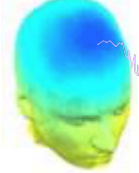
Clustering Independent Components of EEG Data

Scott Makeig
Institute for Neural Computation
University of California San Diego

25th EEGLAB Workshop

Tokyo, Japan

September, 2017



Why cluster independent components across subjects or sessions?

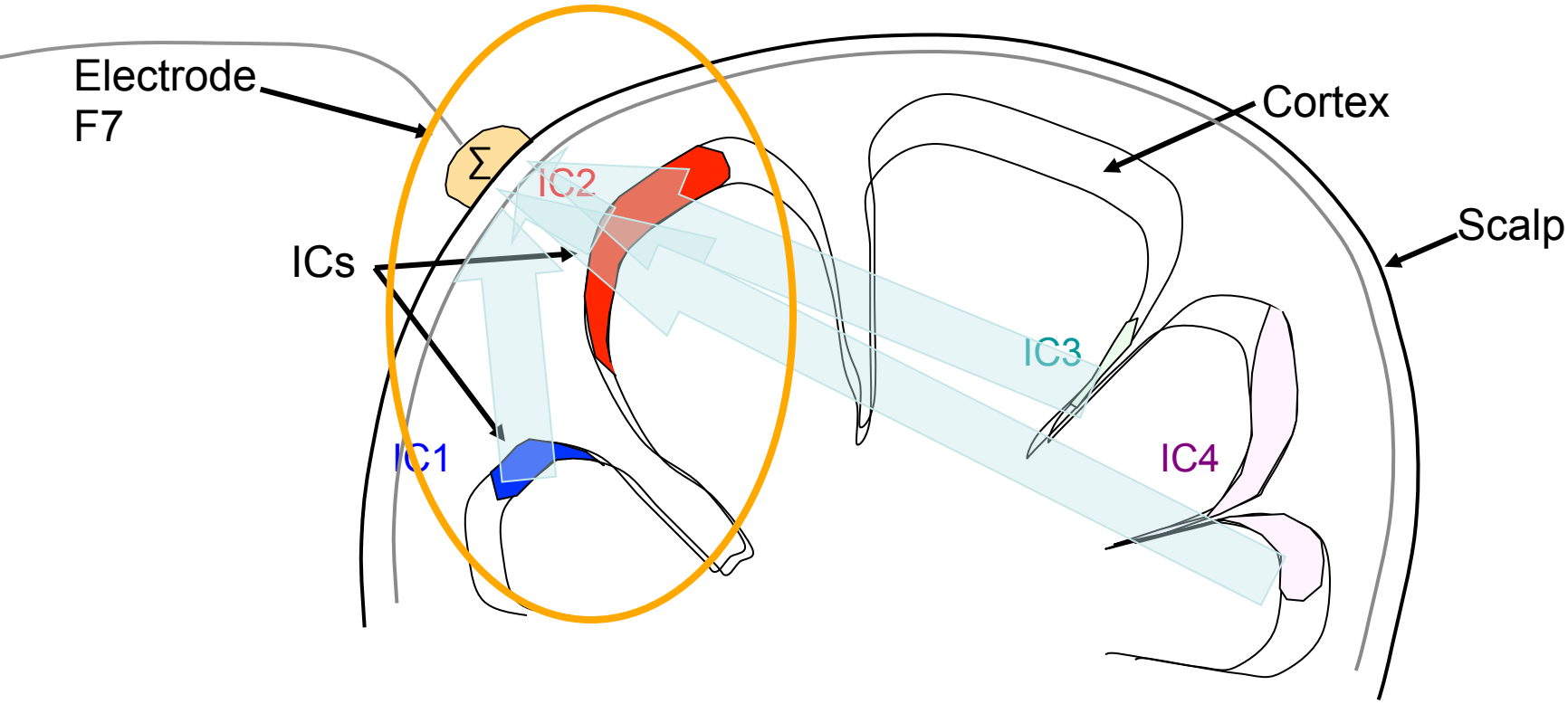
- ICA transforms the data from a channel basis (activity recorded at each channel)
  - to a component basis (activity computed at each IC).
- Normally, EEG researchers assume that, for example, electrode channel F7 == F7 == F7 ... in each subject – and then ‘cluster‘ their data assuming channel equivalence.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

  “Your Cz is My Cz!“

- But this is only ***roughly*** correct !

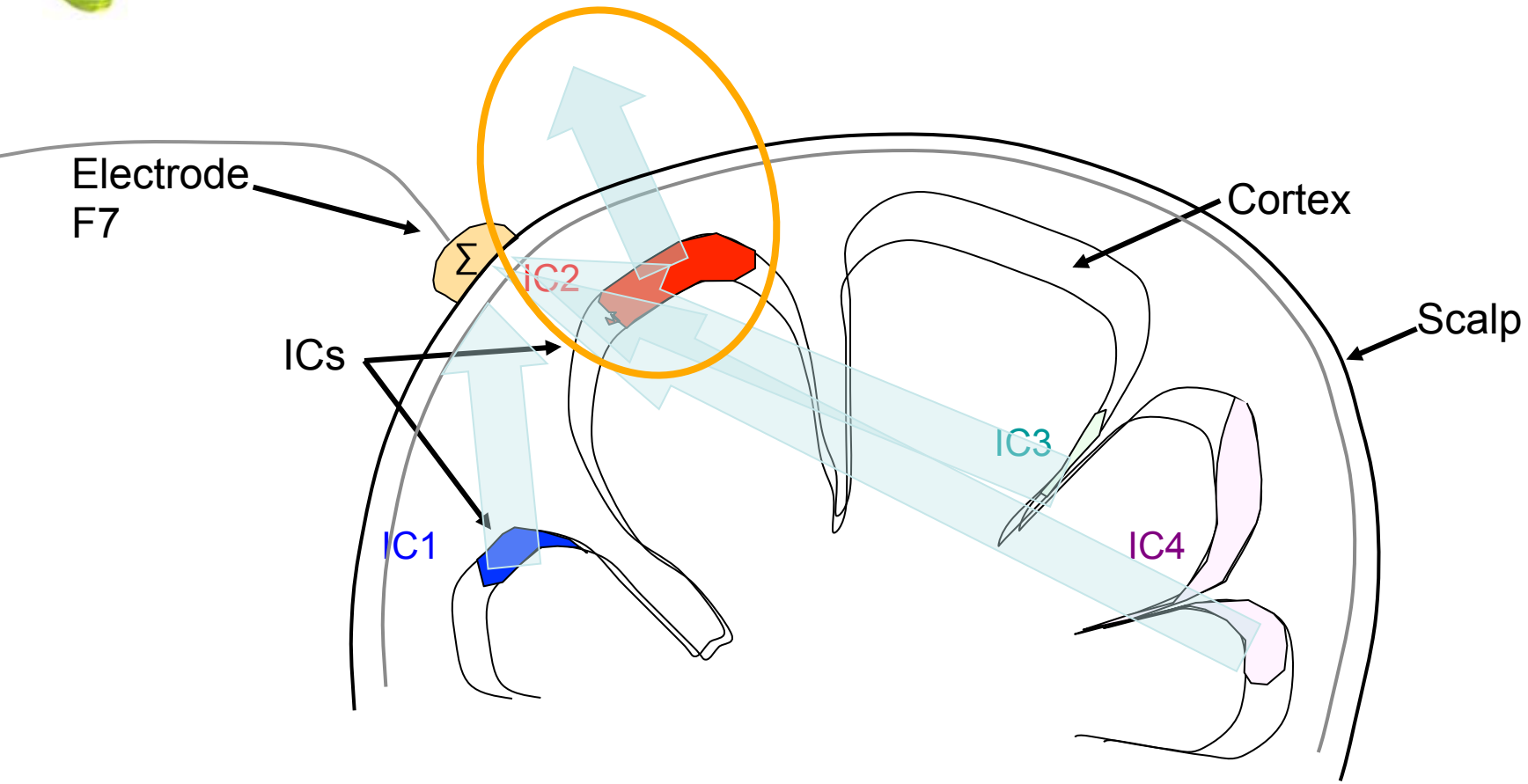
Makeig, 2007

Example: First Subject



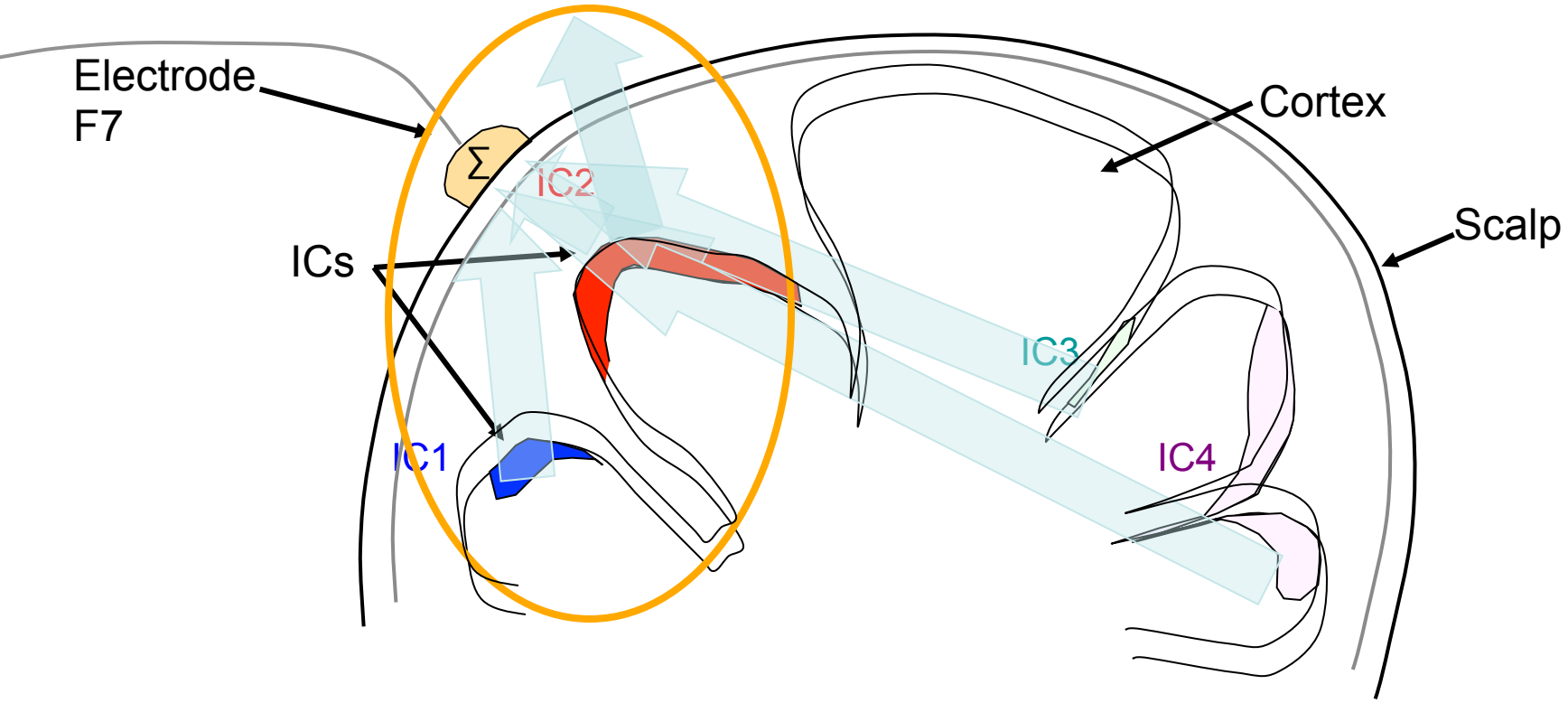
Makeig, 2005

Seond Subject



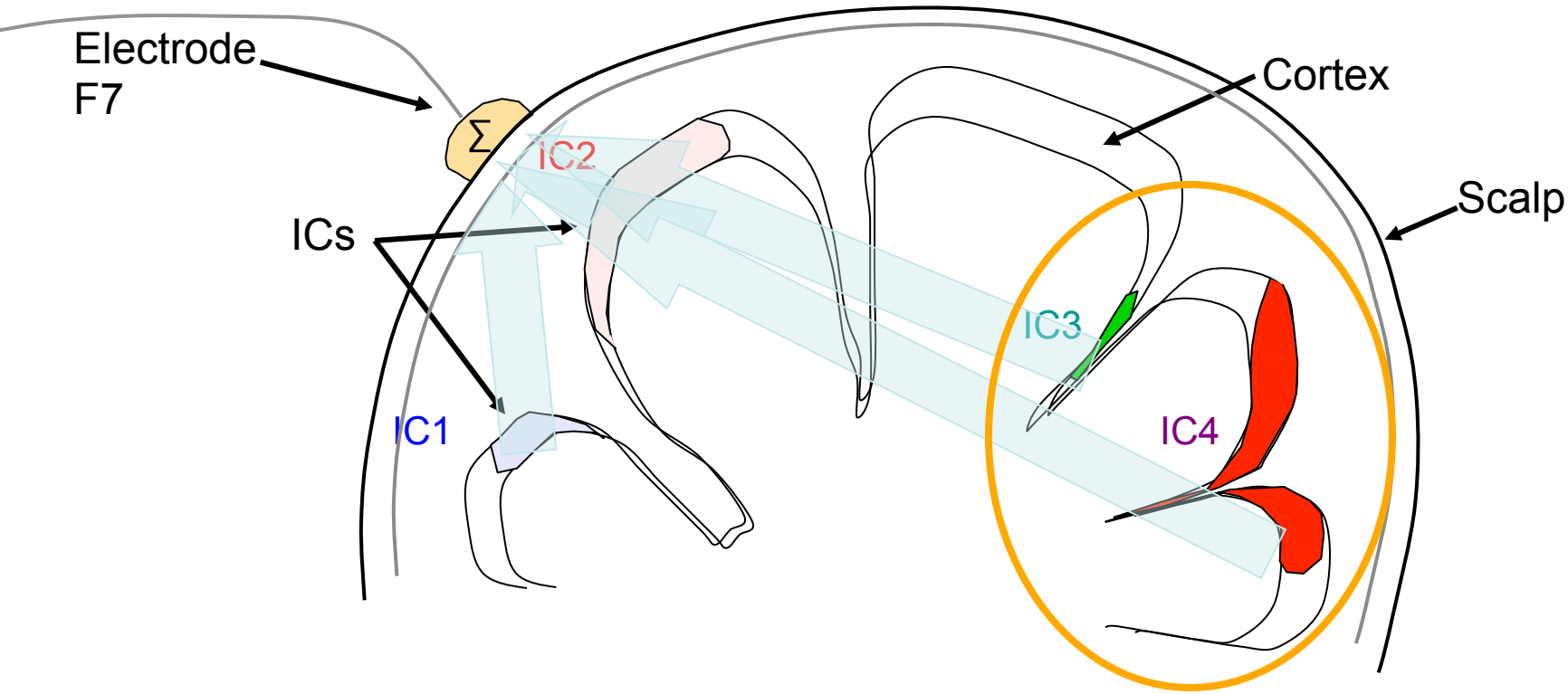
Makeig, 2005

Third Subject



Makeig, 2005

Fourth Subject

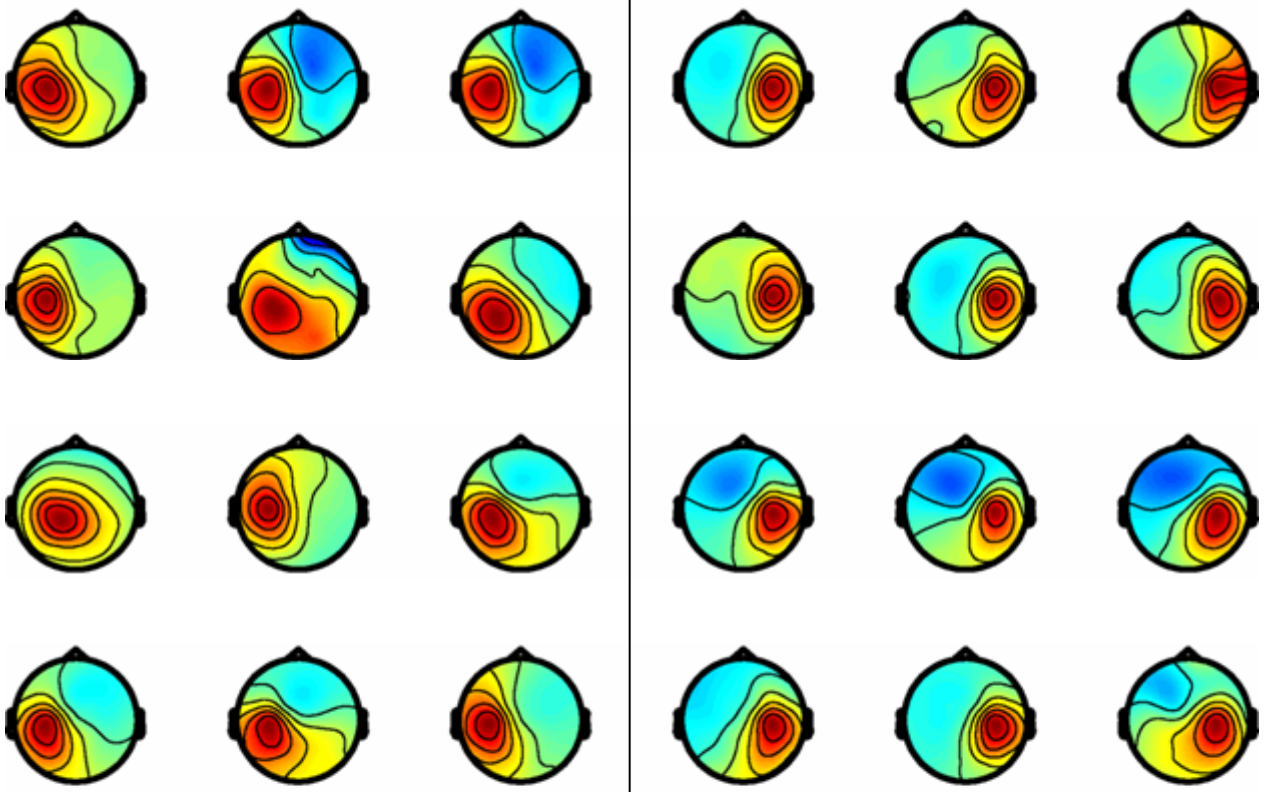


Makeig, 2005

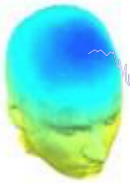
Clustering ICA components by eye

Left mu

Right mu



Makeig et al., ~2000 *unpublished*



So how to cluster components?

The same problems hold for clustering independent components

Across Ss, components don't even have "the same" scalp maps!

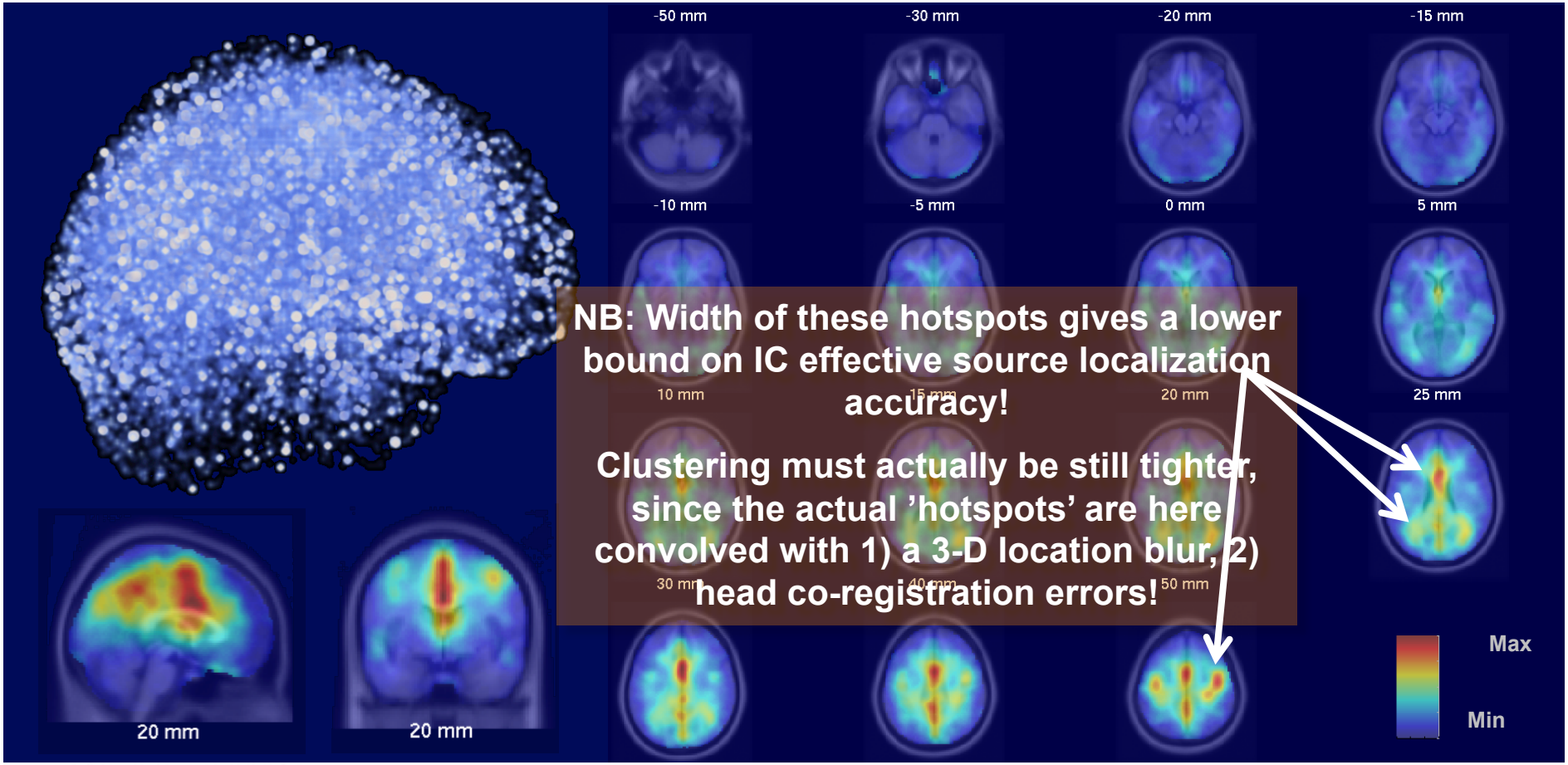
→ Are "the same" components found across subjects?

