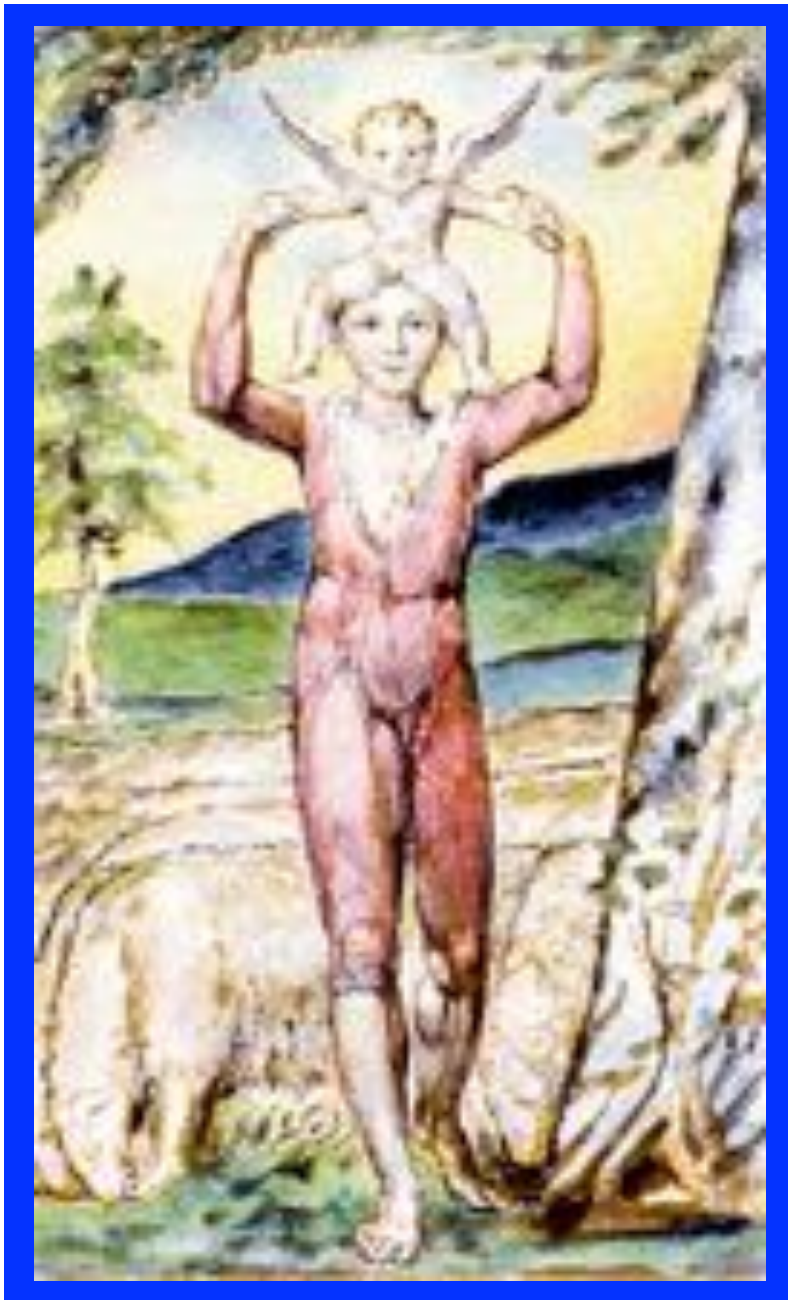


EEG, Event-Related Response Measures, Phase locking, Source clustering

Scott Makeig
Institute for Neural Computation
University of California San Diego

November 2012
UCSD Bioengineering,

Embodied Agency

