS 2004
N1 Component Clusters

Makeig et al., Science 2002
Effects of Mis-Estimating Skull Conductivity

Next, we present simulation results on the effects of using incorrect skull conductivity values on equivalent dipole source localization. In the 1970's and 1980's, the adult brain-to-skull conductivity ratio was reported to be near 80:1 (Cohen 1983; Rush 1968), a value still commonly used for EEG source localization. However, more recent studies have found this ratio to be lower, as low as 15:1 (Oostendorp 2000). For example, a 2005 study on adult epilepsy patients undergoing pre-surgical evaluation using simultaneous intra-cranial and scalp EEG recordings estimated average brain-to-skull conductivity ratio as 25:1 (Lai 2005).

Here, we used the four-layer reference BEM model for subject S1 and set the forward-model (ground truth) brain-to-skull conductivity ratio to 25:1. We then solved the inverse source localization problem using the same head model incorporating the assumed (and still commonly used) value of 80:1. This produced large equivalent dipole localization errors of up to 31 mm (Figure 13, top row). When we used the four-layer head-shape warped MNI template model to solve the inverse problem (Figure 13, middle row) the errors were still larger and more evenly distributed across the cortical region (Figure 4 bottom row). The estimated positions of the simulated dipoles generally moved towards the scalp surface. Conversely, when the brain-to-skull conductivity ratio was mis-estimated as 15:1 instead of 25:1 (Figure 13, bottom row), the estimated dipole locations moved towards the center of the brain, with error magnitudes up to 13 mm. Thus, correct modeling of skull conductivity is an important factor for EEG source localization, quite possibly outweighing the choice of head model.

Figure 13: Equivalent dipole source localization error directions (arrows) and magnitudes (colors) for model dipoles in a four-layer realistic BEM head model when the brain-to-skull conductivity ratio was mis-estimated as 80:1 (top row) or as 15:1 (bottom row) instead of the simulated forward-model value (25:1). The middle row shows errors when source localization was performed using a warped fc the forward model brain-to-skull ratio was again mis-estimated as 80:1. Note that, maximum error shown was 20 mm as to use the same scaling while retaining some contrast for the lower-error plots. Maximum localization errors were as in Figure 3.