- What should define "***the same***" (i.e., "***component equivalence***")?
  - 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?? …

Makeig, 2007

EEG IC Source Locations

(135,794 IC equivalent dipoles!)



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

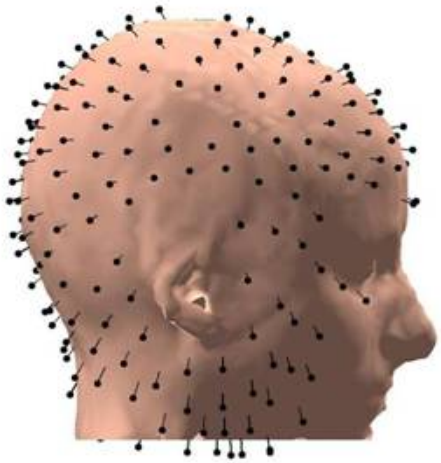
Clustering must actually be still tighter, since the actual 'hotspots' are here convolved with 1) a 3-D location blur, 2) head co-registration errors!

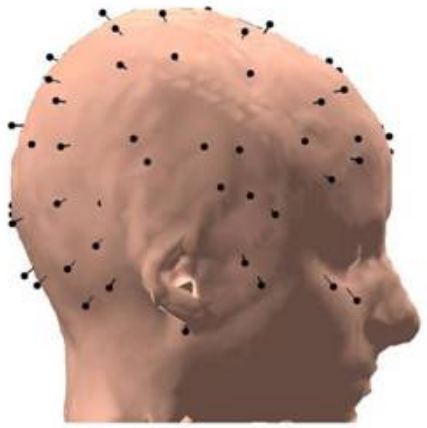
Nima Bigdely-Shamlo, Kay Robbins, Christian Kothe, Jessica His, Scott Makeig, 2013

… Some caveats

In this *dipoledensity()* assay …

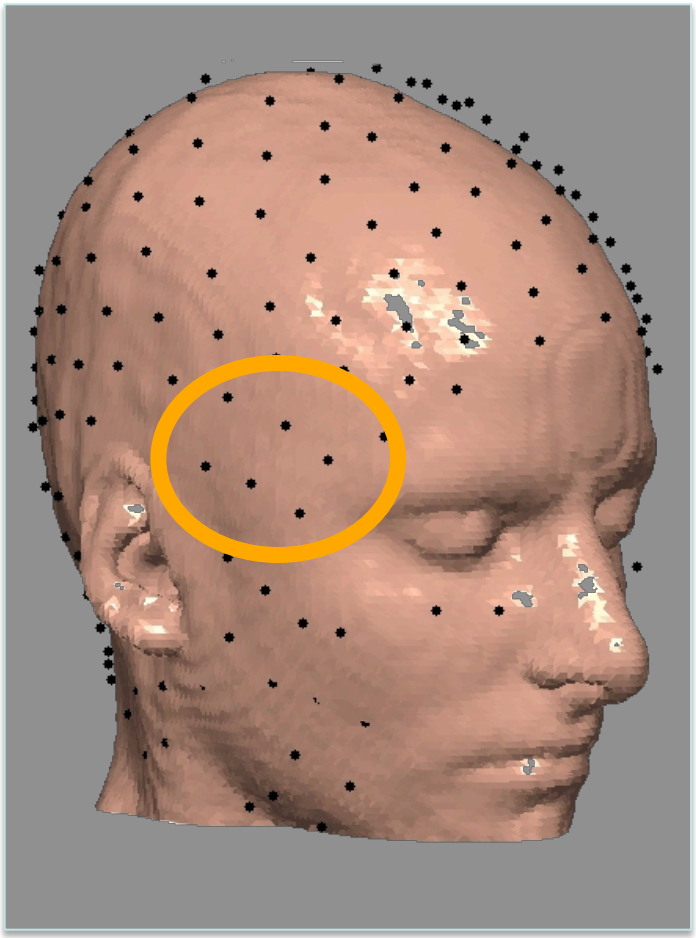
- MR head images were not available → brain co-registration crude.
- Single versus dual-dipole model selection was subjective.
- Different electrode montages → mis-localization effects.
- Electrode locations were not all digitized – some ‘guestimated’ !
- Brain geometries differ!



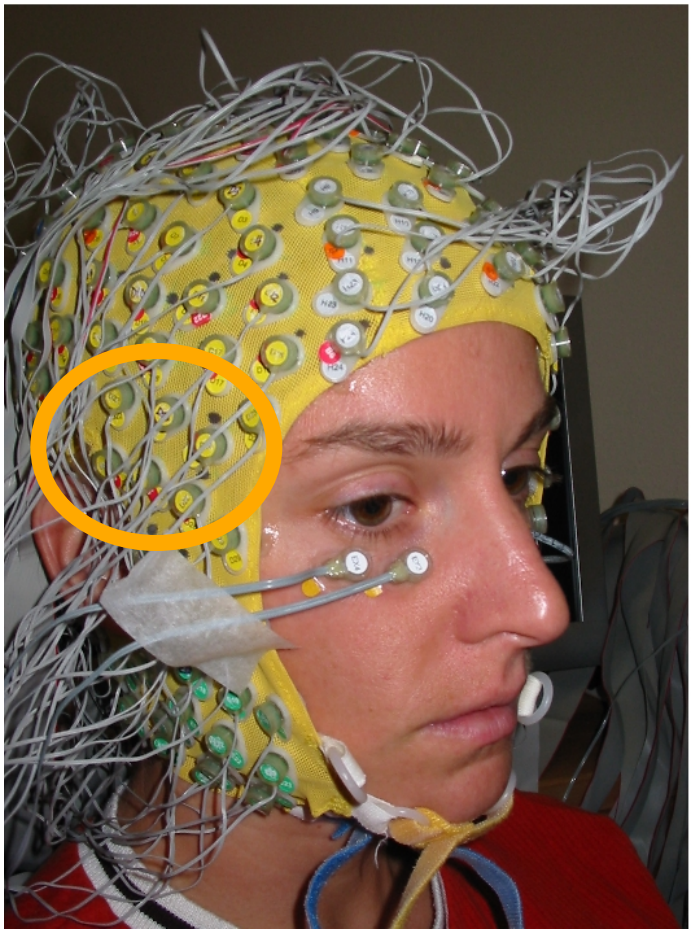


Graphics: Julie Onton, 2005

Co-Registration of Electrodes with MR Image



MR + EEG



EEG

Onton & Makeig, 2004

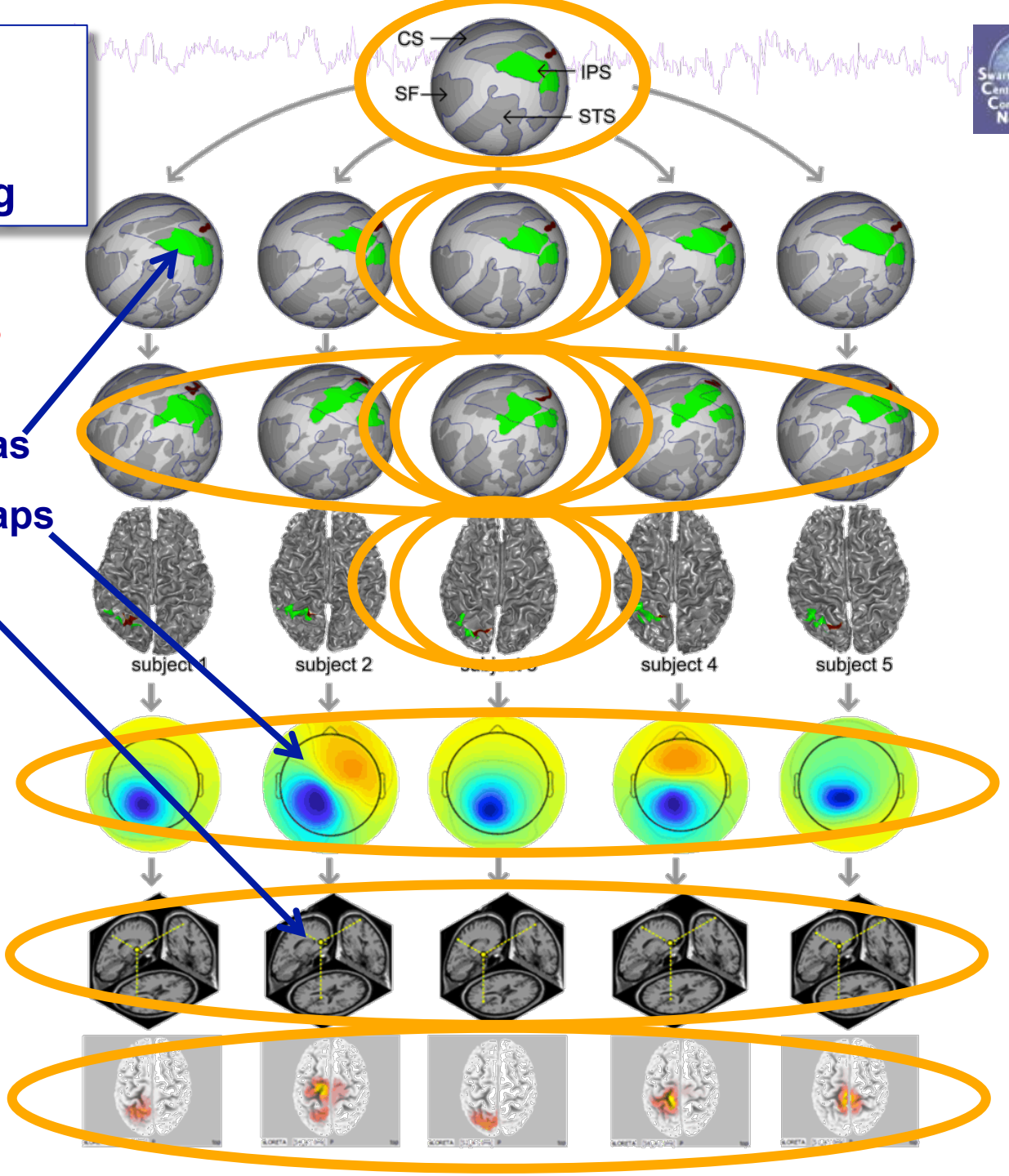
Arthur Tsai – Topological source clustering

Why should IC clusters have breadth?

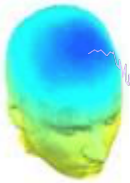
Equivalent cortical areas

Have different scalp maps

And dipole locations!



Arthur Tsai et al., *NeuroImage*, 2014



Swartz Center for Computational Neuroscience

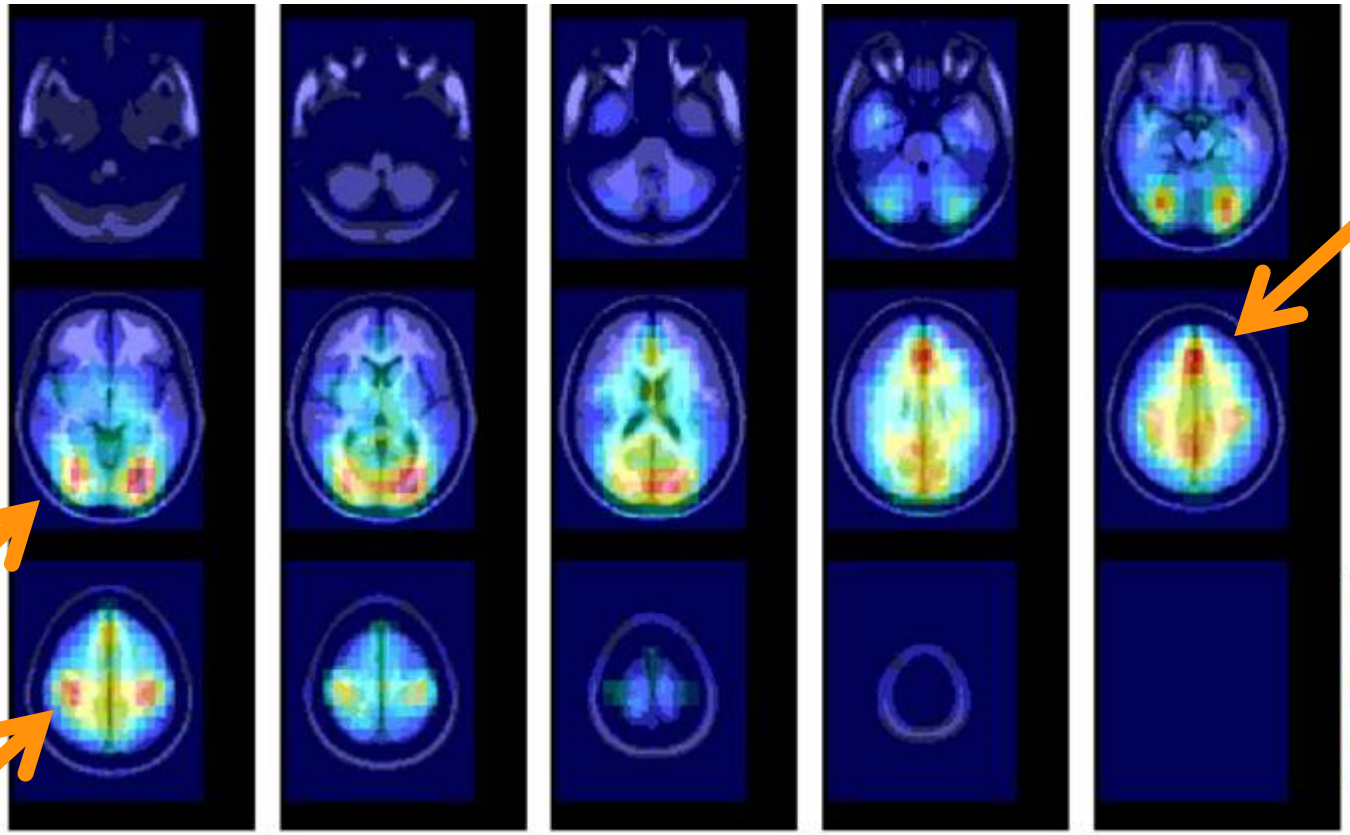
Does the spatial distribution of IC equivalent dipole source locations depend on the task the subject performs?

i.e.

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

Makeig, 2007

Equivalent dipole density



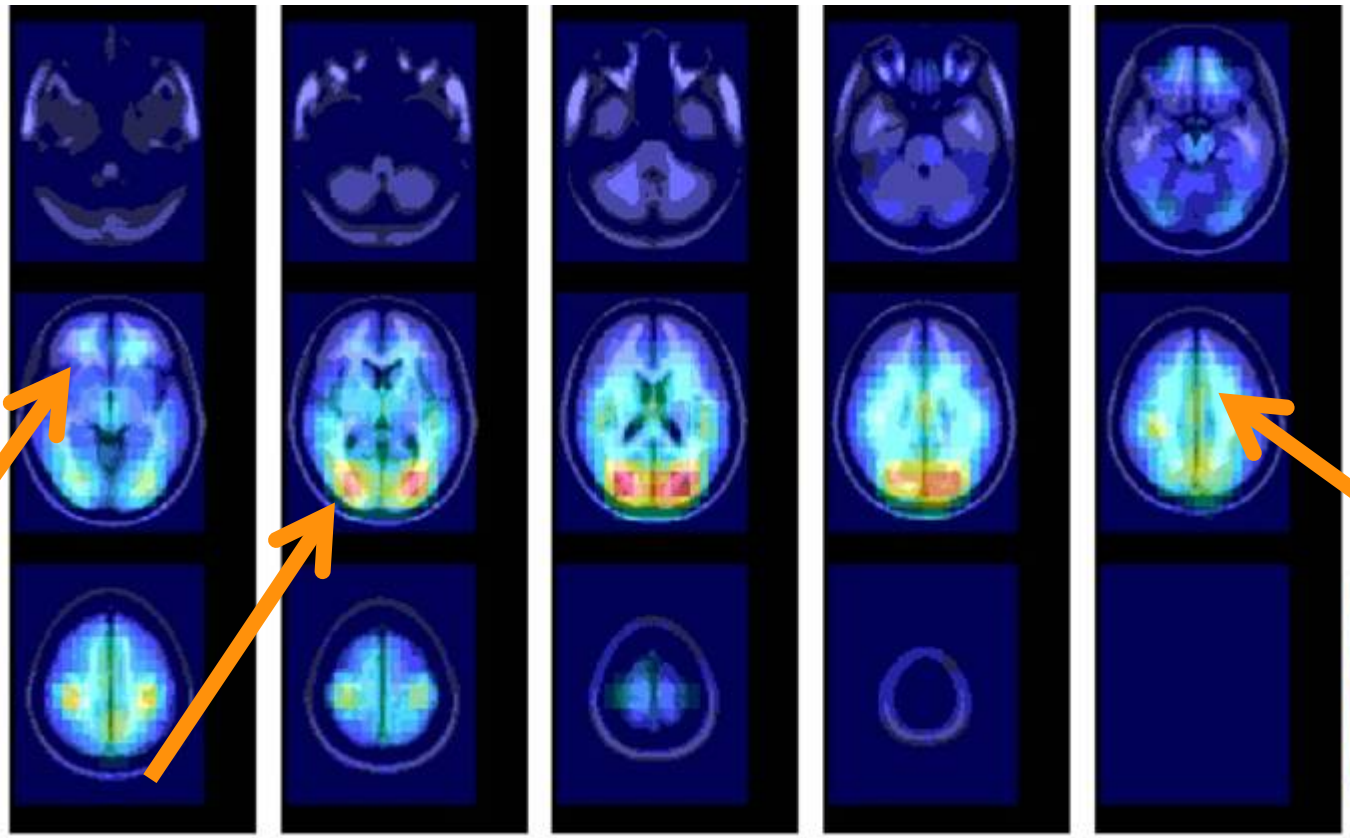
Sternberg letter memory task

>> dipoledensity()

Onton et al., 2

Onton et al., '05

Equivalent dipole density



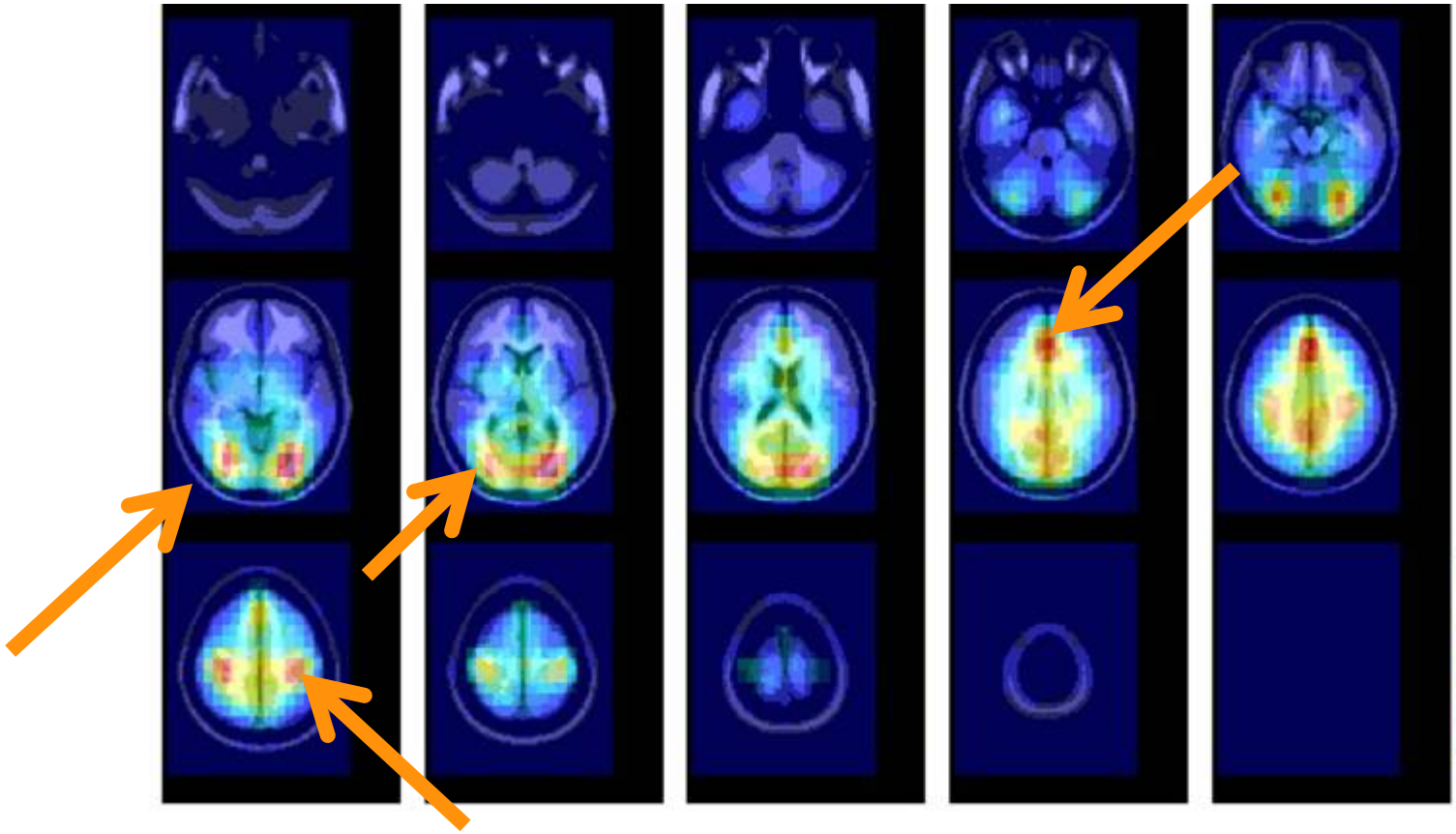
Emotion imagery task

>> dipoledensity()