Brain processes

have evolved and function

to optimize the ***outcome***

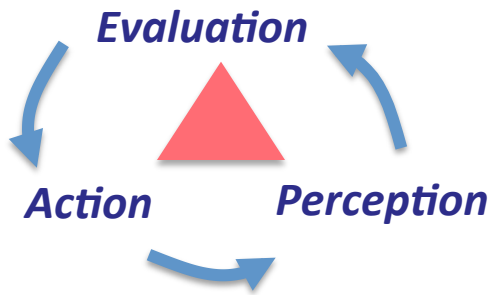
of the ***behavior***

the brain organizes

in response to

perceived challenges

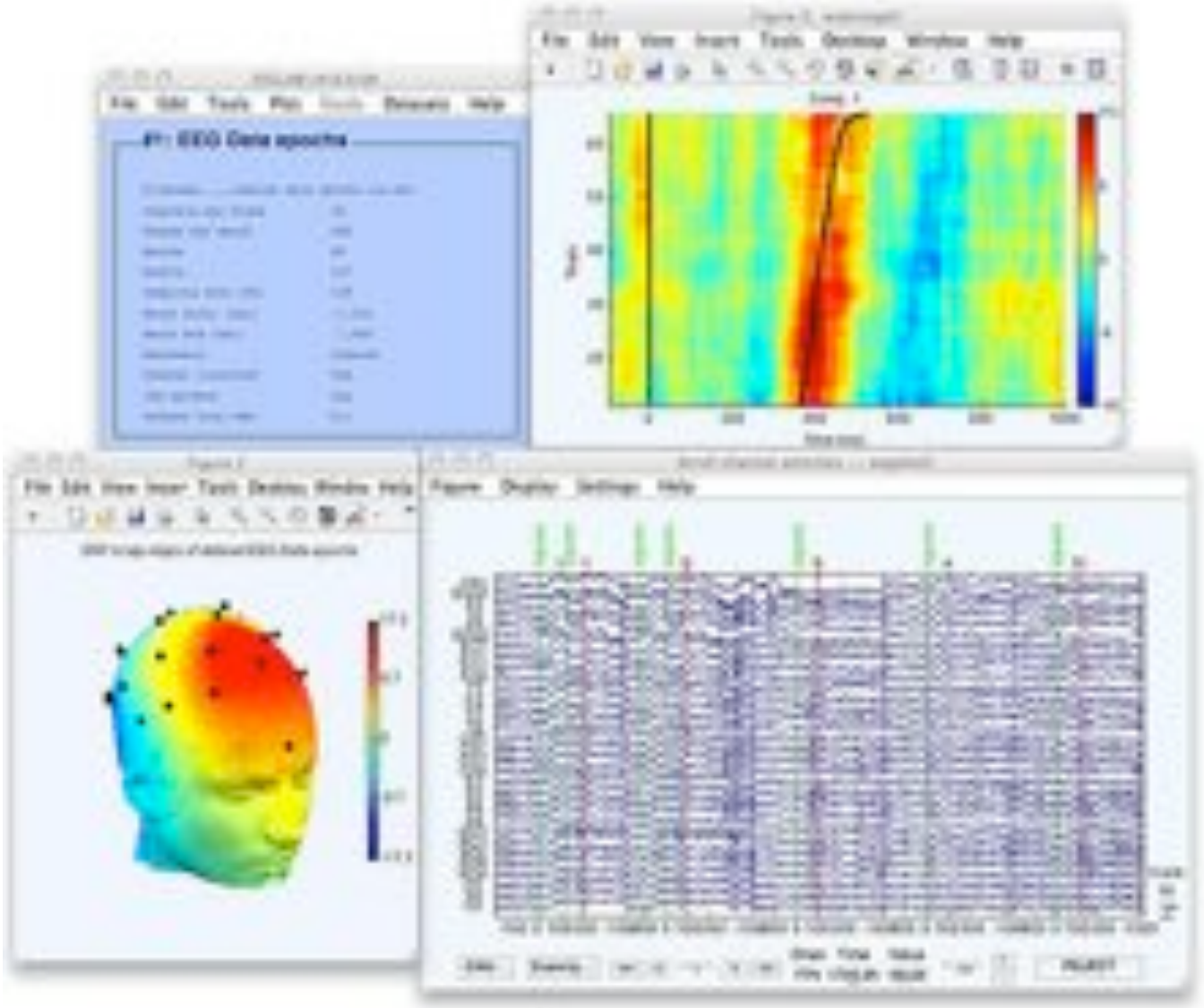
and opportunities.