Onton et al., 2

Onton et al., '05

Equivalent dipole density



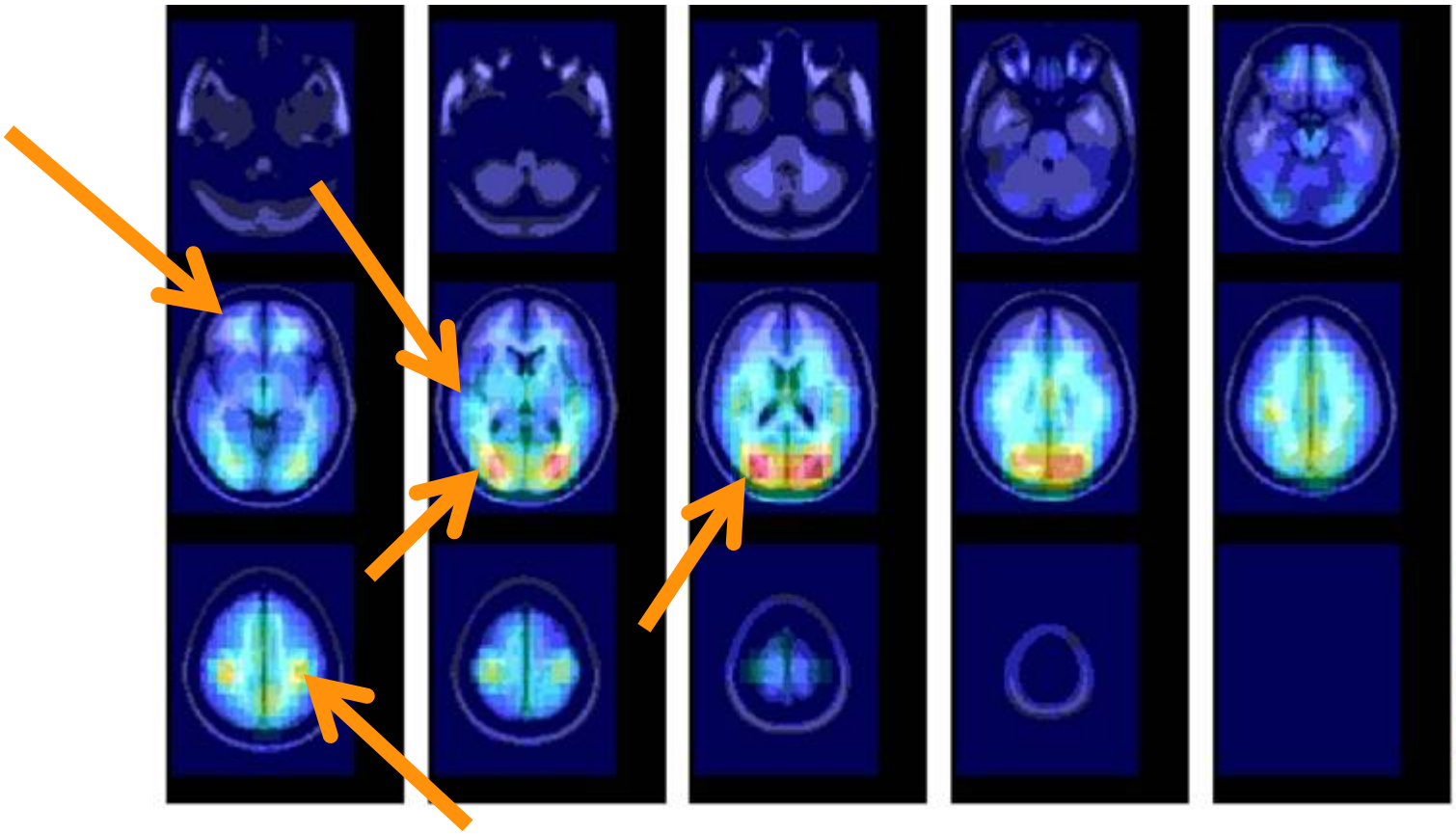
Sternberg letter memory task

>> dipoledensity()

Onton et al., 2

Onton et al., '05

Equivalent dipole density

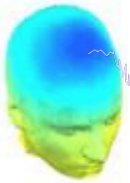


Emotion imagery task

>> dipoledensity()

Onton et al., 2

Onton et al., '05



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")?
  - 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?? …
  - 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.

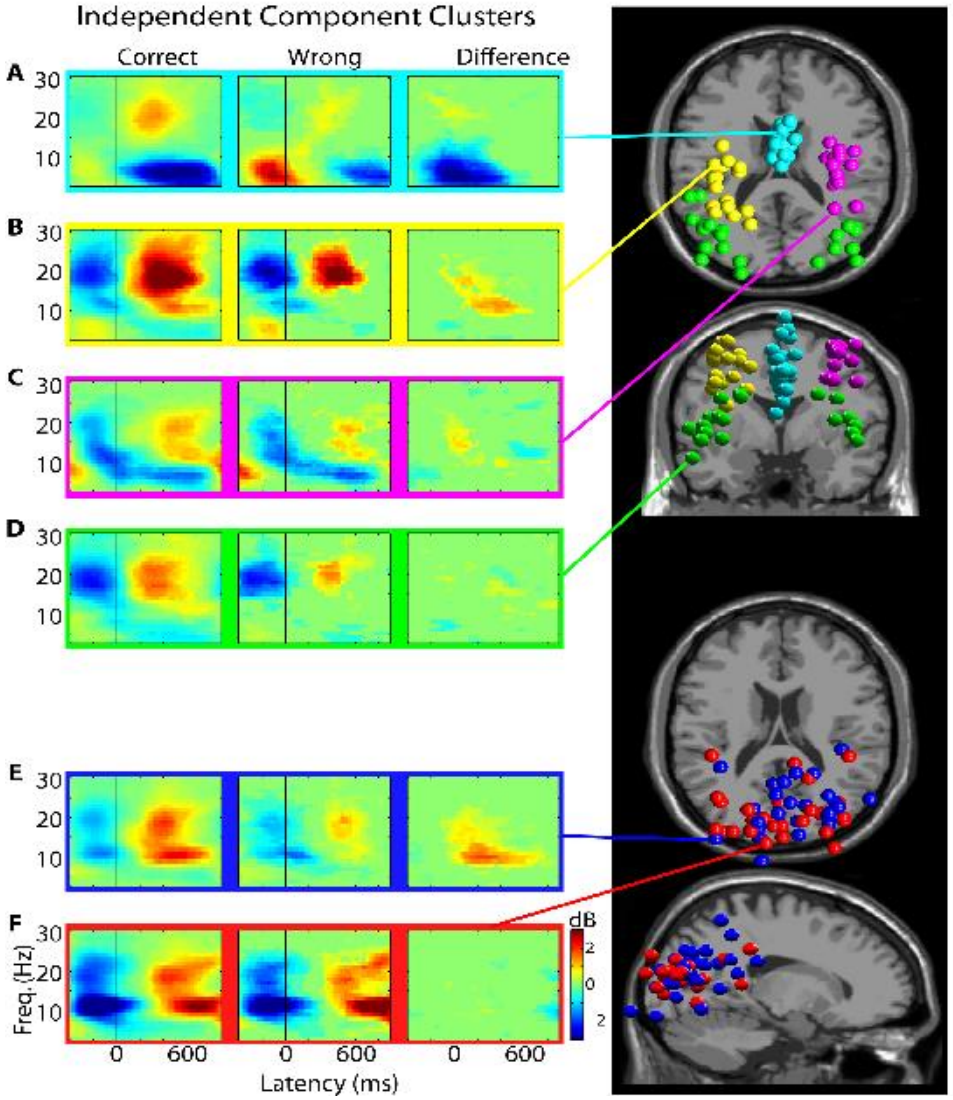
Makeig, 2007

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

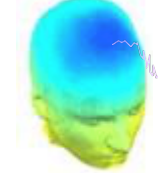
Study IC Clustering



Sometime clusters are spatially separate AND have distinct responses.

In other cases, they may have similar responses or may overlap spatially.

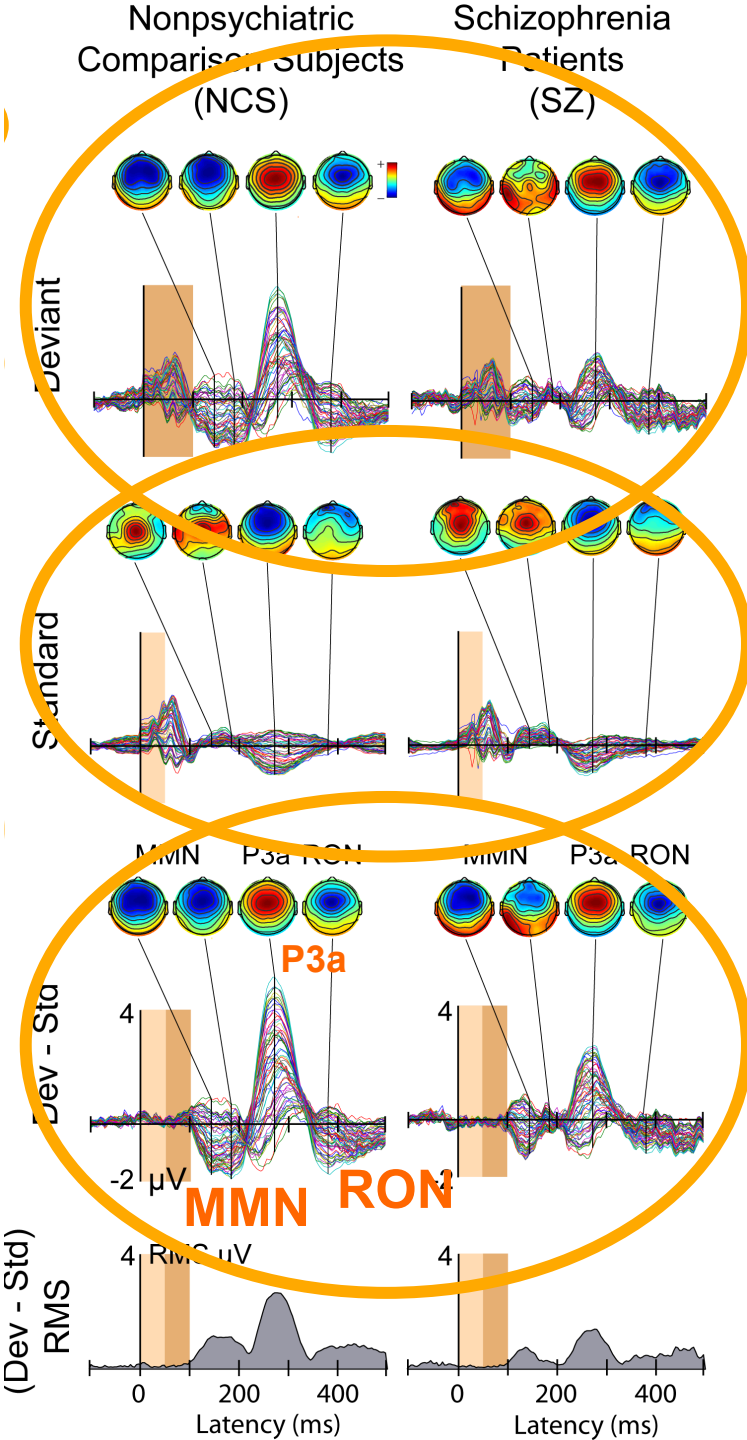
Onton & Makeig, 2007



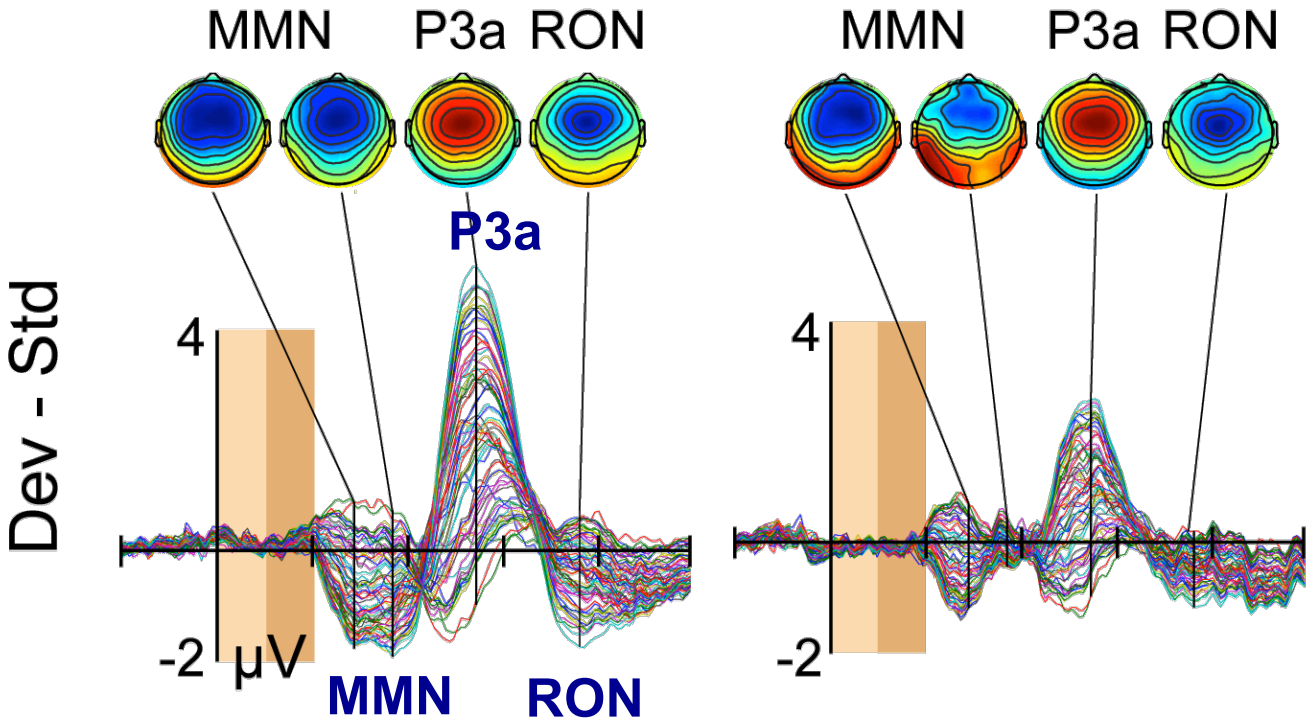
EEGLAB Study Clustering procedure

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

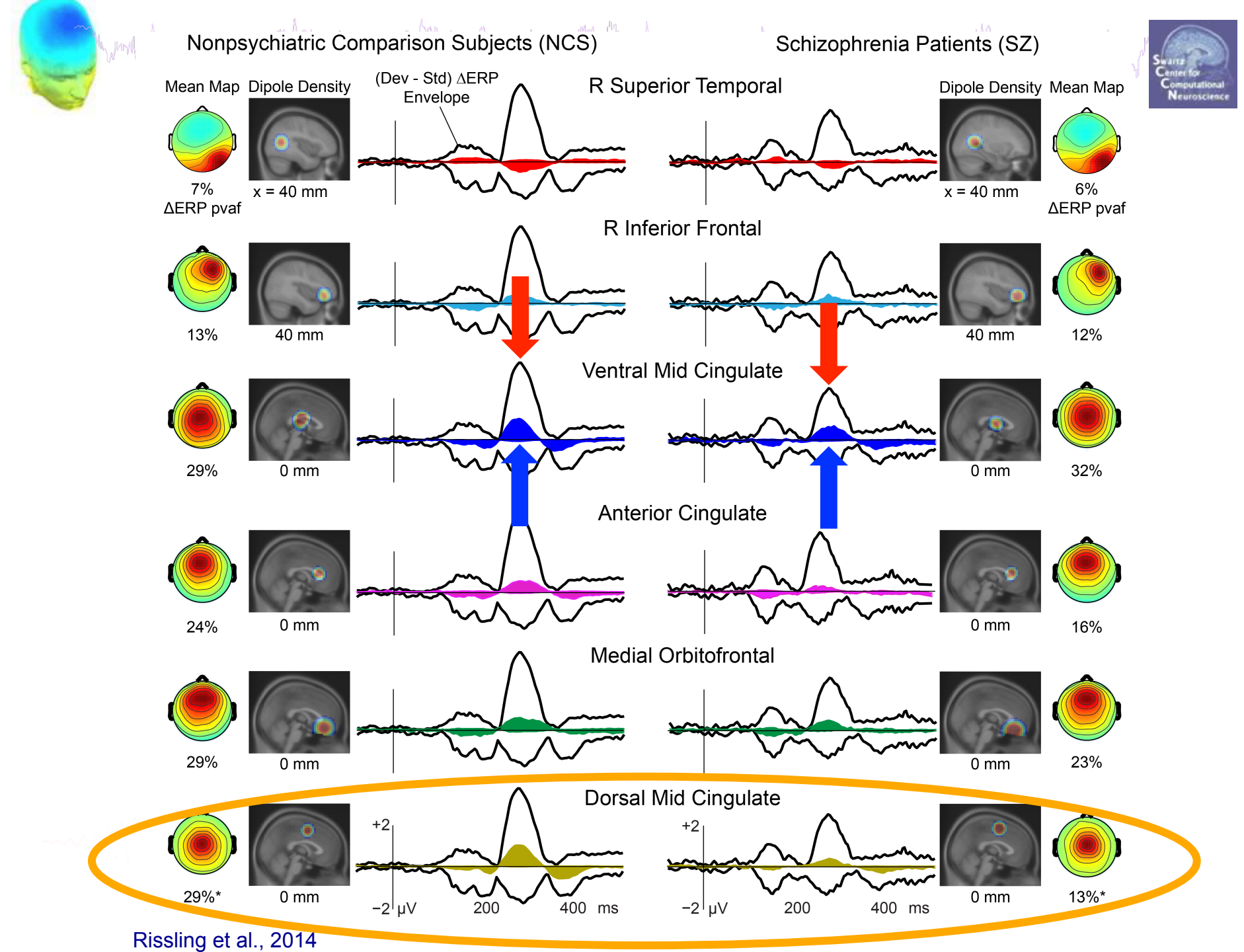

Nonpsychiatric
Comparison Subjects
(NCS)
Schizophrenia
Patients
(SZ)
Deviant
Standard
MMN
P3a
RON
P3a
MMN
RON
4
-2 μV
4 RMS μV
(Dev - Std)
RMS
0
200
400
Latency (ms)

Auditory Deviance Response



Cntrl **SZ**

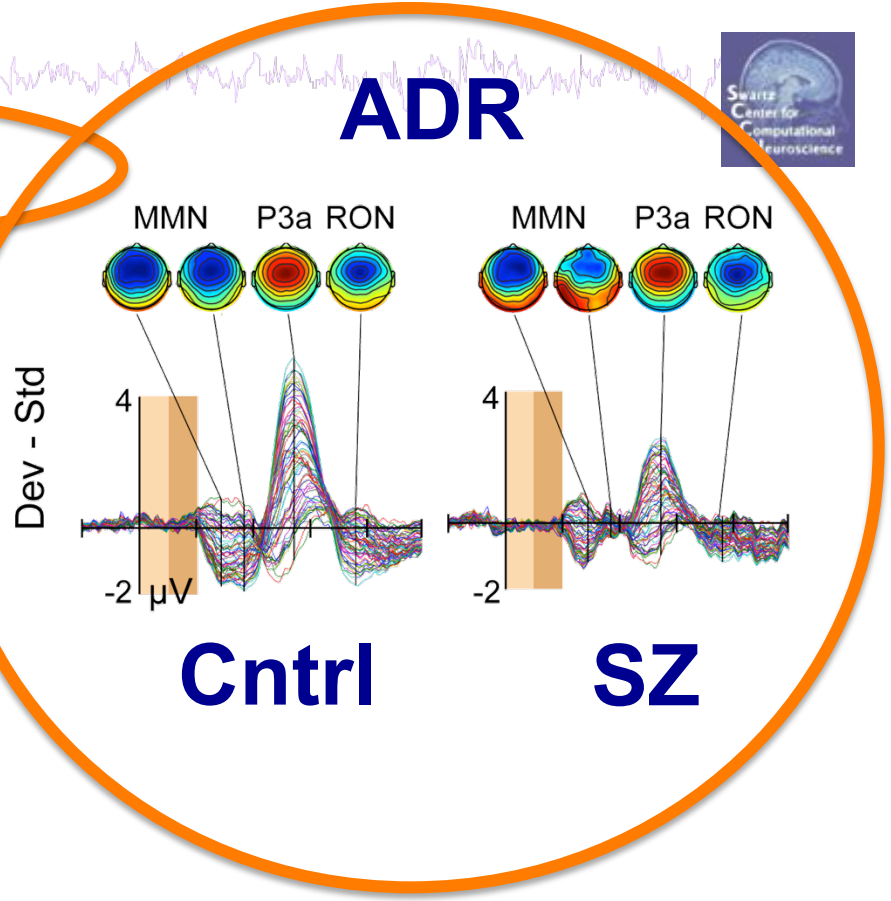
The deepest mental trap in electrophysiology lies in the word "THE" !!!



Rissling et al., 2014

PEAK AMPLITUDES

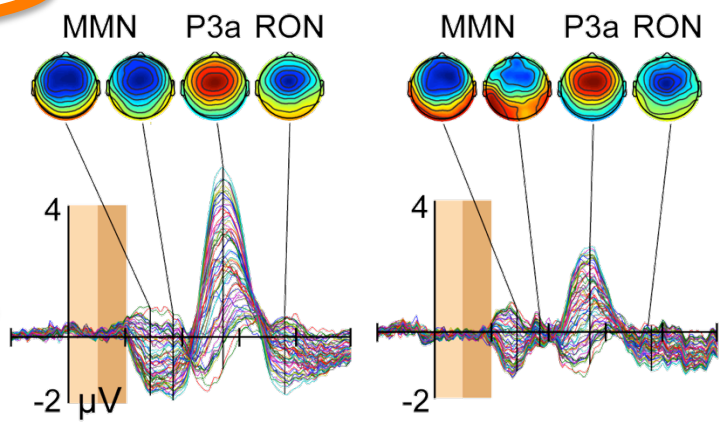
	ERP	r^2
Scalp Electrode (Fz)		
Verbal IQ (WRAT)	P3a	0.11
Functional Capacity (UPS	RON	0.12
R Superior Temporal		
Working Memory (LNS Reorder)	RON	0.15
Verbal IQ (WRAT)	RON	0.15
Immediate Verbal Memory (CVLT)	**RON**	**0.28**
Delayed Verbal Memory (CVLT)	RON	0.26
Functional Capacity (UPSA)	**MMN**	**0.48**
Functional Capacity (UPSA)	RON	0.26
R Inferior Frontal		
Negative Symptoms (SANS)	**RON**	**0.36**
Psychosocial Functioning (SOF)	RON	0.24
Auditory Attention (LNS Forward)	**MMN**	**0.38**
Working Memory (LNS Reorder)	**MMN**	**0.30**
Verbal IQ (WRAT)	**MMN**	**0.46**
Ventral Mid Cingulate		
Positive Symptoms (SAPS)	**RON**	**0.29**
Negative Symptoms (SANS)	**P3a**	**0.36**
Immediate Verbal Memory (CVLT)	**RON**	**0.41**
Delayed Verbal Memory (CVLT)	RON	0.24
Verbal IQ (WRAT)	**RON**	**0.29**
Executive Functioning (WCST)	RON	0.24
Anterior Cingulate		
Functional Status (GAF)	MMN	0.18
Functional Status (GAF)	RON	0.17
Immediate Verbal Memory (CVLT)	RON	0.25
Delayed Verbal Memory (CVLT)	RON	0.17
Medial Orbitofrontal		
Positive Symptoms (SAPS)	**P3a**	**0.40**
Negative Symptoms (SANS)	**P3a**	**0.54**
Psychosocial Functioning (SOF)	**P3a**	**0.37**
Functional Capacity (UPSA)	**P3a**	**0.32**
Dorsal Mid Cingulate		
Verbal IQ (WRAT)	P3a	0.15
Executive Functioning (WCST)	MMN	0.18



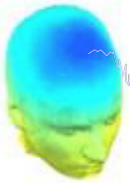
PEAK LATENCIES

	ERP	r^2
Scalp Electrode (Fz)		
---n/a---	---	---
R Superior Temporal		
Functional capacity (UPSA)	MMN	0.25
Delayed Verbal Memory (CVLT)	MMN	0.17
R Inferior Frontal		
Negative Symptoms (SANS)	**RON**	**0.51**
Psychosocial Functioning (SOF)	RON	0.25
Executive Functioning (WCST)	**MMN**	**0.30**
Executive Functioning (WCST)	**P3a**	**0.28**
Ventral Mid Cingulate		
Negative Symptoms (SANS)	**P3a**	**0.33**
Negative Symptoms (SANS)	**RON**	**0.33**
Psychosocial Functioning (SOF)	**P3a**	**0.31**
Verbal IQ (WRAT)	MMN	0.25
Executive Functioning (WCST)	**P3a**	**0.30**
Anterior Cingulate		
Functional Capacity (UPSA)	RON	0.17
Verbal IQ (WRAT)	MMN	0.24
Auditory Attention (LNS-Forward)	MMN	0.17
Medial Orbitofrontal		
Negative Symptoms (SANS)	**RON**	**0.41**
Positive Symptoms (SAPS)	**RON**	**0.40**
Auditory Attention (LNS-Forward)	**MMN**	**0.29**
Executive Functioning (WCST)	**P3a**	**0.32**
Dorsal Mid Cingulate		
Negative Symptoms (SANS)	MMN	0.20
Negative Symptoms (SANS)	P3a	0.17
Global Functioning (GAF)	RON	0.24
Functional Capacity (UPSA)	P3a	0.13

ADR



Cntrl **SZ**



Should every subject be included in every cluster?

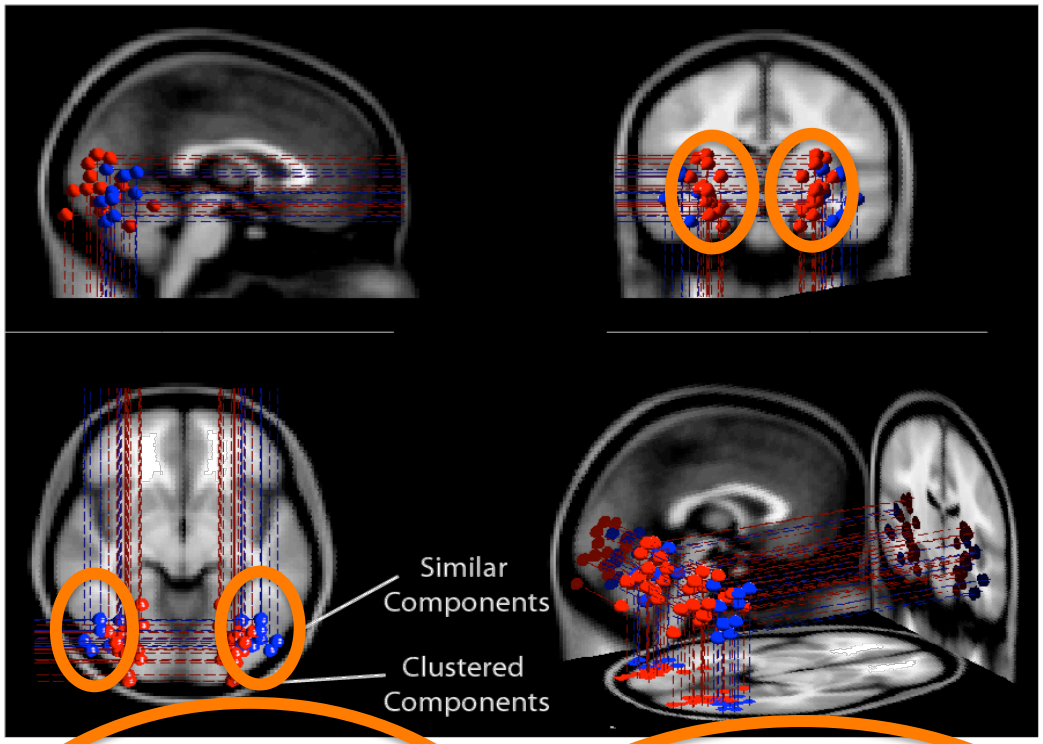
Not all subjects contribute components to each cluster.

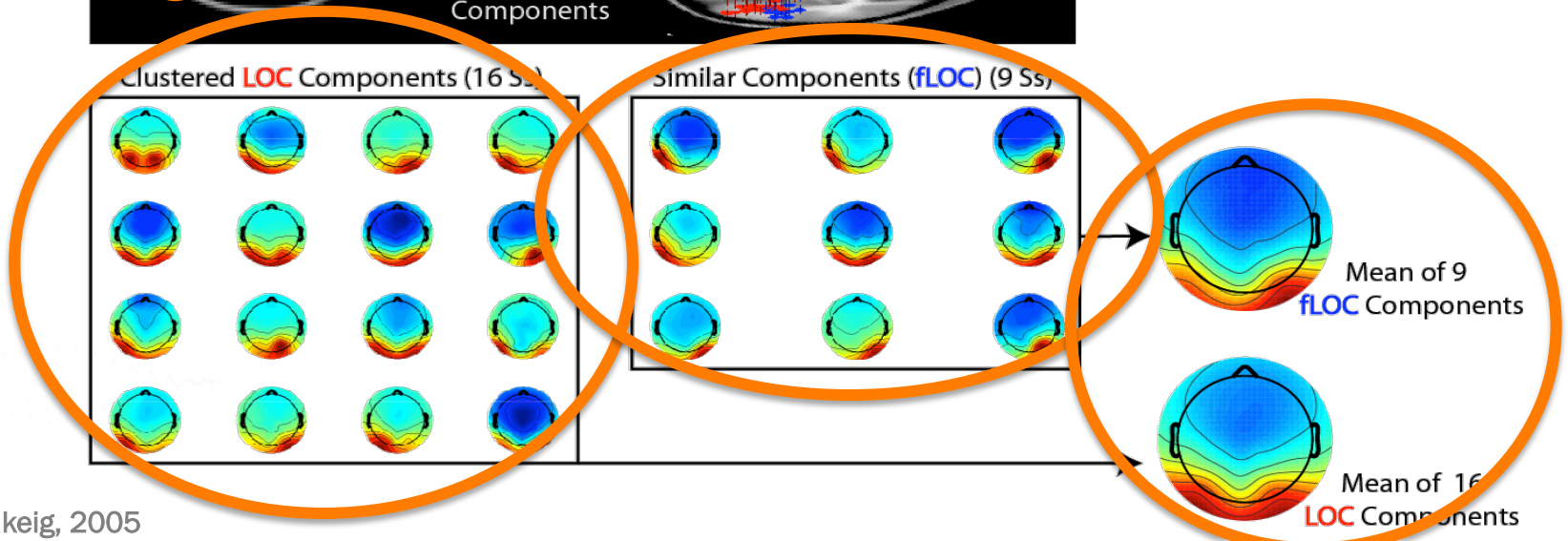
Why not?

- 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' ??

Makeig, 2007

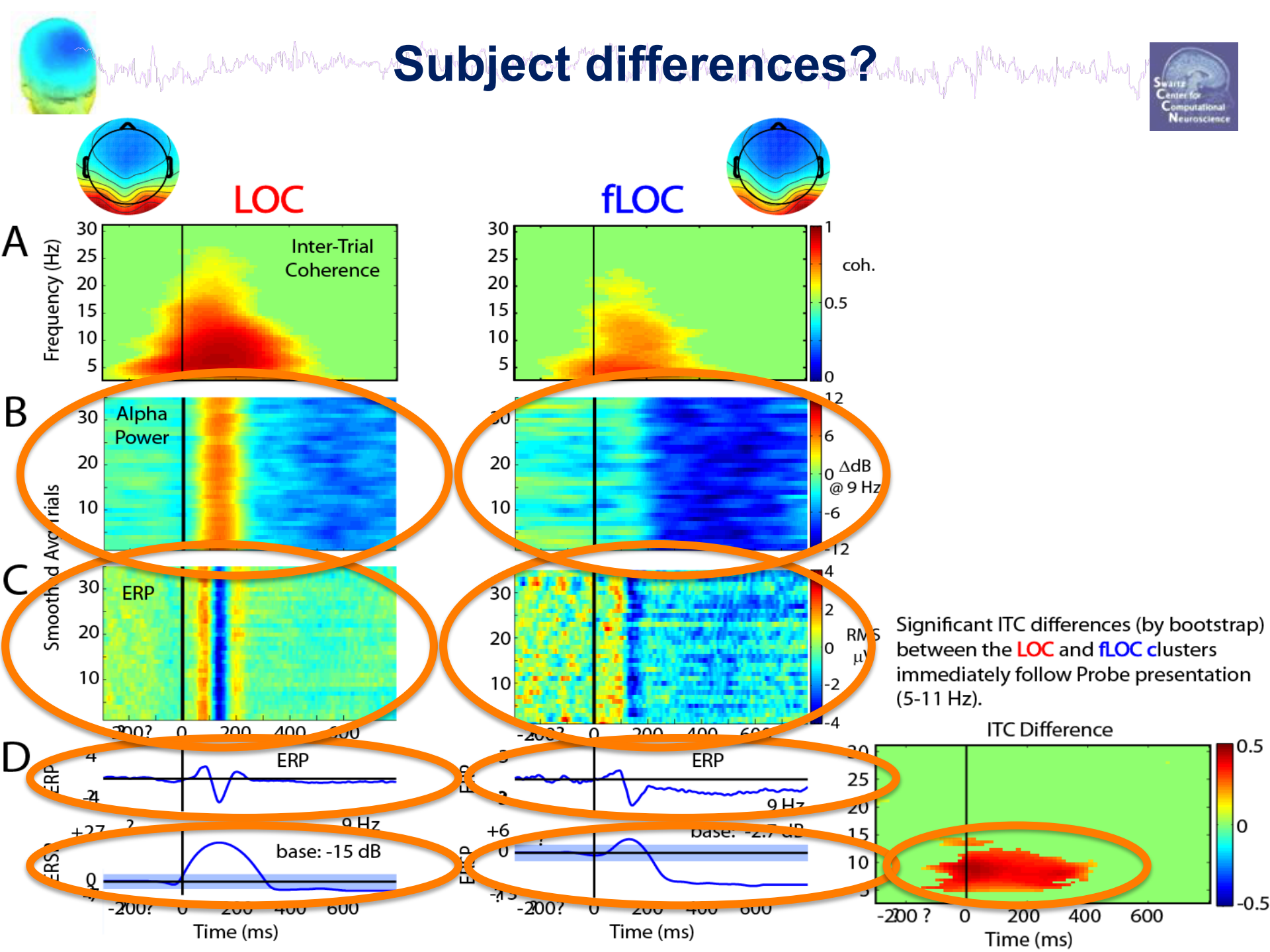
Why aren't all participants in every IC cluster?



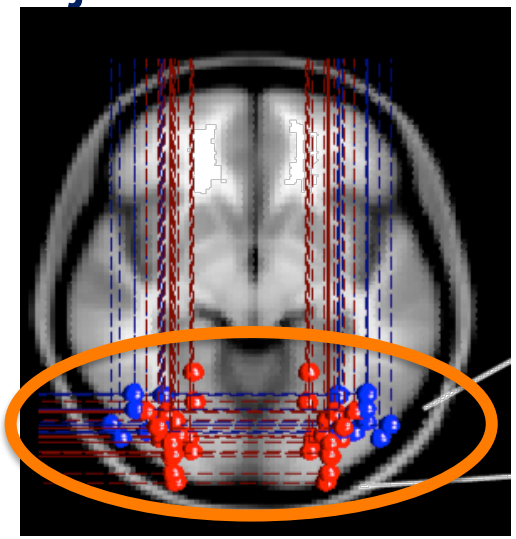


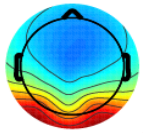
Onton & Makeig, 2005

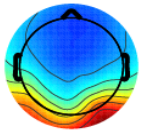
Subject differences?

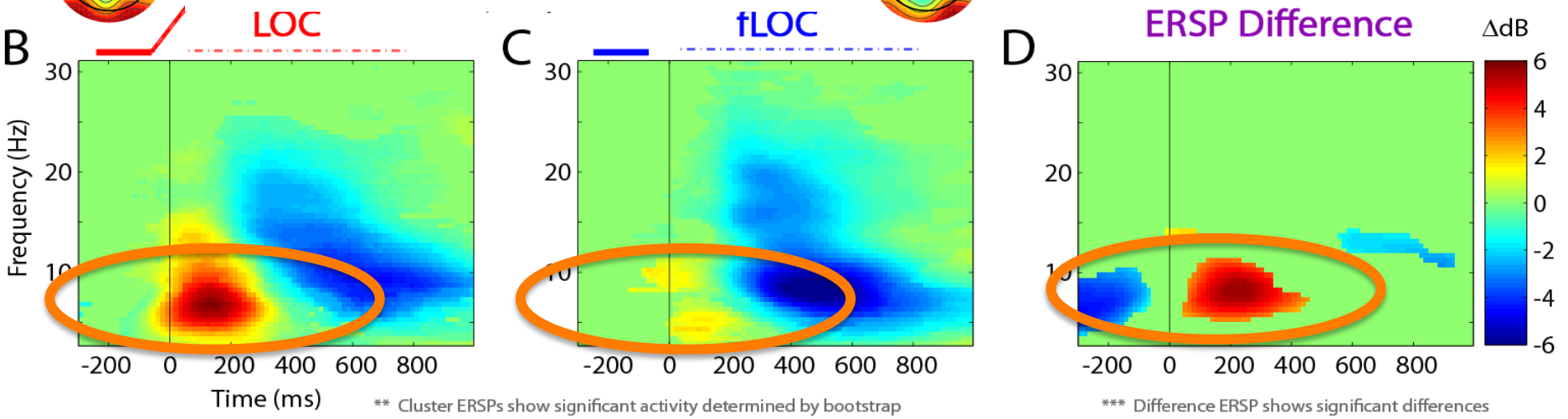


Subject differences?





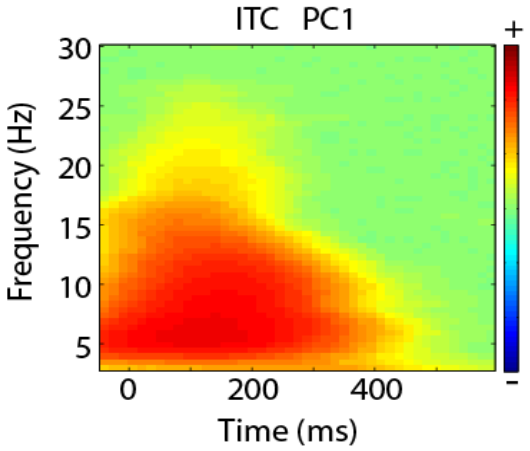


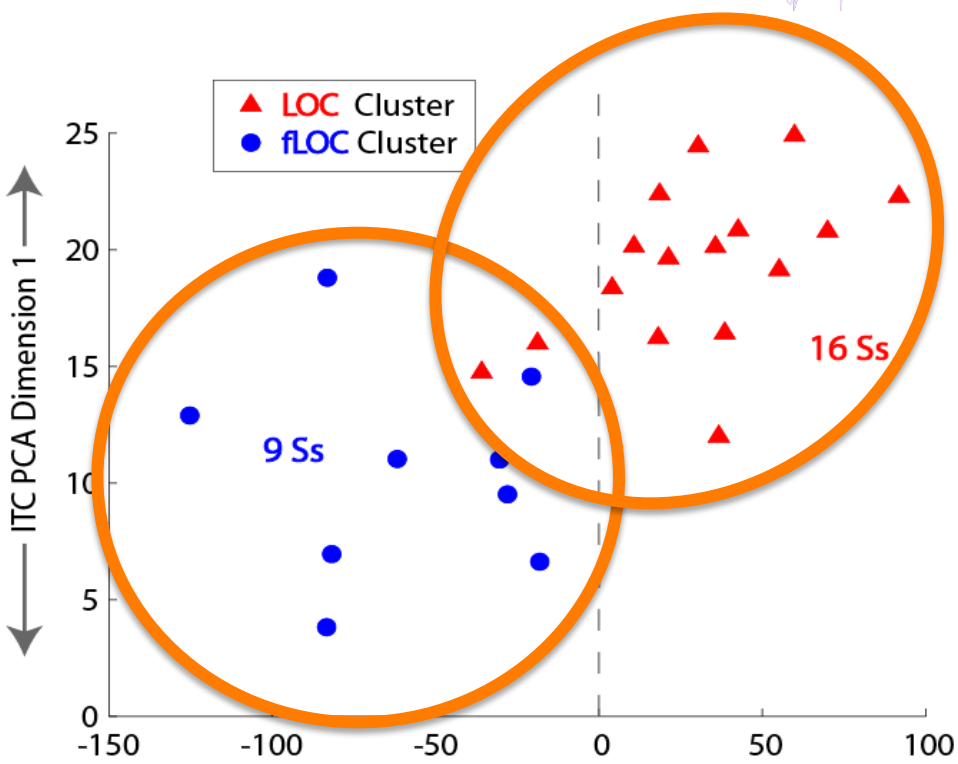


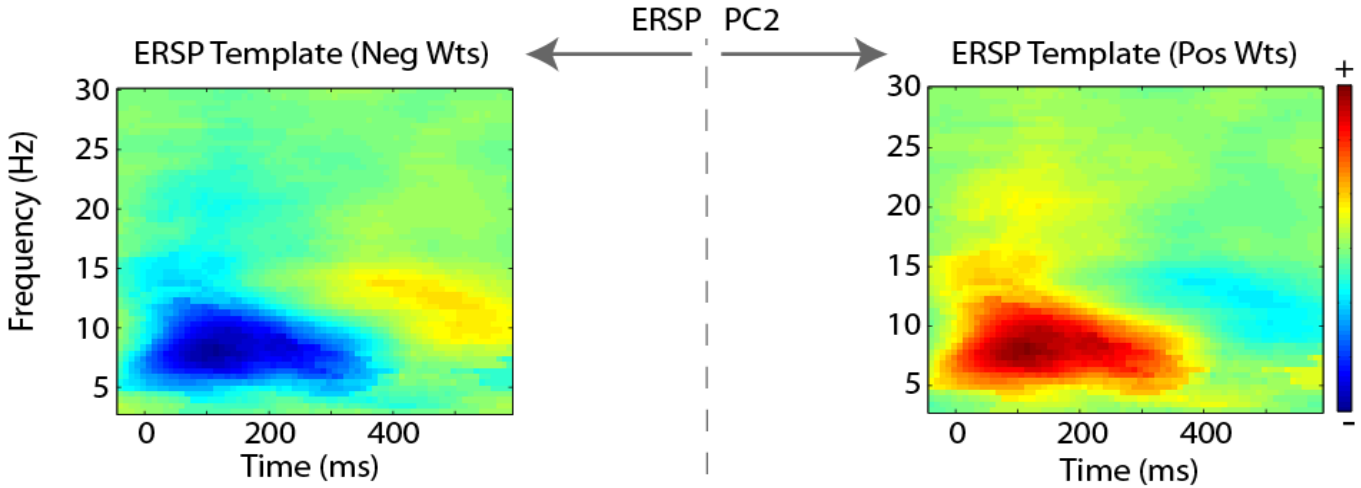
** Cluster ERSPs show significant activity determined by bootstrap statistics within subject and binomial probability between subjects ($p < 0.01$)

*** Difference ERSP shows significant differences between the two clusters by bootstrap statistics ($p < 0.001$)

Subject differences?