Brains meet the challenge of the moment!

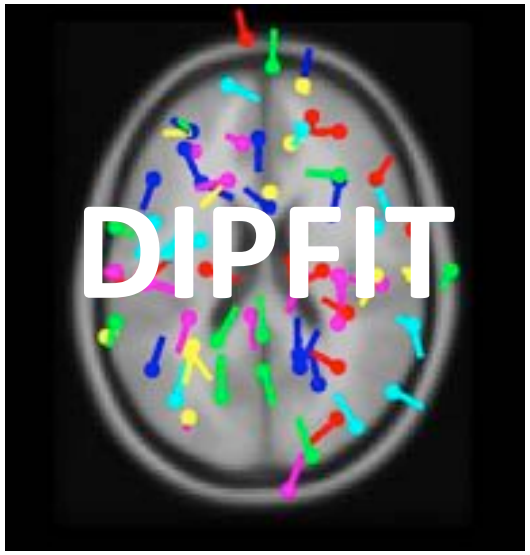
S Makeig 2010

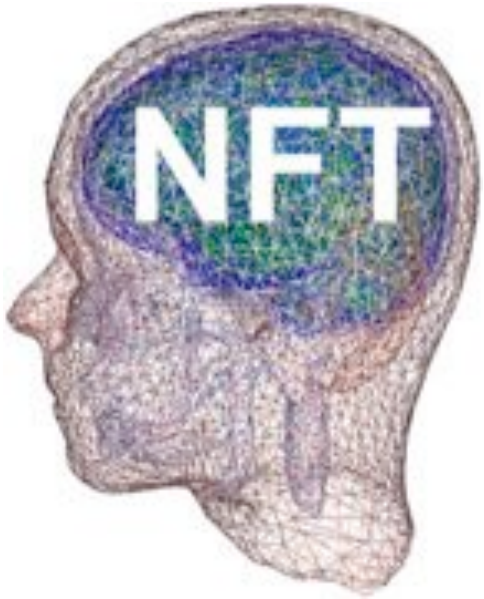
EEGLAB

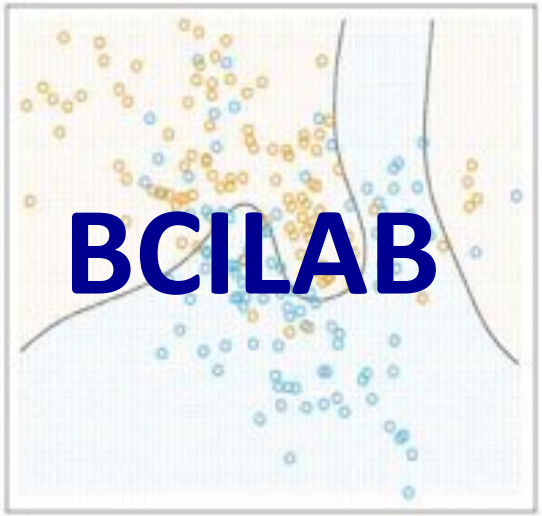


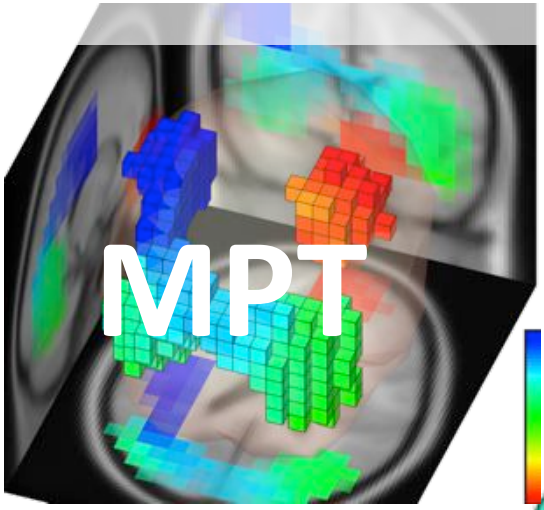
sccn.ucsd.edu/eeglab

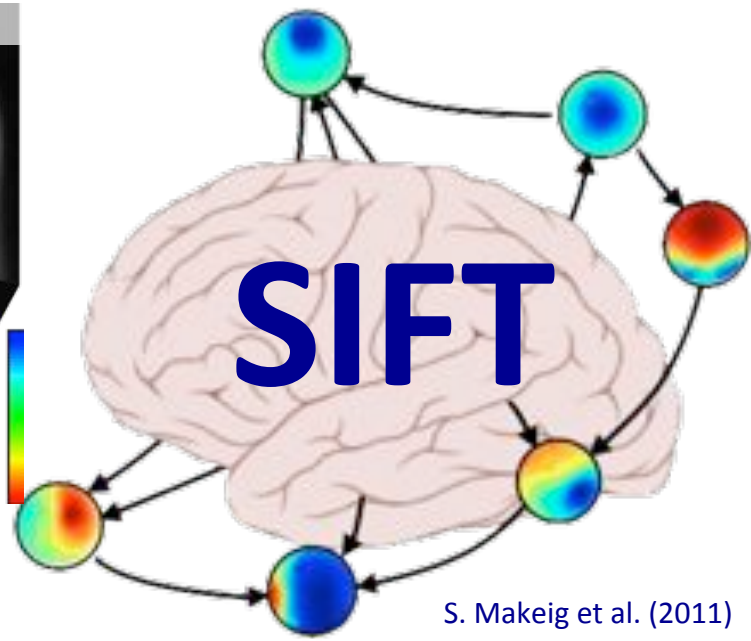
EEGLAB Plug-In Toolboxes





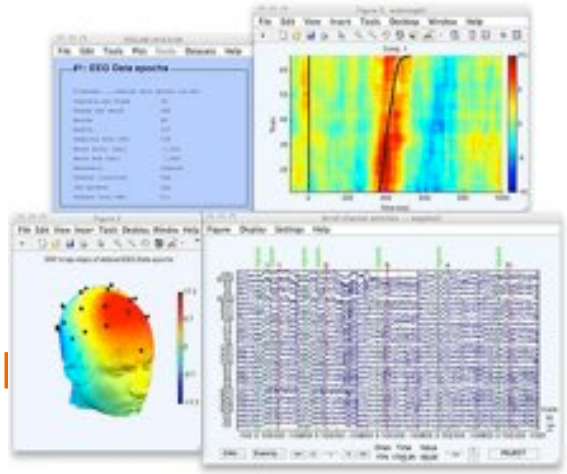






S. Makeig et al. (2011)

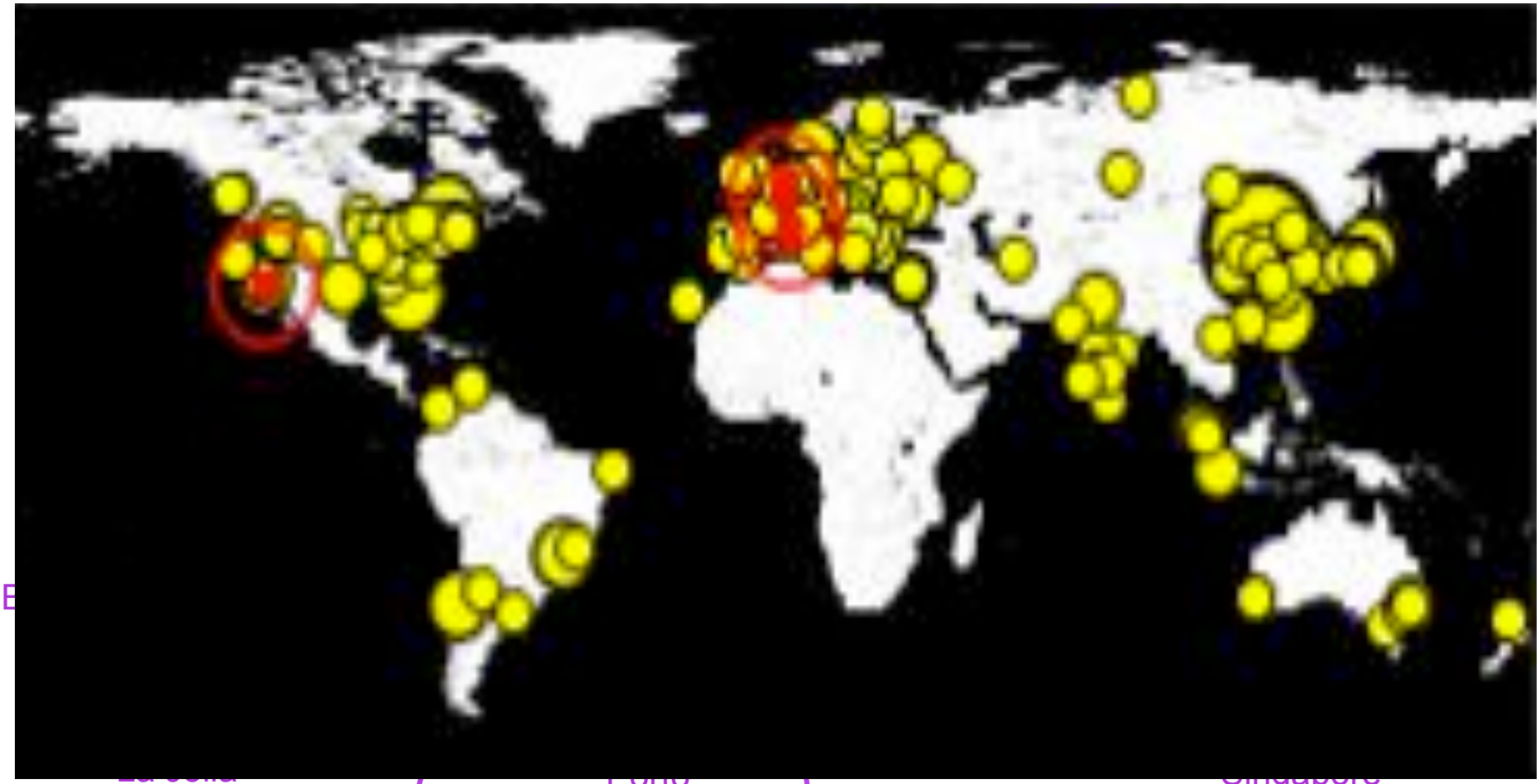
EEGLAB History