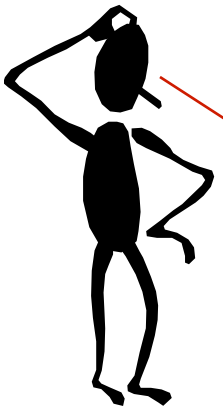


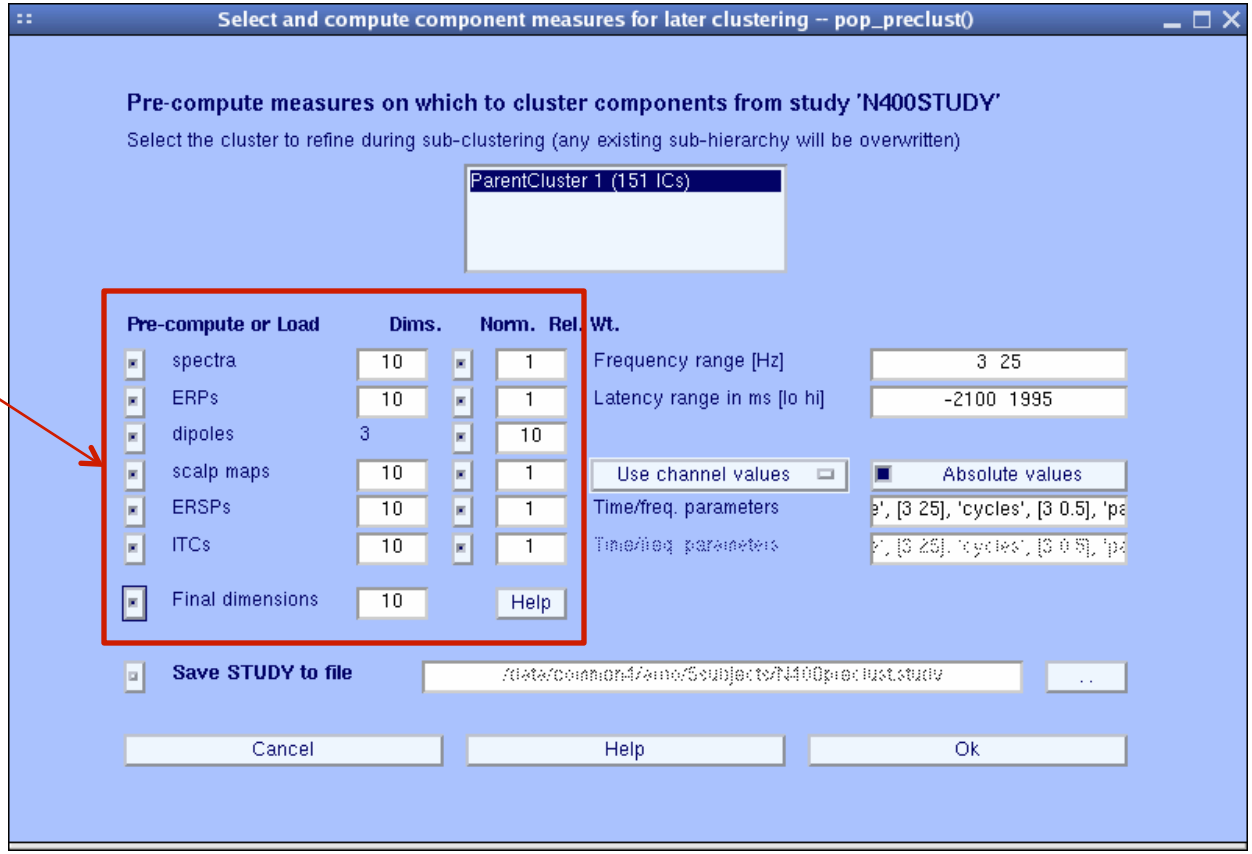


STUDY IC Clustering: Practical Problems

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

EEGLAB clustering has ~12 parameters

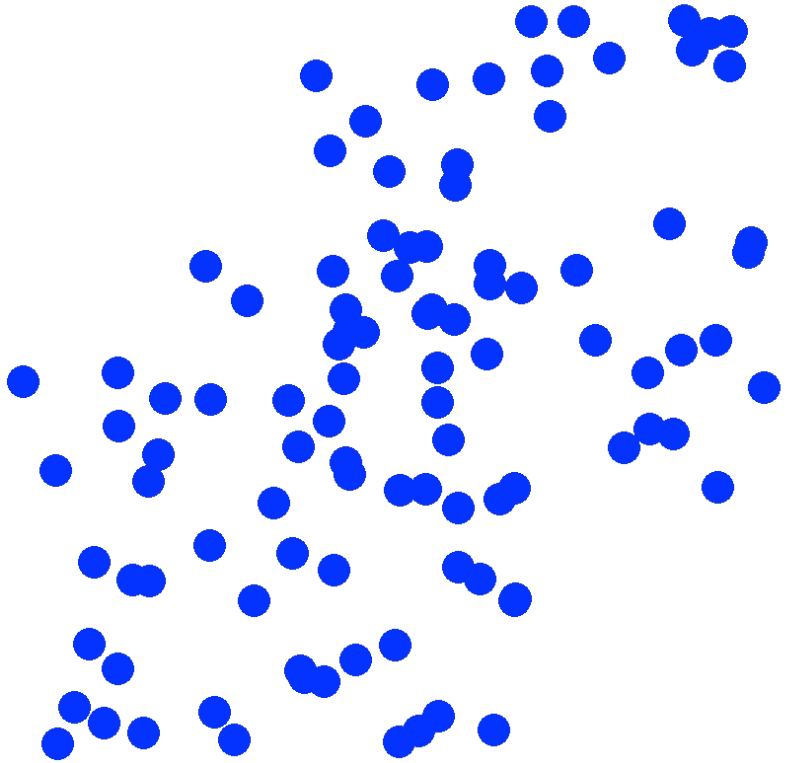




Problems with multi-measure clustering

In a uniform density distribution,

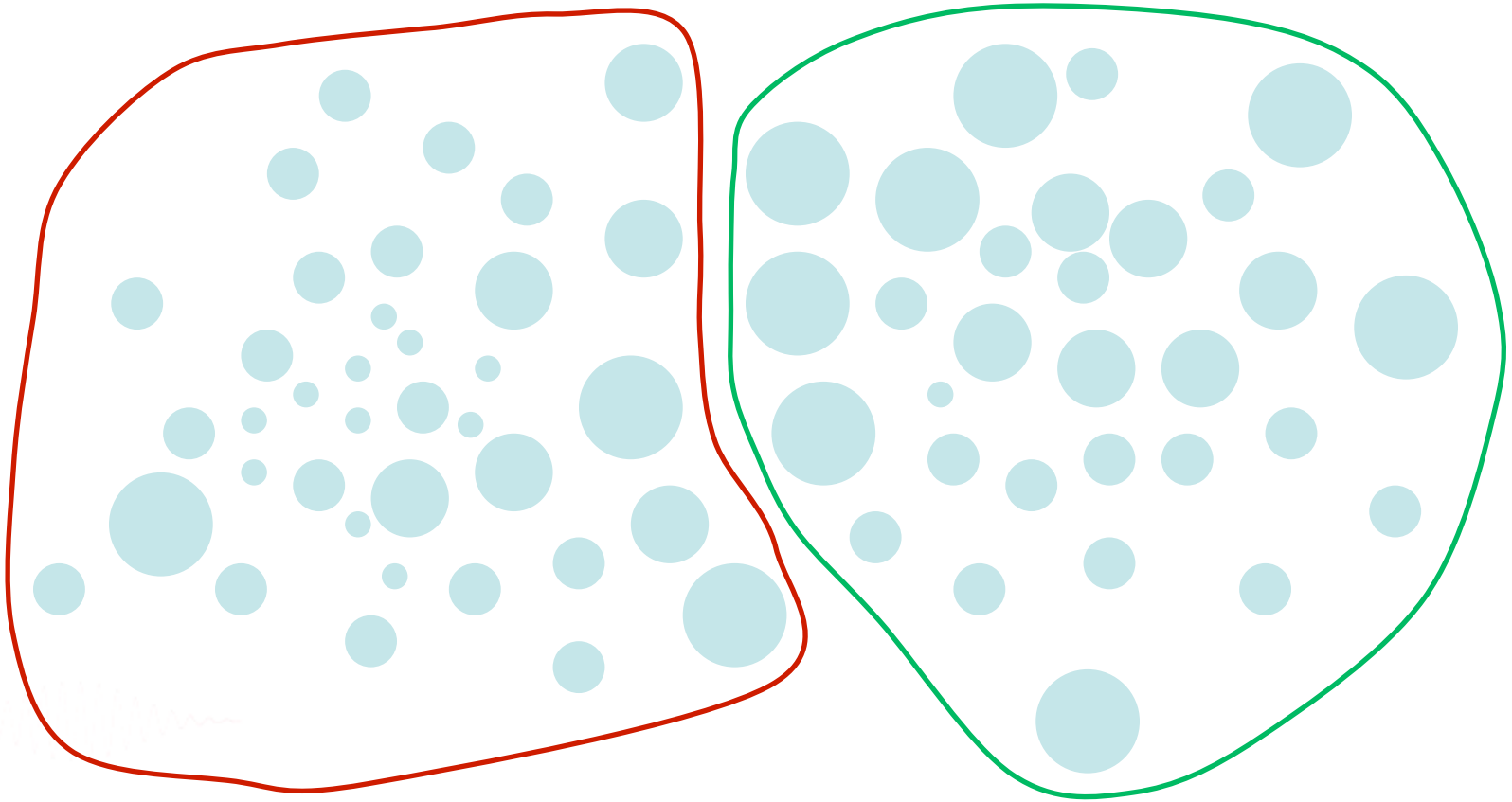
where are the clusters by location?



N. Bigdely-Shamlo, 2010

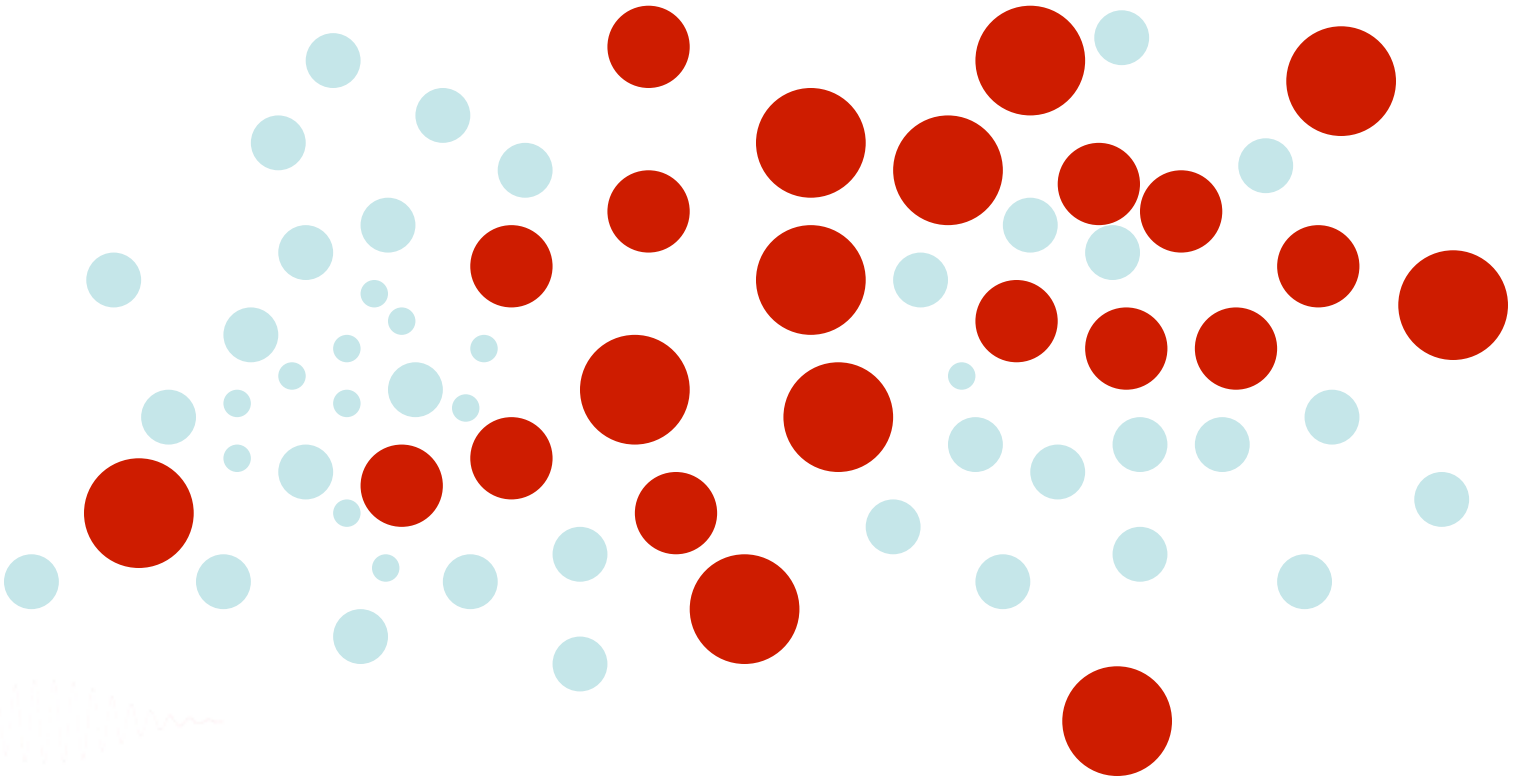
Problems with multi-measure clustering

What are the clusters according to location?



Problems with multi-measure clustering

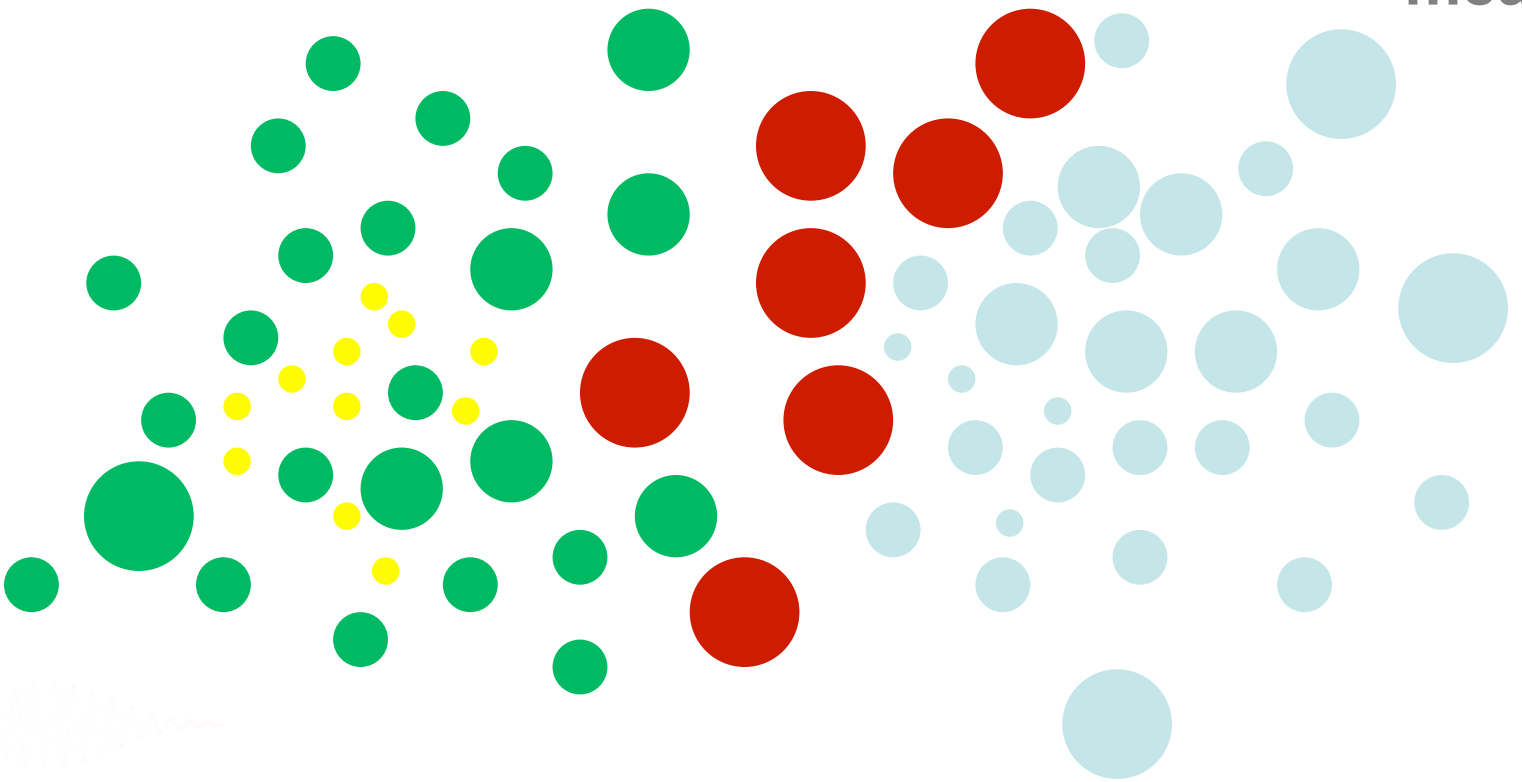
What are the clusters according to size ?



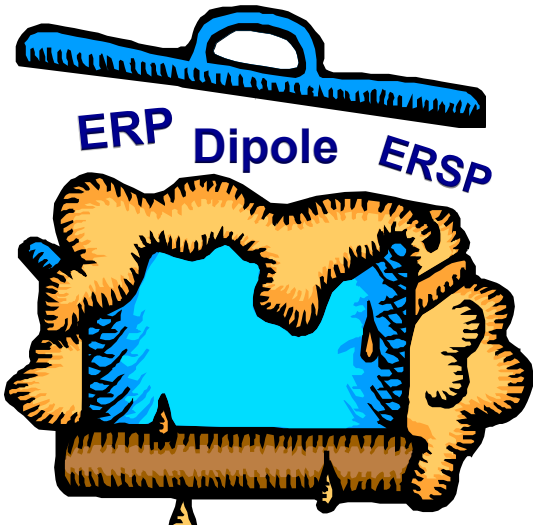
Problems with multi-measure clustering

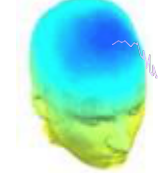
What are the clusters according to location and size?

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

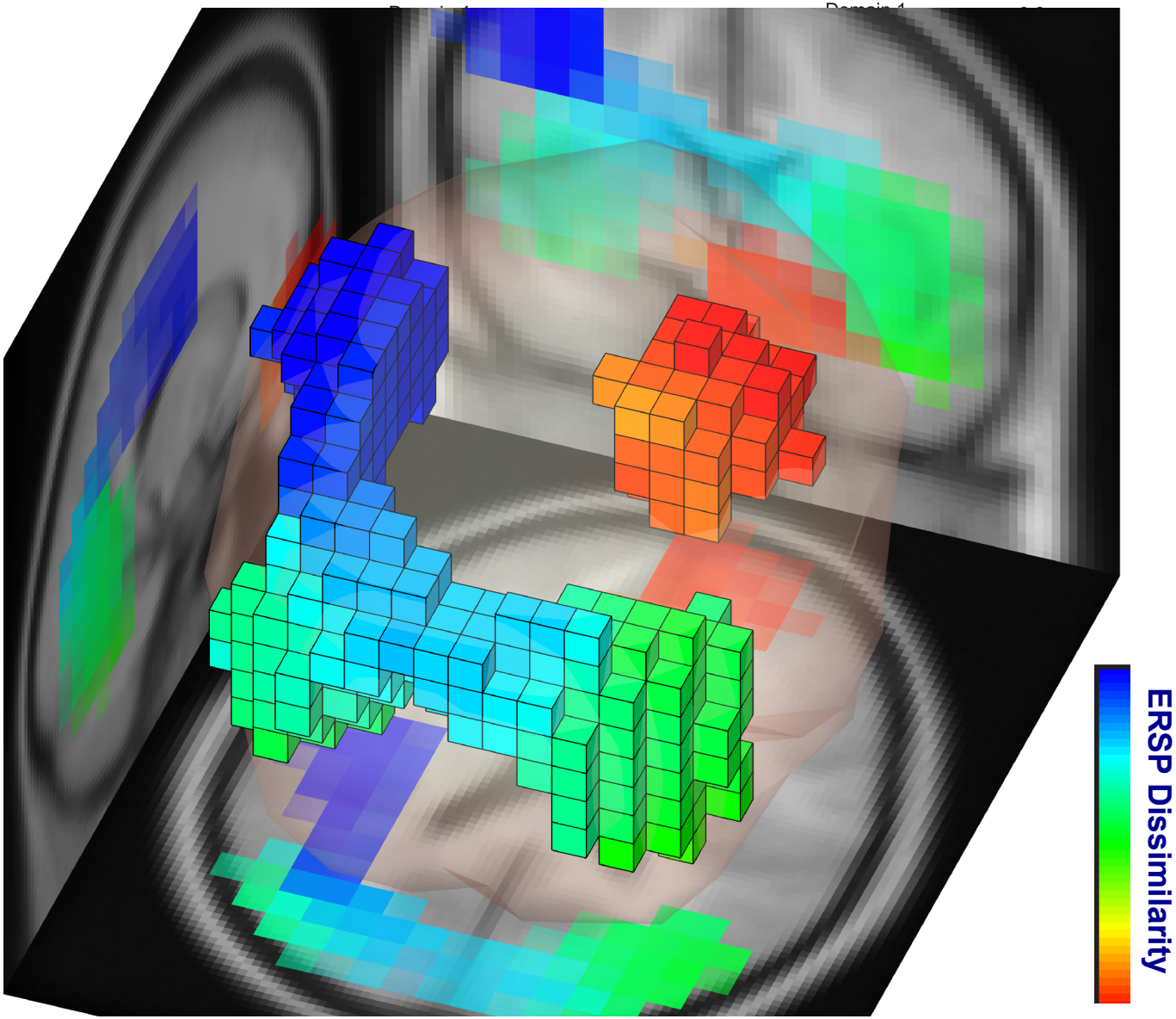
- **Instead**, we can directly work on pair-wise similarity matrices and prevent ICs with similarities less than certain threshold (e.g., ERSP corr. < 0.5) to be clustered together.
- The most important measure is **equivalent dipole location**.
- Assuming a certain variability estimate for dipole location (due to error in localization and subject variability), one can also estimate an optimum number of clusters.