- 1993 – ERSP / ITC (Makeig)
- 1995 – Infomax ICA for EEG (Makeig, Bell, Jung, Sejnowsl
- **1997 - EEG/ICA Toolbox (cnl.salk.edu), ITC & ERC**
- 1999 - ERP-image plotting (Jung & Makeig)
- **2000 – EEGLAB GUI design (Delorme)**
- **2002 – 1st EEGLAB (sccn.ucsd.edu)**
- **2004 - 1st EEGLAB plug-ins**
- **2006 - 1st EEGLAB STUDY structure and component clustering tools**
- **2009 – NFT (Neuroelectromagnetic Forward Head Modeling Toolbox)**
- **2009 – New toolboxes: SIFT, BCILAB, MPT**
- **2012 - HeadIT resource, ERICA (Exp. Real-time Interactive Control & Analysis)**

S. Makeig 2010

EEGLAB Usage & Workshops



S. Makeig 2011

Arnaud Delorme

Swartz Center for Computational Neuroscience

Christian Kothe

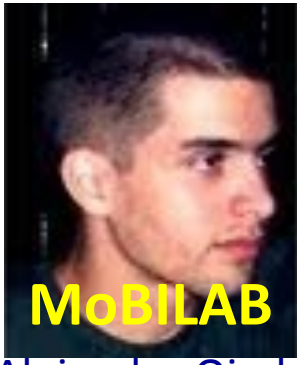
David Groppe

Julie Onton

Jason Palmer

Tim Mullen

Tzyy-Ping Jung



Alejandro Ojeda

Tony Bell

Zeynep Akalin Acar

Nima Bigdely Shamlo

S. Makeig (2011)

To average
or
Not to average?