Measure Projection asks:

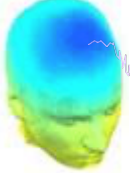
1. Where in 'template brain space' does our data have evidence that our measure of interest is consistent across nearby ICs?
2. Which such brain space voxel *domains* show consistent differences?

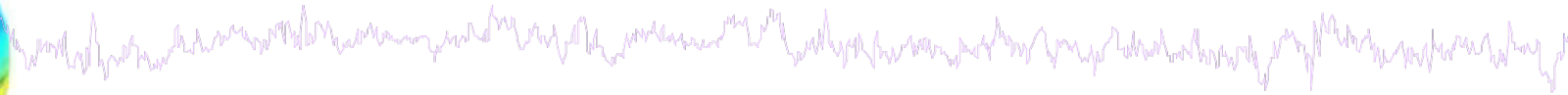
N. Bigdely-Shamlo, 2010

Measure Projection: RSVP Task Example



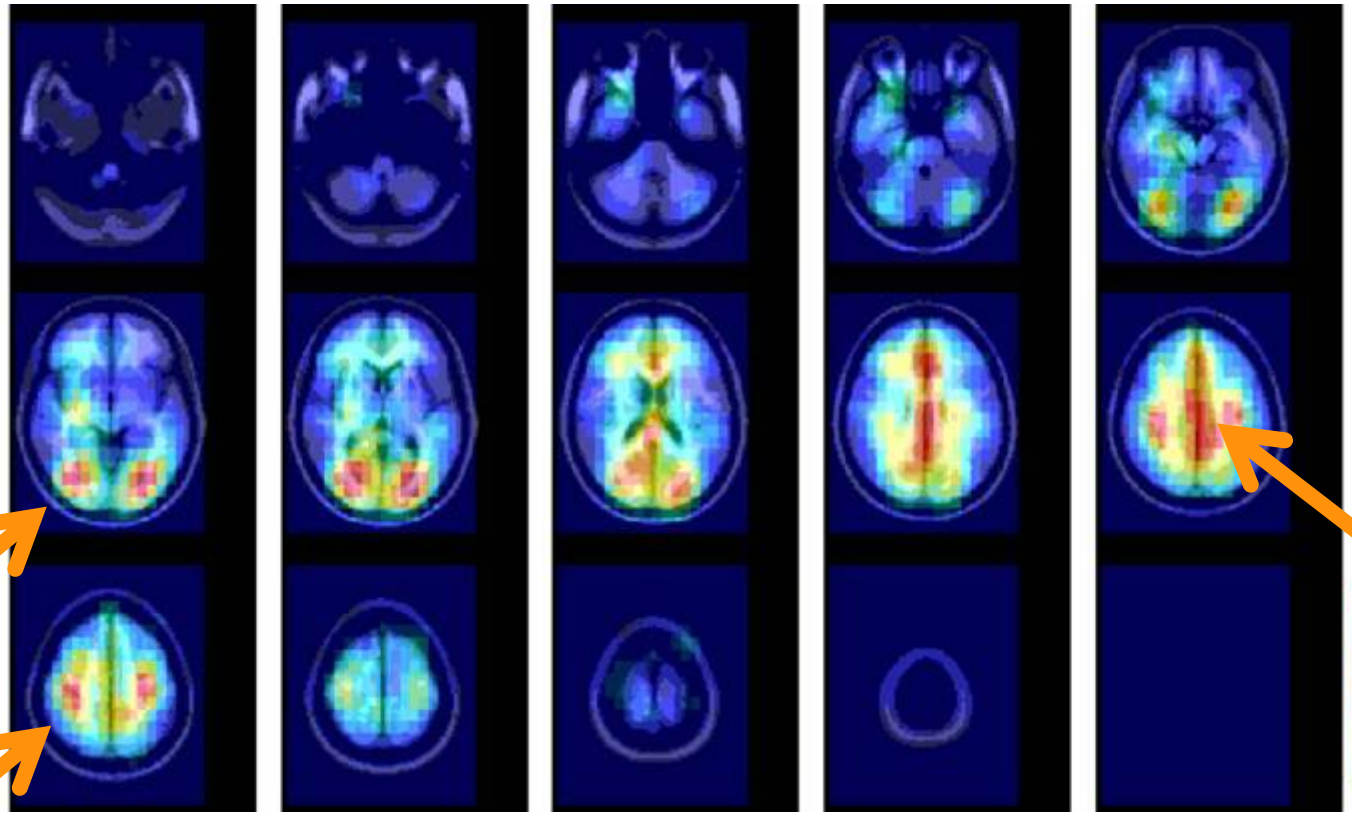
N. Bigdely-Shamlo, 2011





Questions?

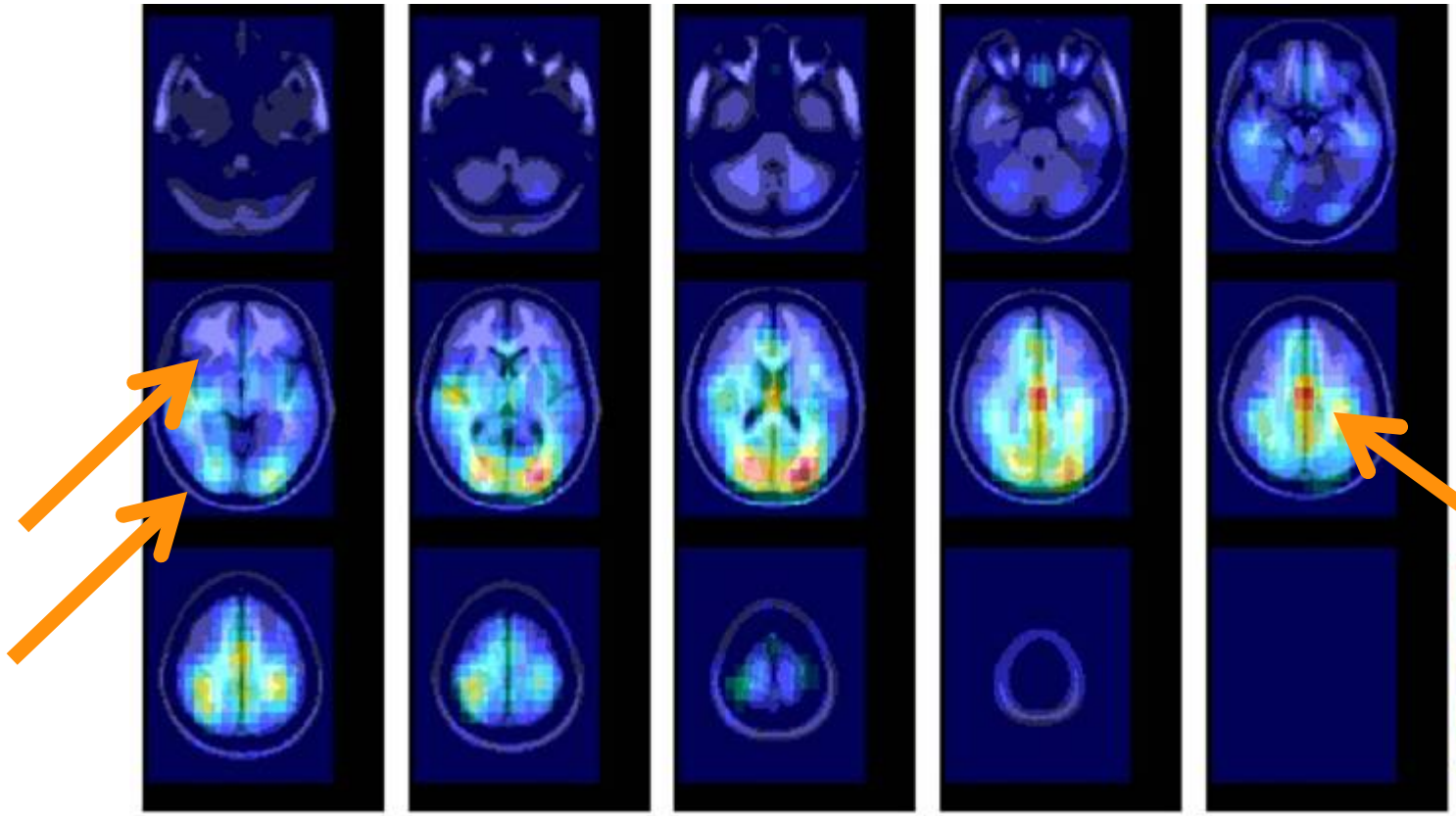
Equivalent dipole density



Letter twoback with feedback

>> dipoledensity()

Equivalent dipole density



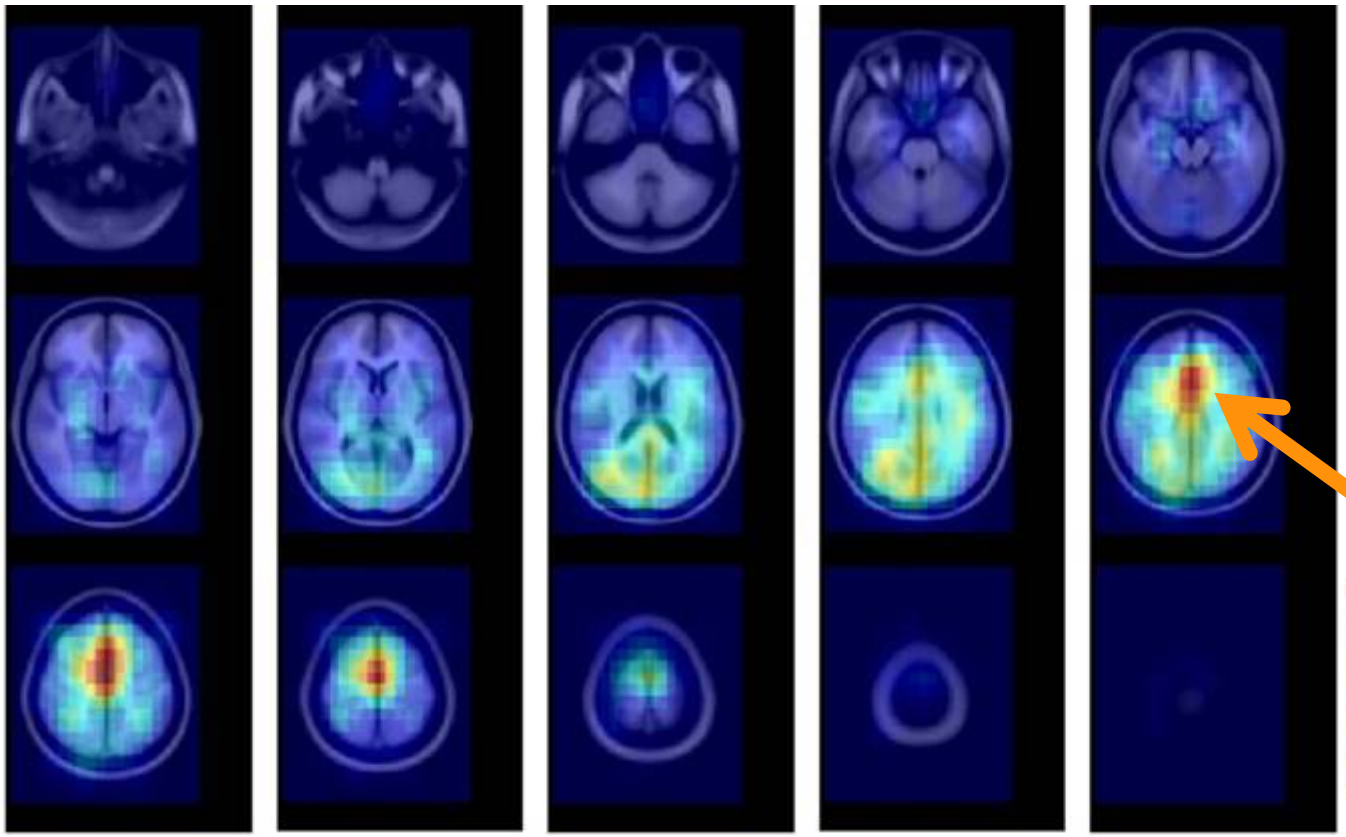
Auditory oddball plus novel sounds

>> dipoledensity()

Onton et al., 2

Onton et al., ‘05

Equivalent dipole density Exp I



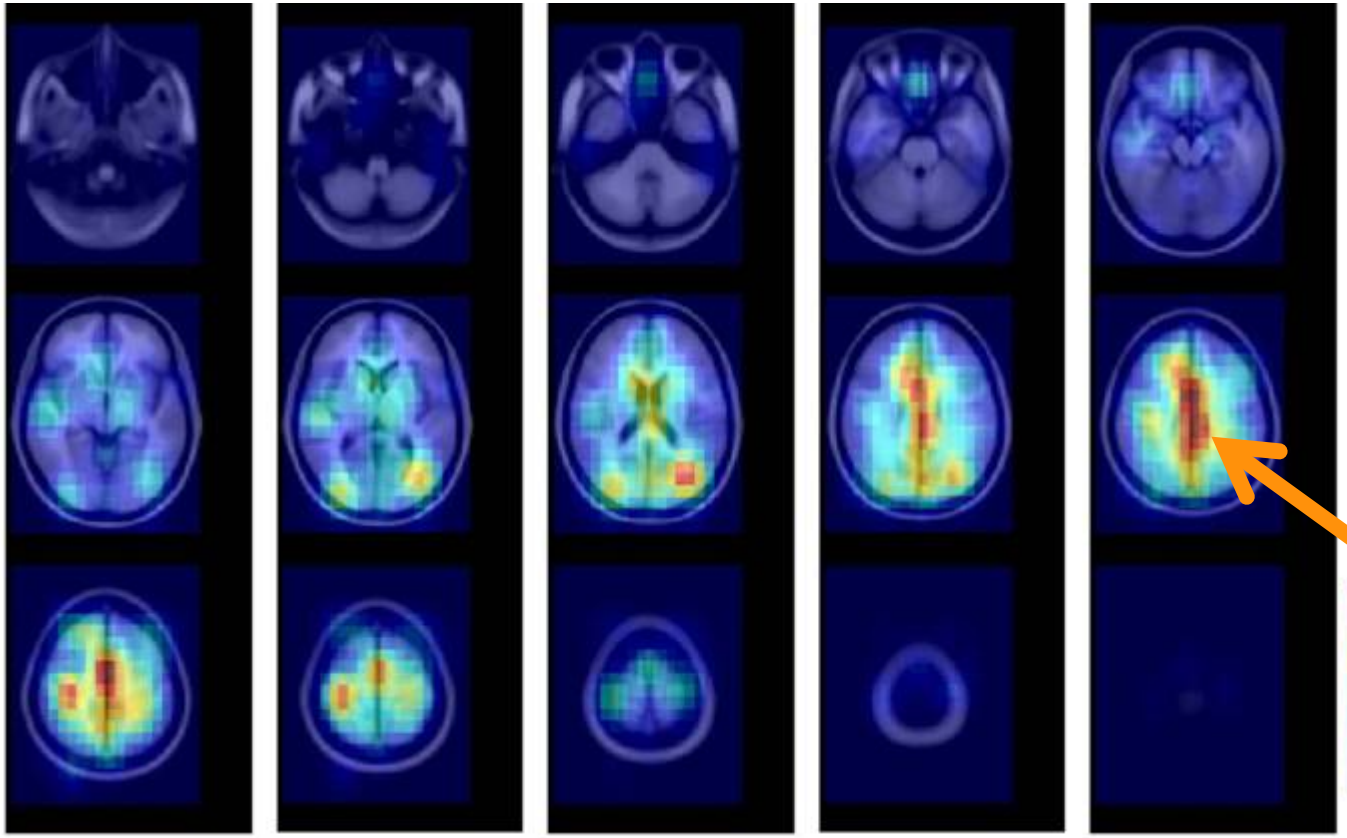
Word memory (old/new) task

>> dipoledensity()

Onton et al., 2

Onton et al., '05

Equivalent dipole density Exp II



Visually cued button press task

>> dipoledensity()

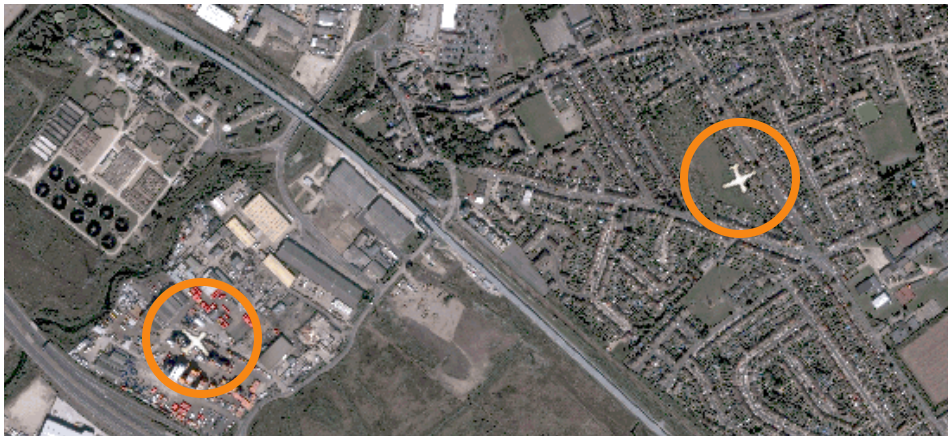
Onton et al., 2

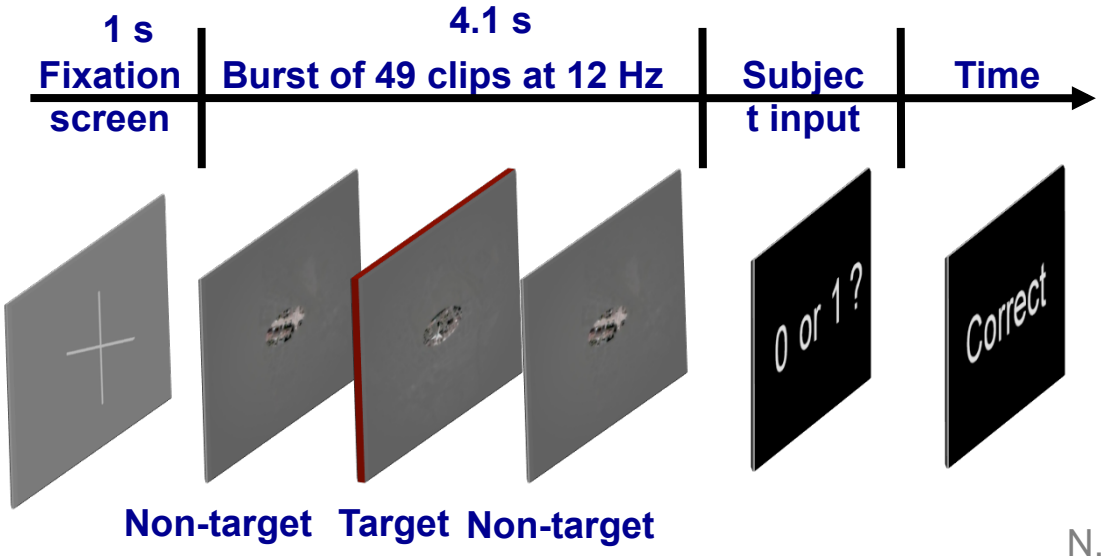
Onton et al., '05

Measure Projection: RSVP Example

Rapid Serial Visual Presentation Experiment

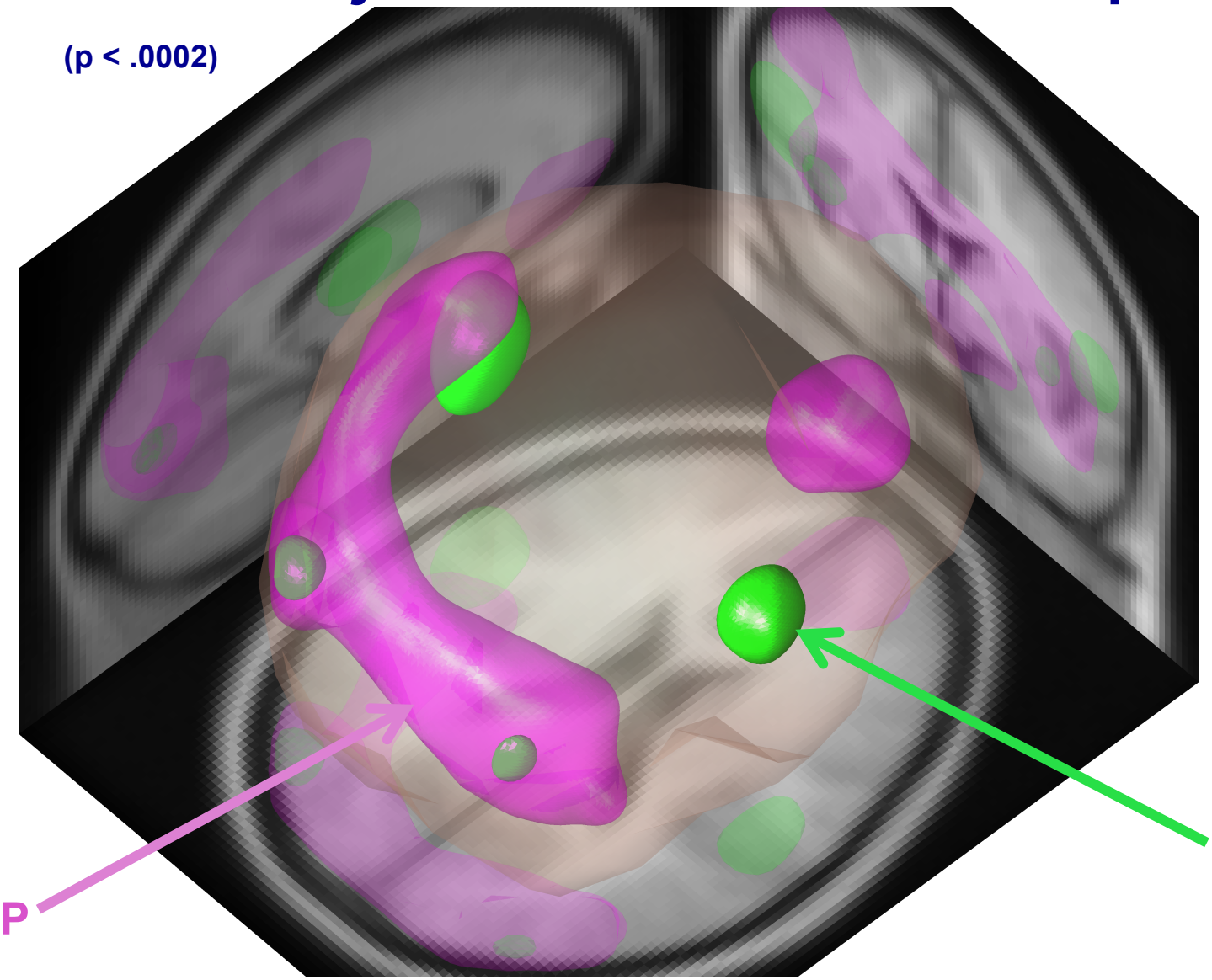
- 8 subjects
- 15 Sessions
- Visual target detection
- 257 components with equiv. dipoles inside the brain