The adequacy of **blind EEG response averaging**

IF ….

- If ‘equivalent’ stimuli (passively) evoke the same macro field responses (with fixed latencies and polarities or phase) in **all** trials… and
- If **all** the REST of the EEG can be considered to be Gaussian noise sources that are **not** affected by the stimuli..

THEN …

- The stimulus-locked average contains **all** the meaningful event-related EEG/MEG brain dynamics.

The inadequacy of blind response averaging

$EEG_{data} = ERP_{mean} + EEG_{NOISEh}$

(Highly) questionable assumptions:

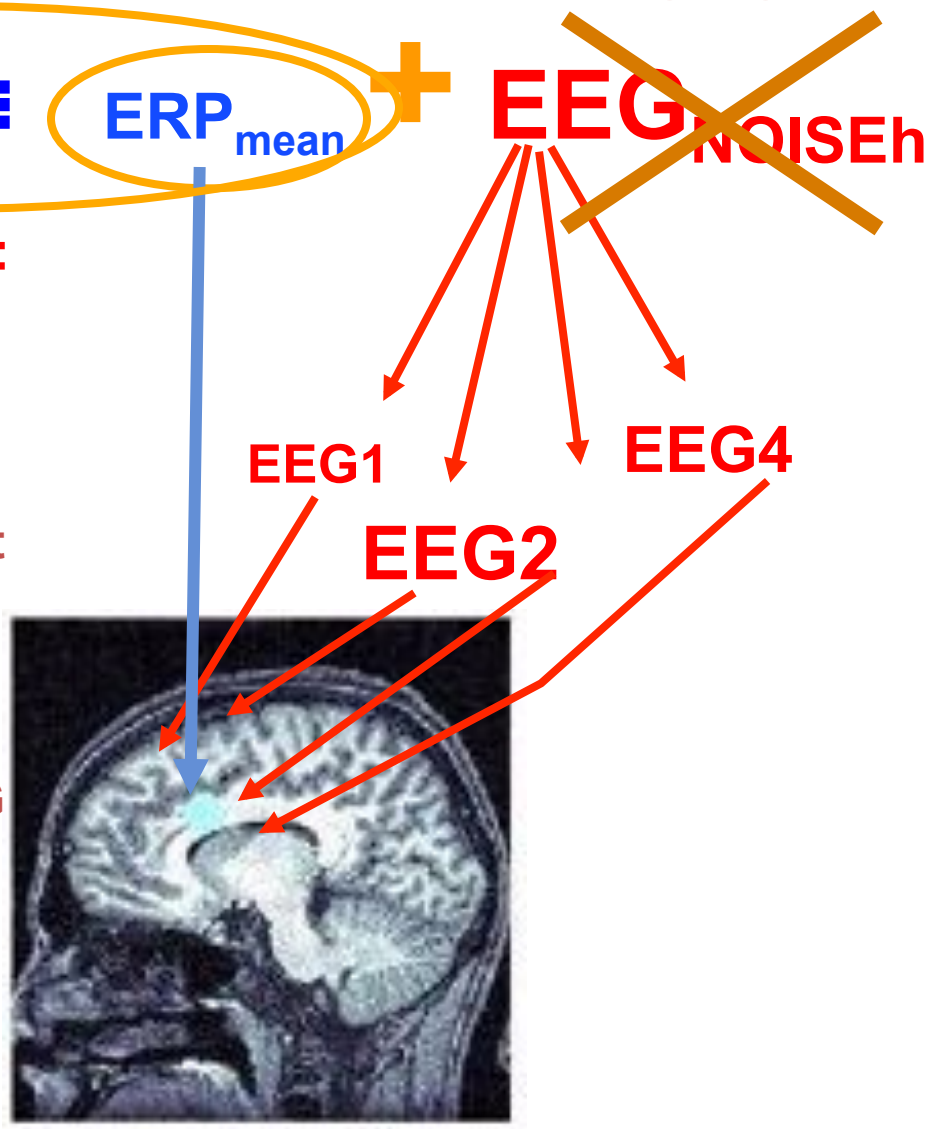
? The living brain produces *passive* responses ??????????????????????