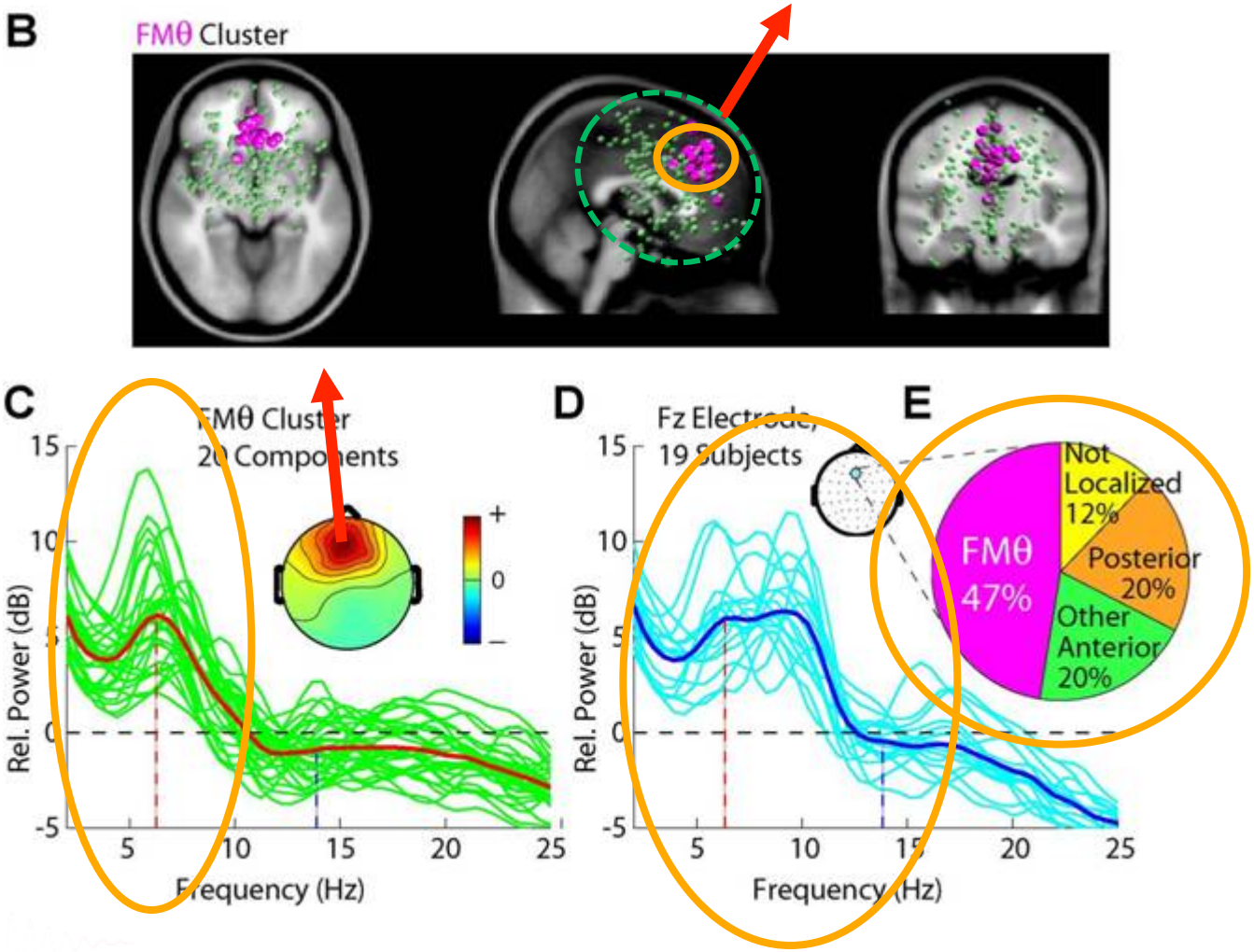


N. Bigdely-Shamlo, 2010

Measure Projection: RSVP Task Example

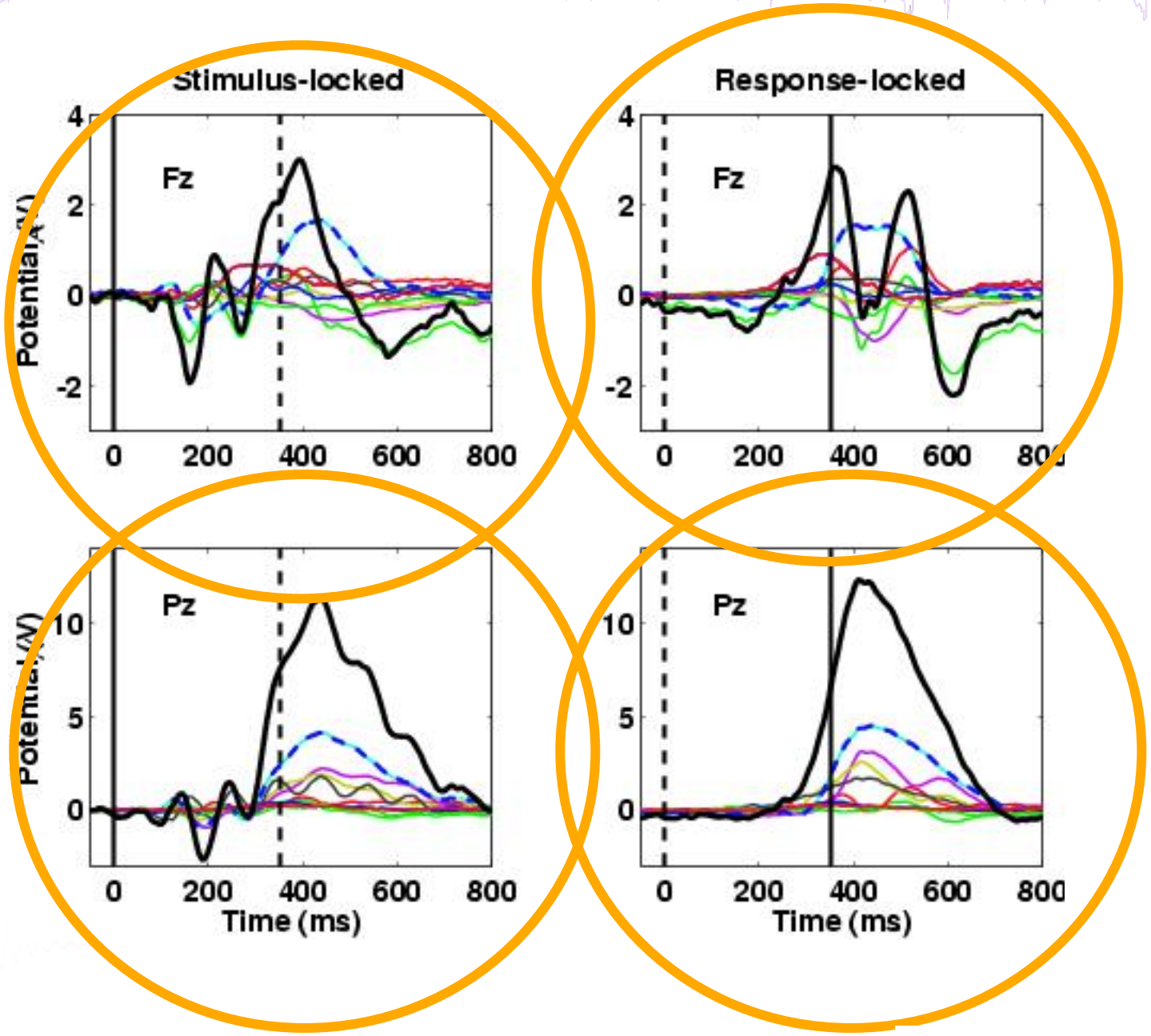


An FM-theta IC cluster
In a working memory task



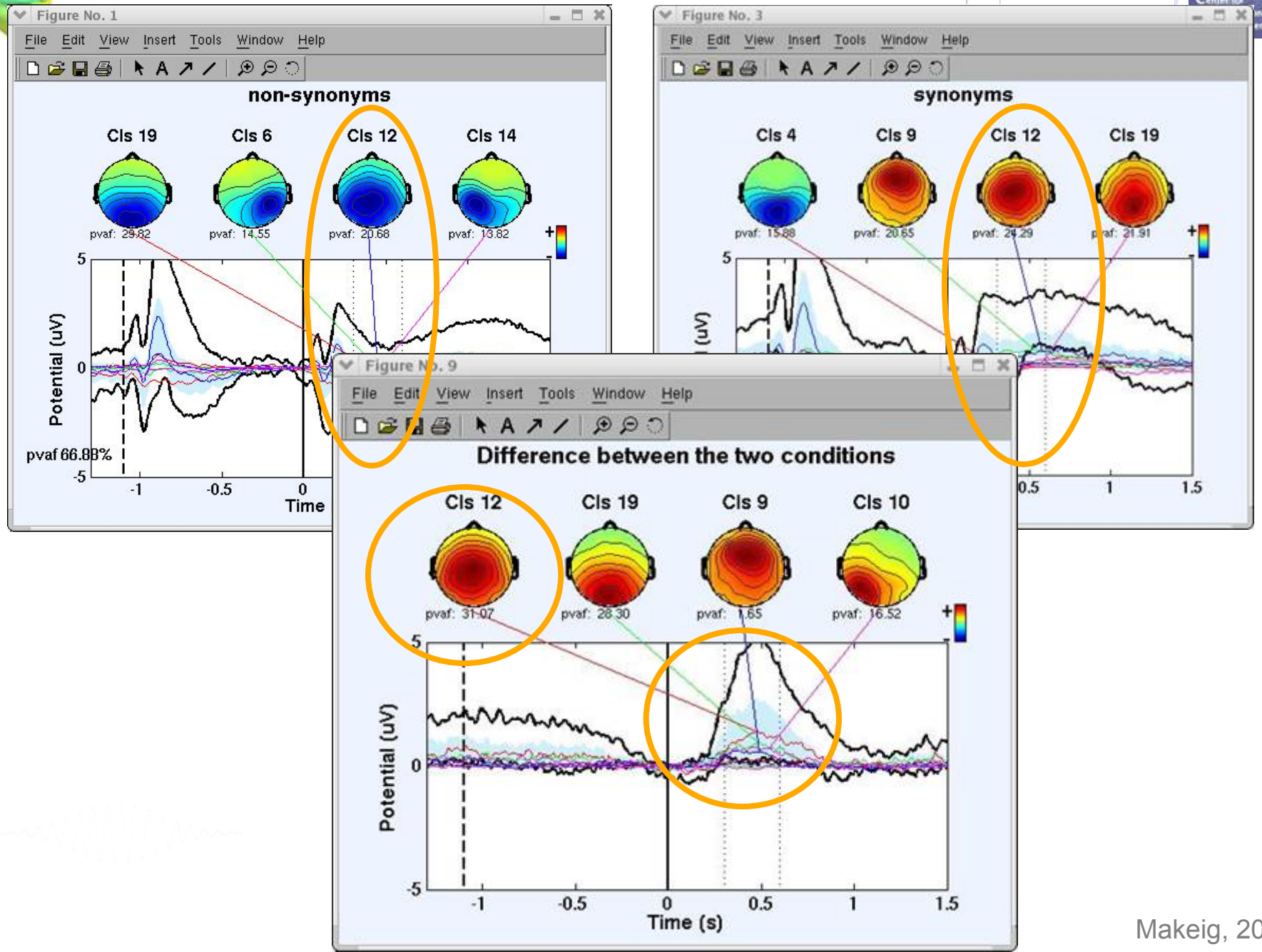
Onton et al., *NeuroImage* 2005

Complex event-related dynamics produce "the" P300

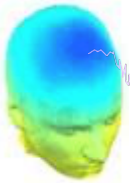


Makeig et al. PLOS 2004

Cluster ERP contributions – *std_envtopo()*



Makeig, 2007

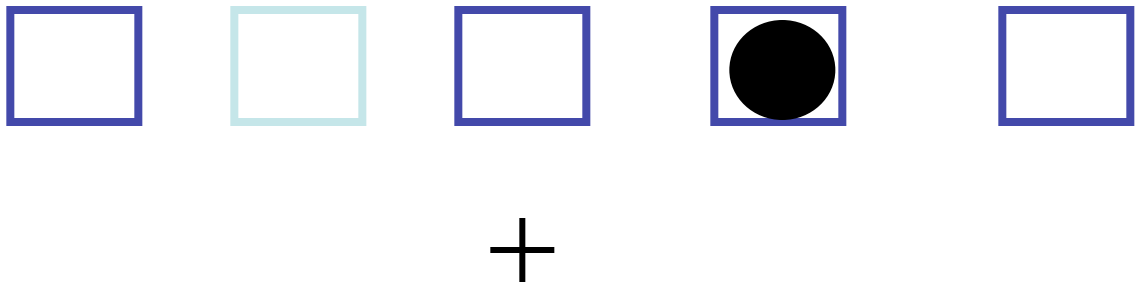


IC clustering of LPC data

- 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.