? Ongoing EEG processes are *not perturbed* by events – without transient phase locking → no ERP contributions from ongoing EEG processes.

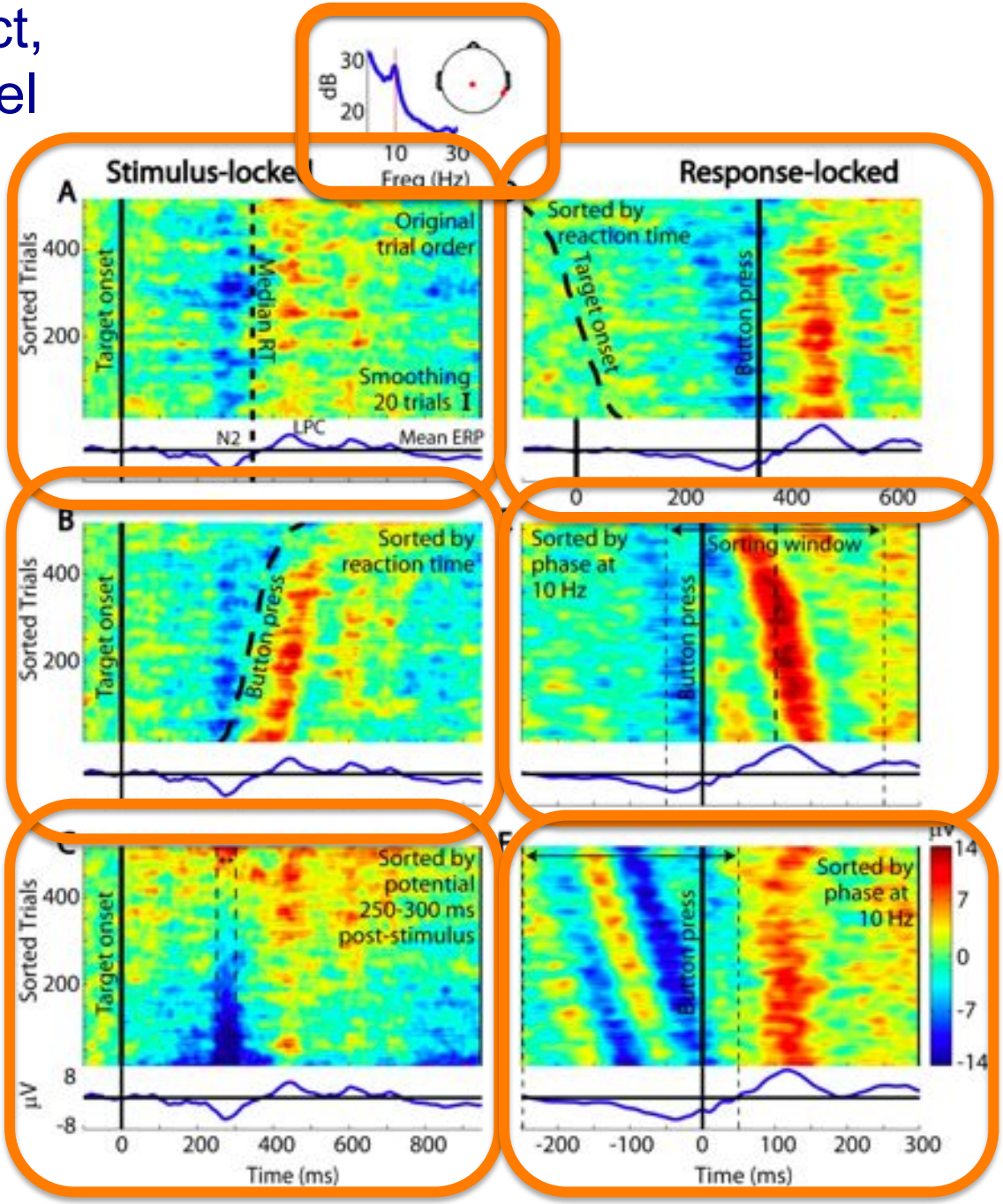
? Evoked response processes are *spatially segregated* from ongoing EEG processes.