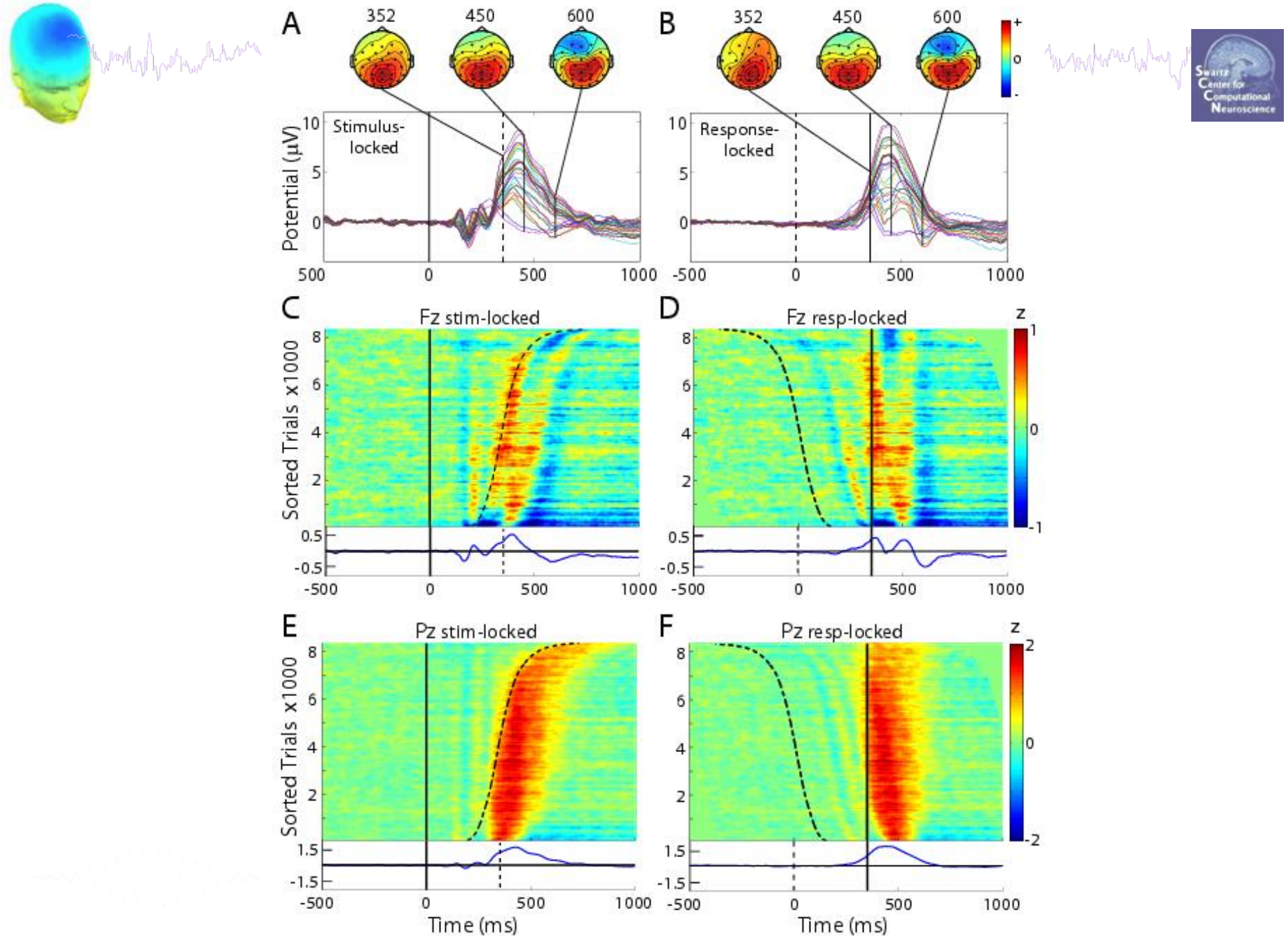
Makeig, 2007

Visual Selective Attention Task



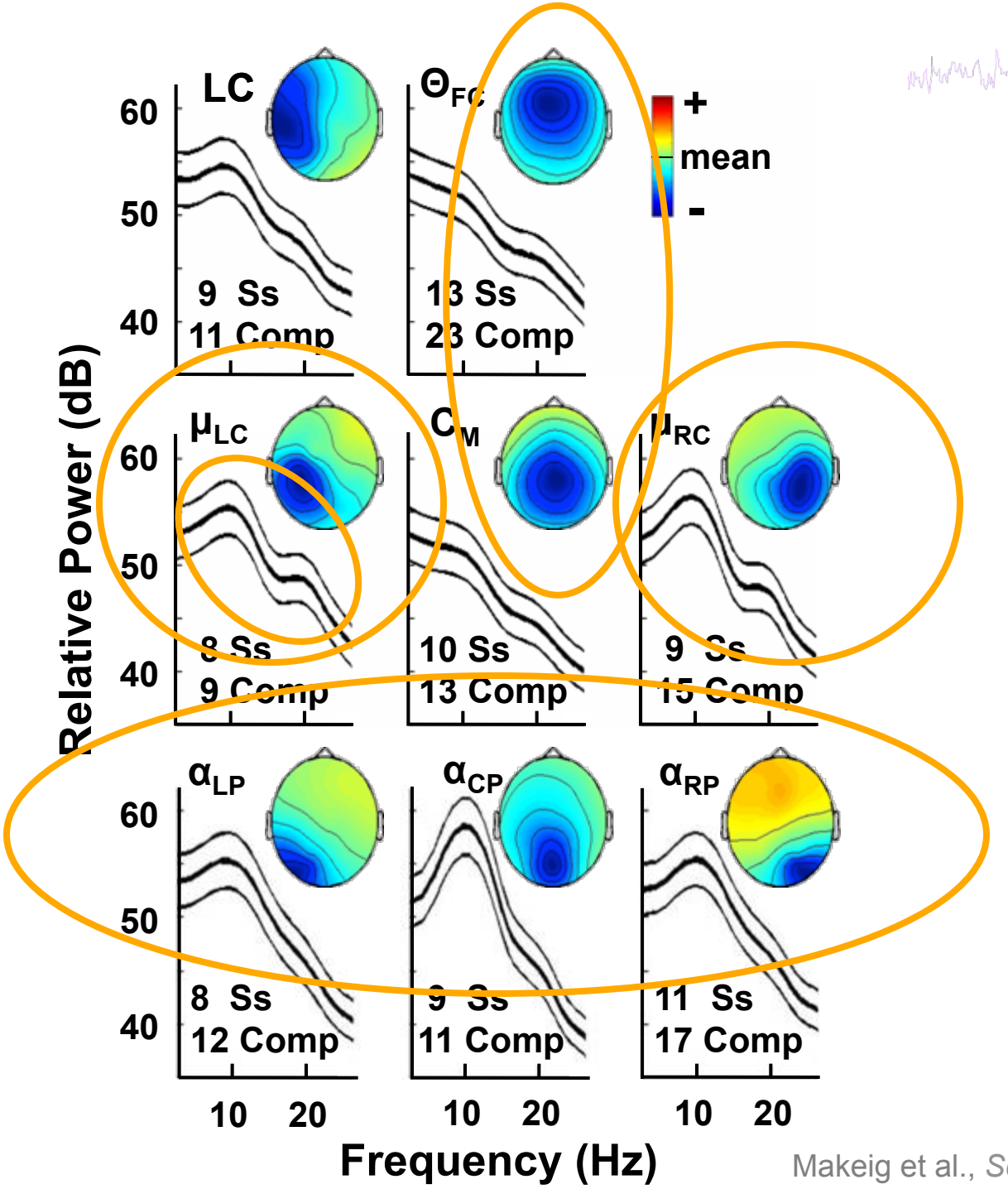
15 subjects

Makeig et al., PLPS 2004

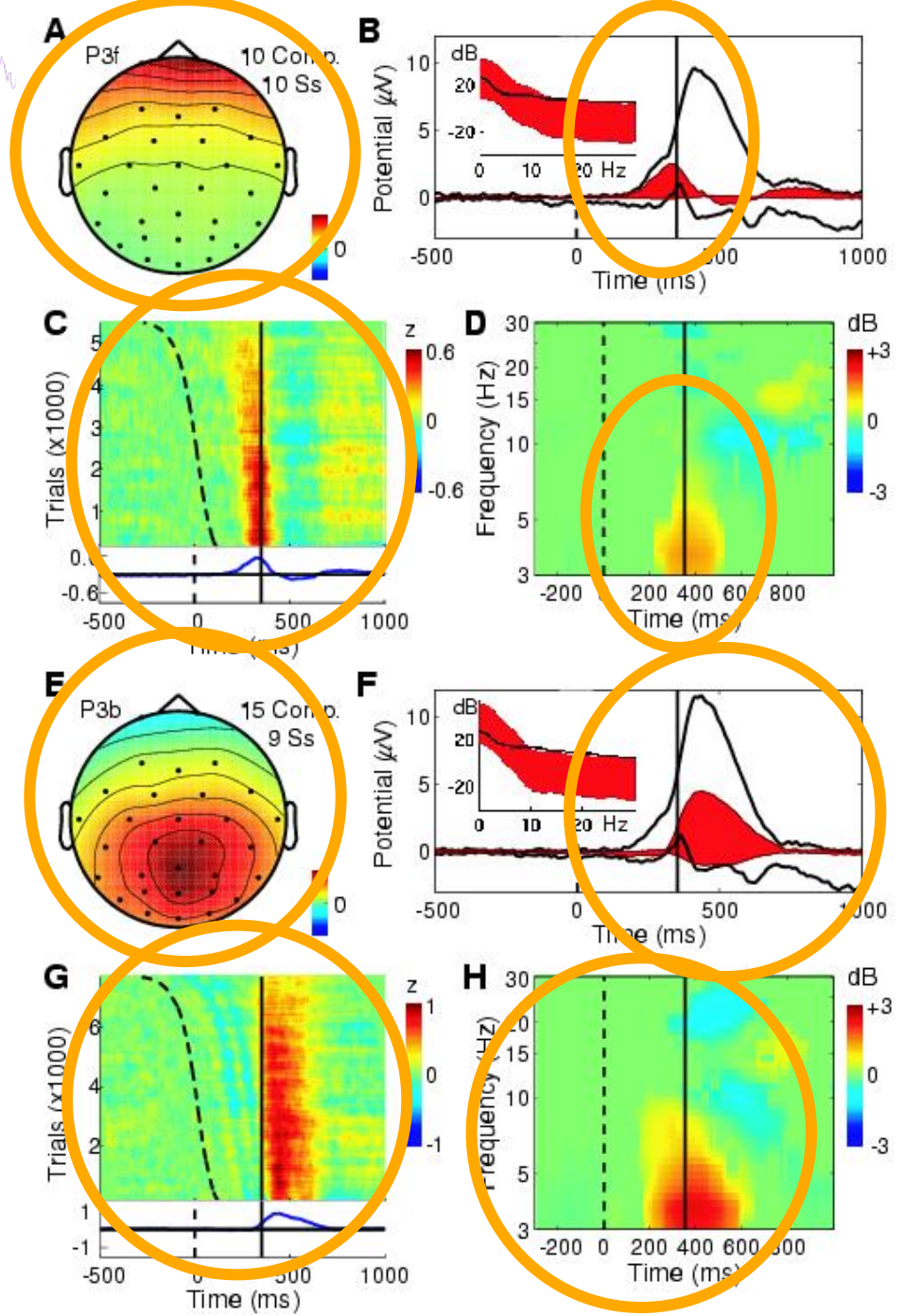


Makeig et al., PLOS 2004

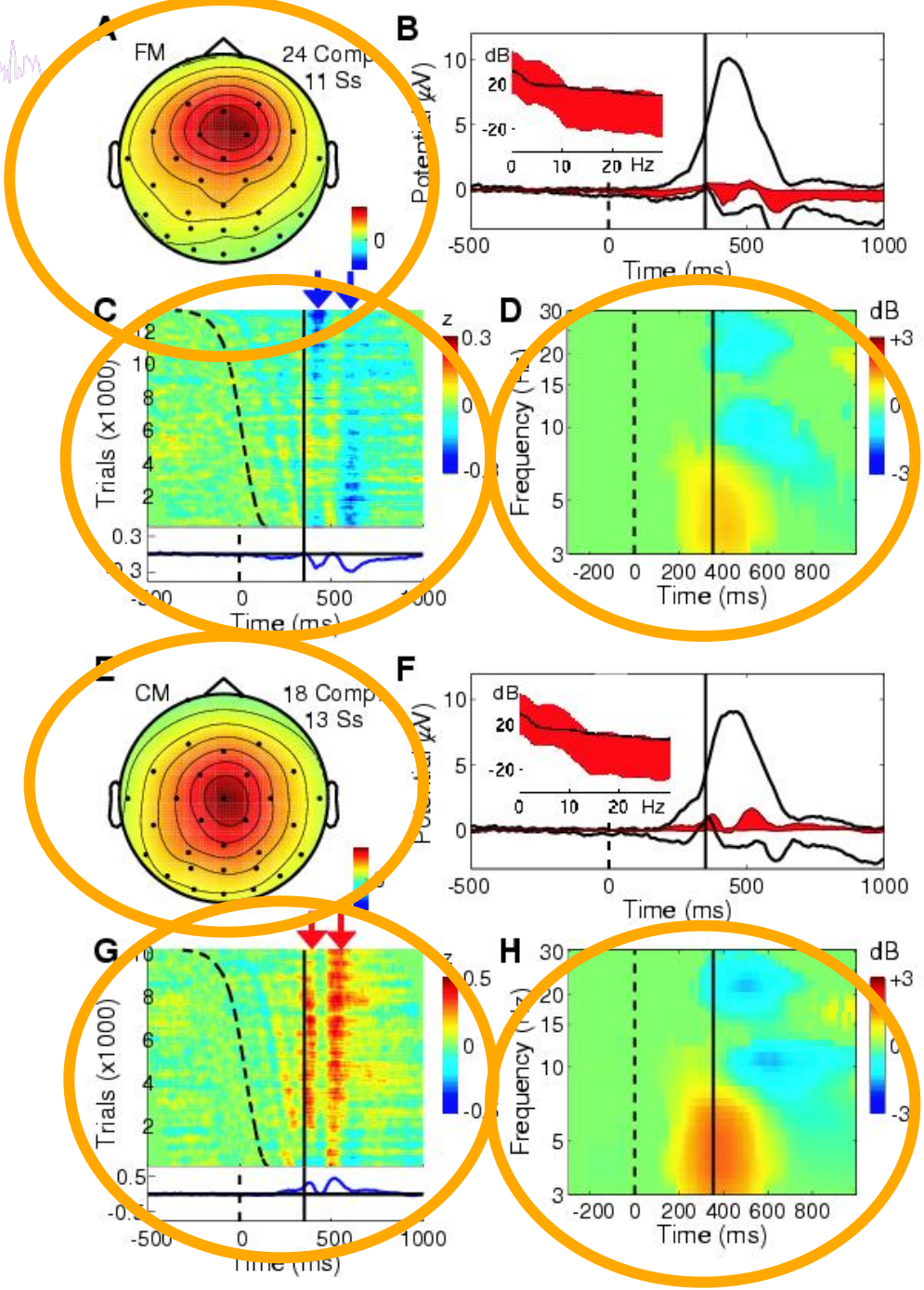
N1 Component Clusters



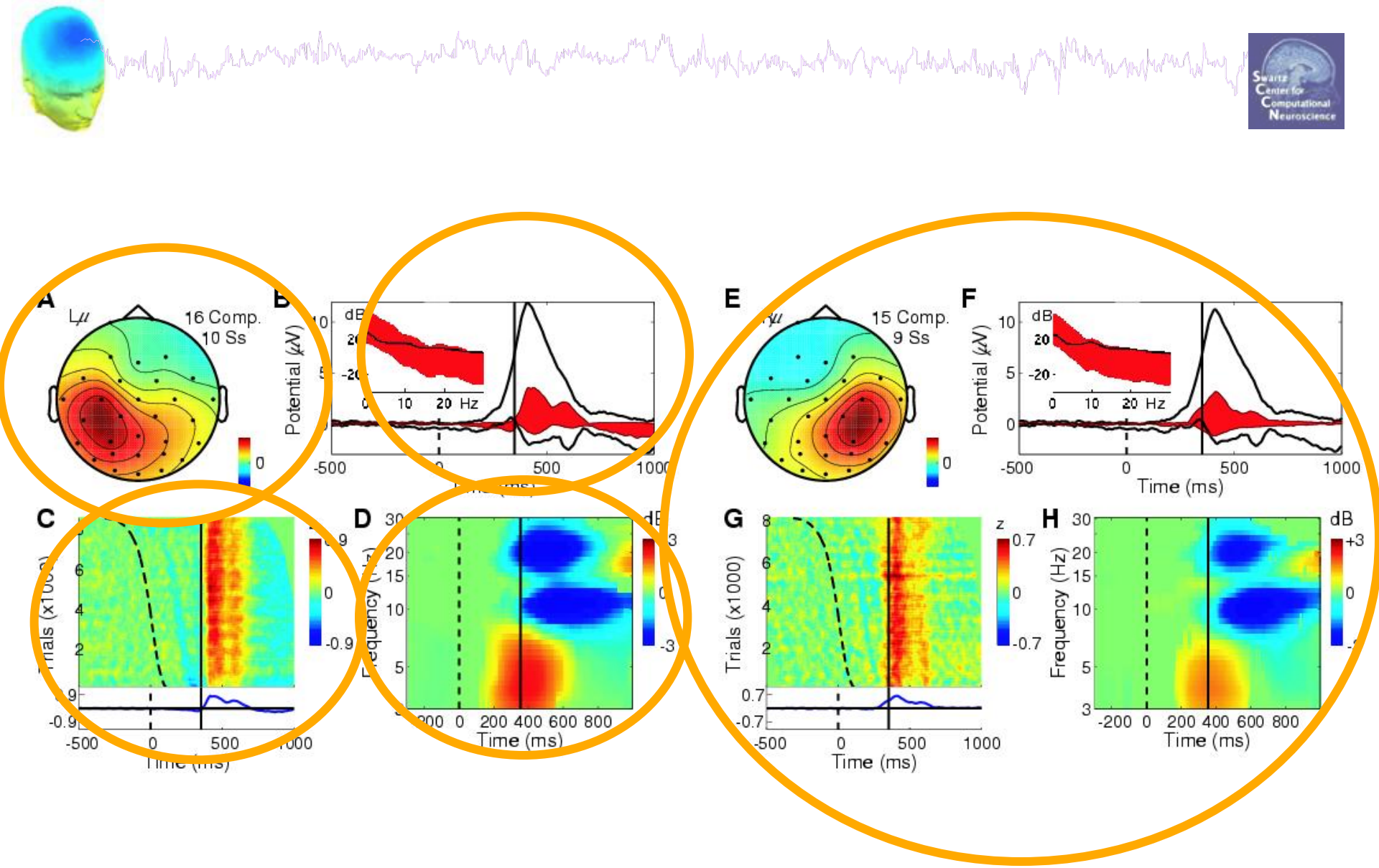
Makeig et al., *Science* 2002



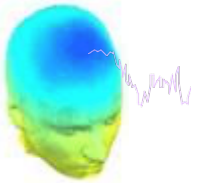
Makeig et al. PLOS 2004

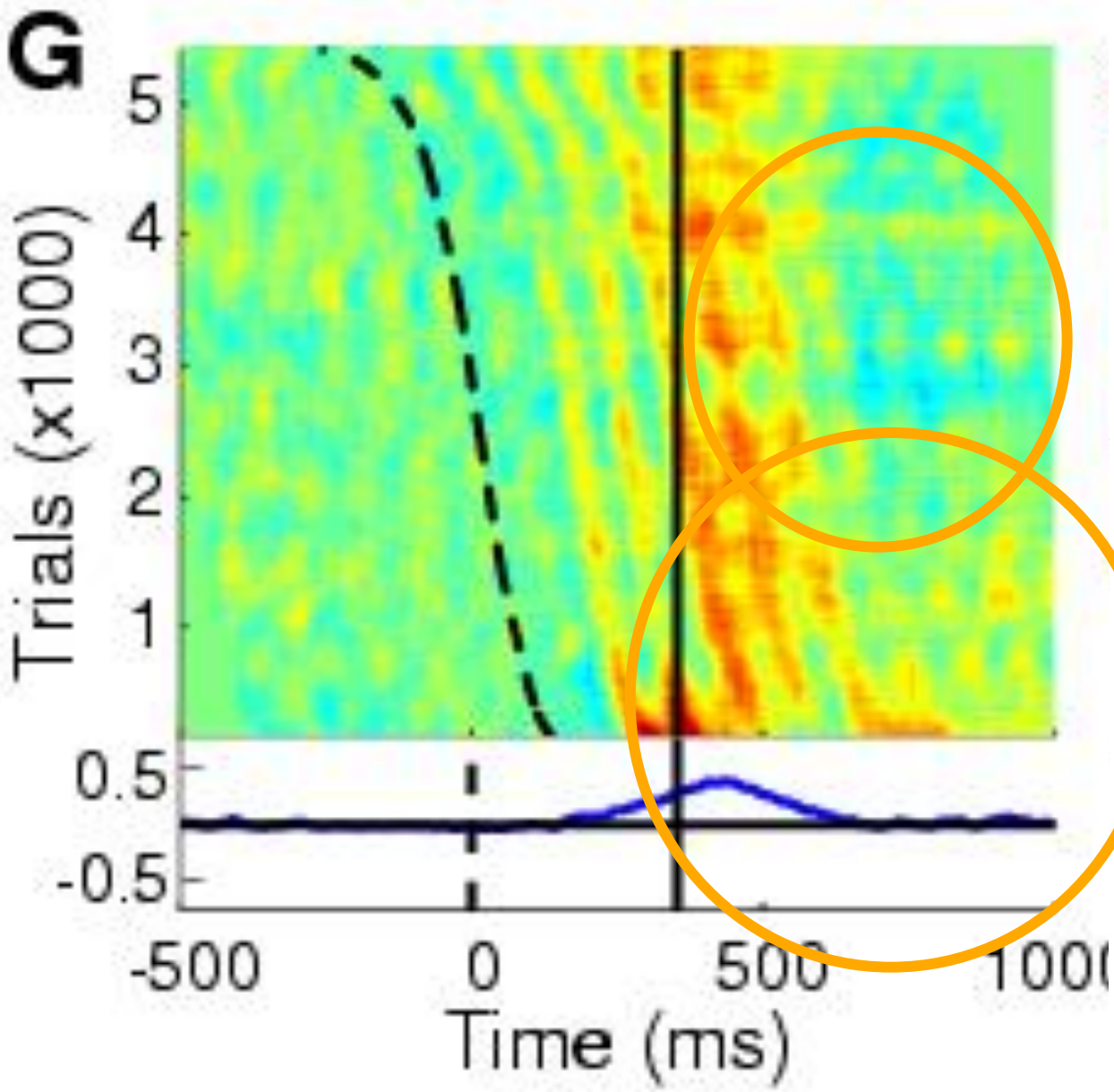


Makeig et al. PLOS 2004

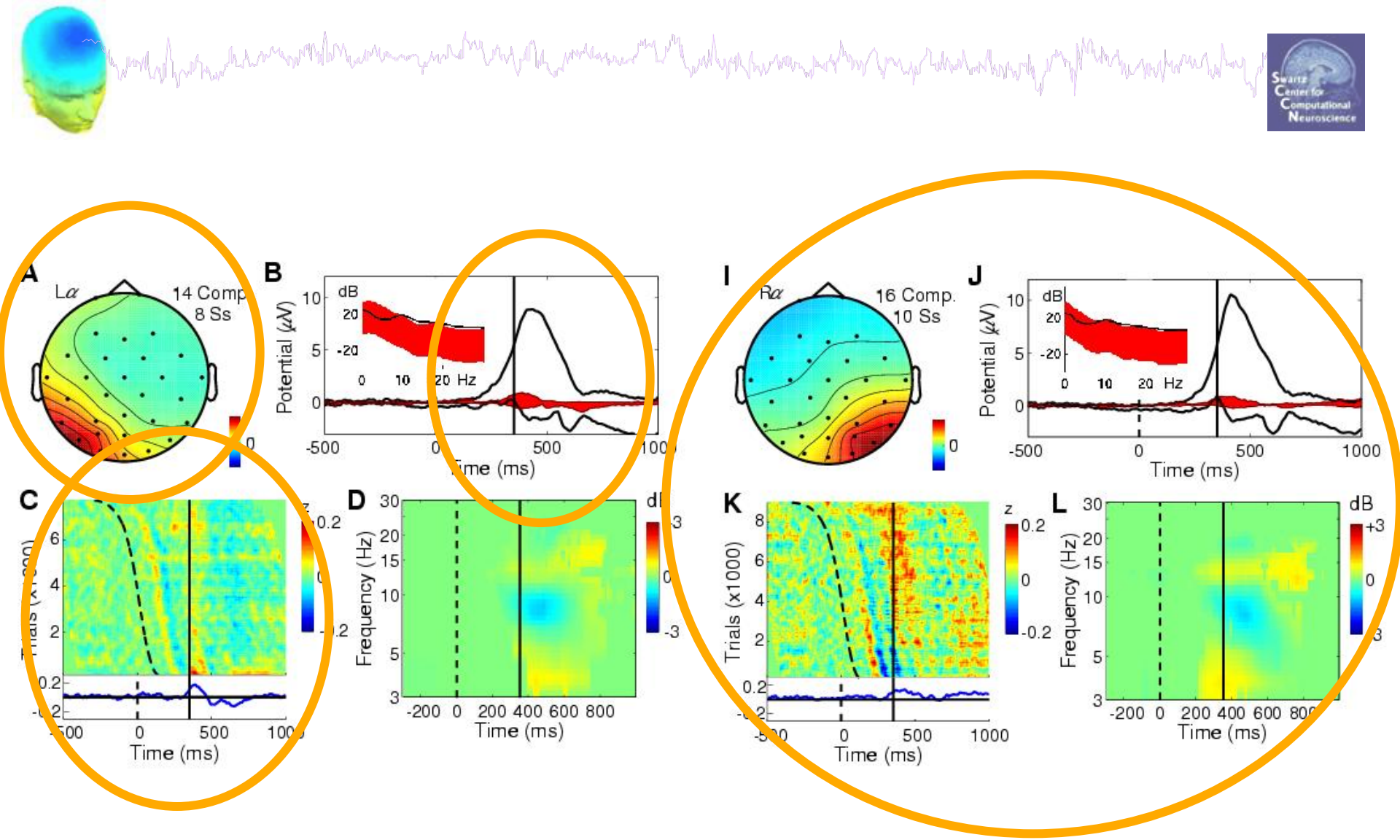


Makeig et al. PLOS 2004

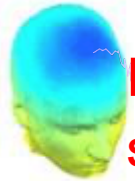




Makeig et al. PLOS 2004



Makeig et al. PLOS 2004



BSCR

Simulate 25

↑ RLS_{25}-4
↓ $wMNI_{80}$-4

Assume 80

↑ RLS_{25}-4
↓ RLS_{15}-4

Simulate 25

Assume 80

Template head

Simulate 25

Assume 15

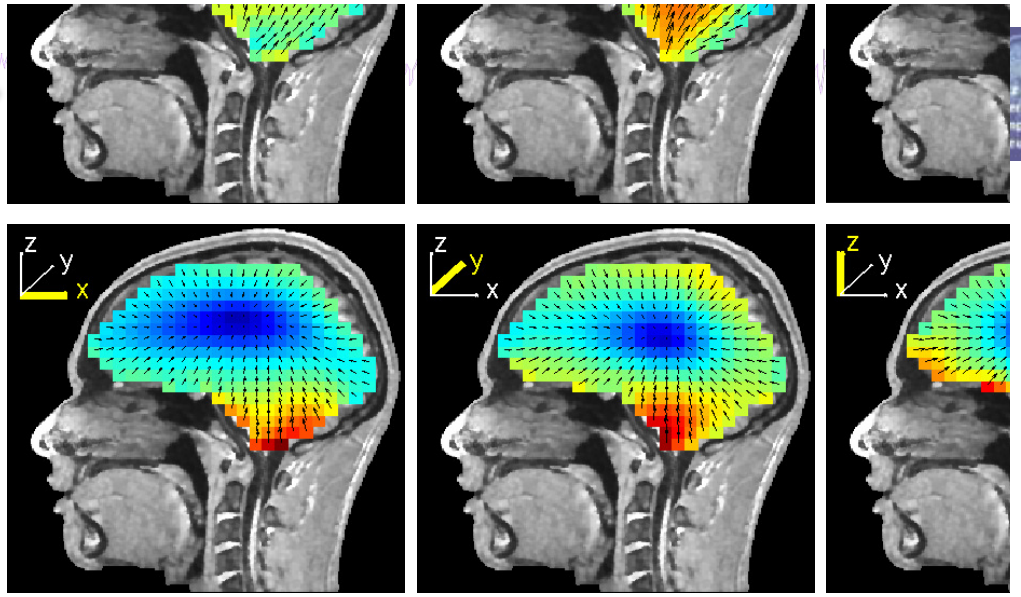


Figure 13: Equivalent dipole source localization error directions (arrows) and magnitudes (colors) for model dipoles
head model when the brain-to-skull conductivity ratio was mis-estimated as 80:1 (top row) or as 15:1 (bottom r
forward-model value (25:1). The middle row shows errors when source localization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

Effects of Mis-Estimating Skull Conductivity

Akalin Acar & Makeig, 2013