? The 'true' response baseline is *flat*.

? 'Equivalent' stimulus events evoke *equivalent* brain responses → event-related brain dynamics are *stationary* from trial to trial.

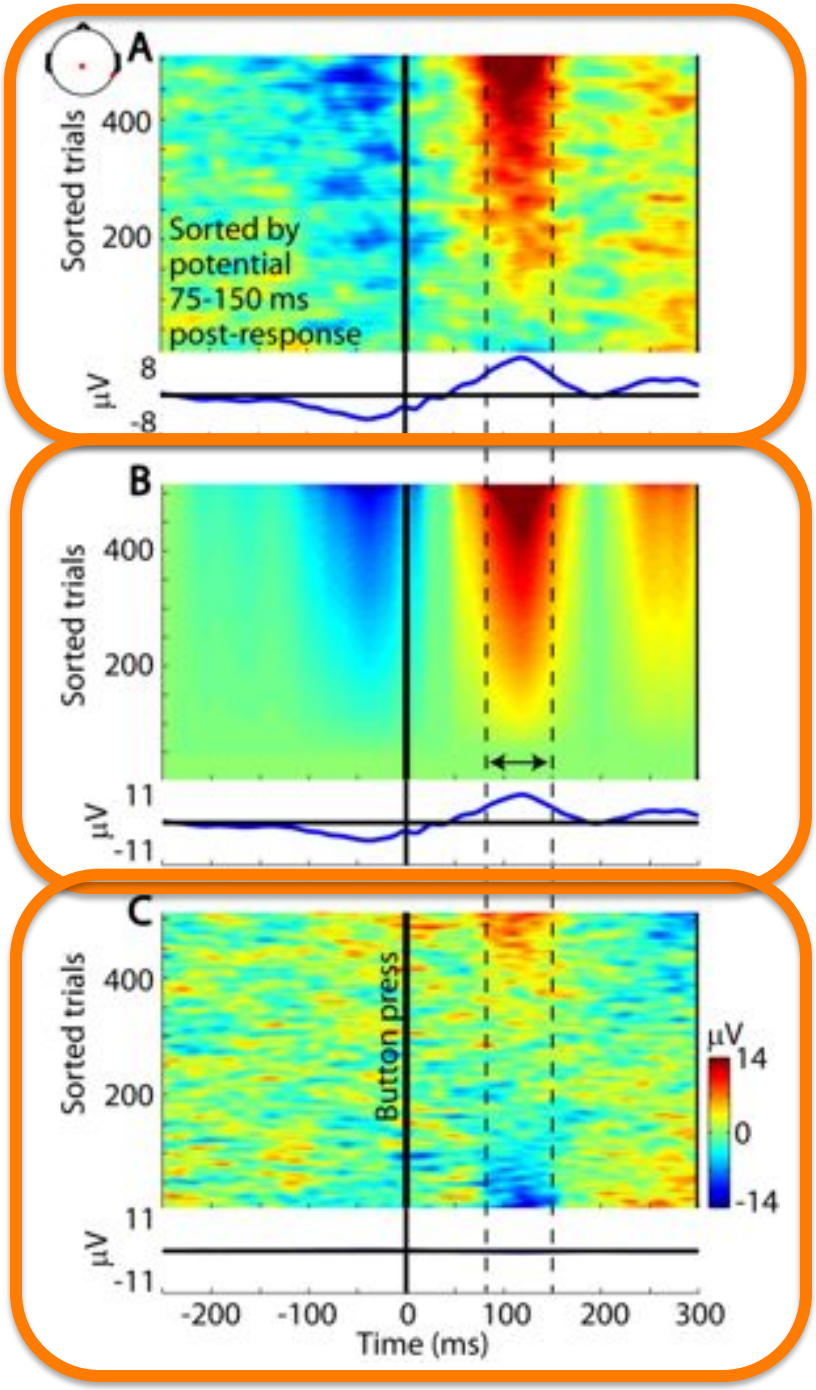


Single-subject, single-channel case study:



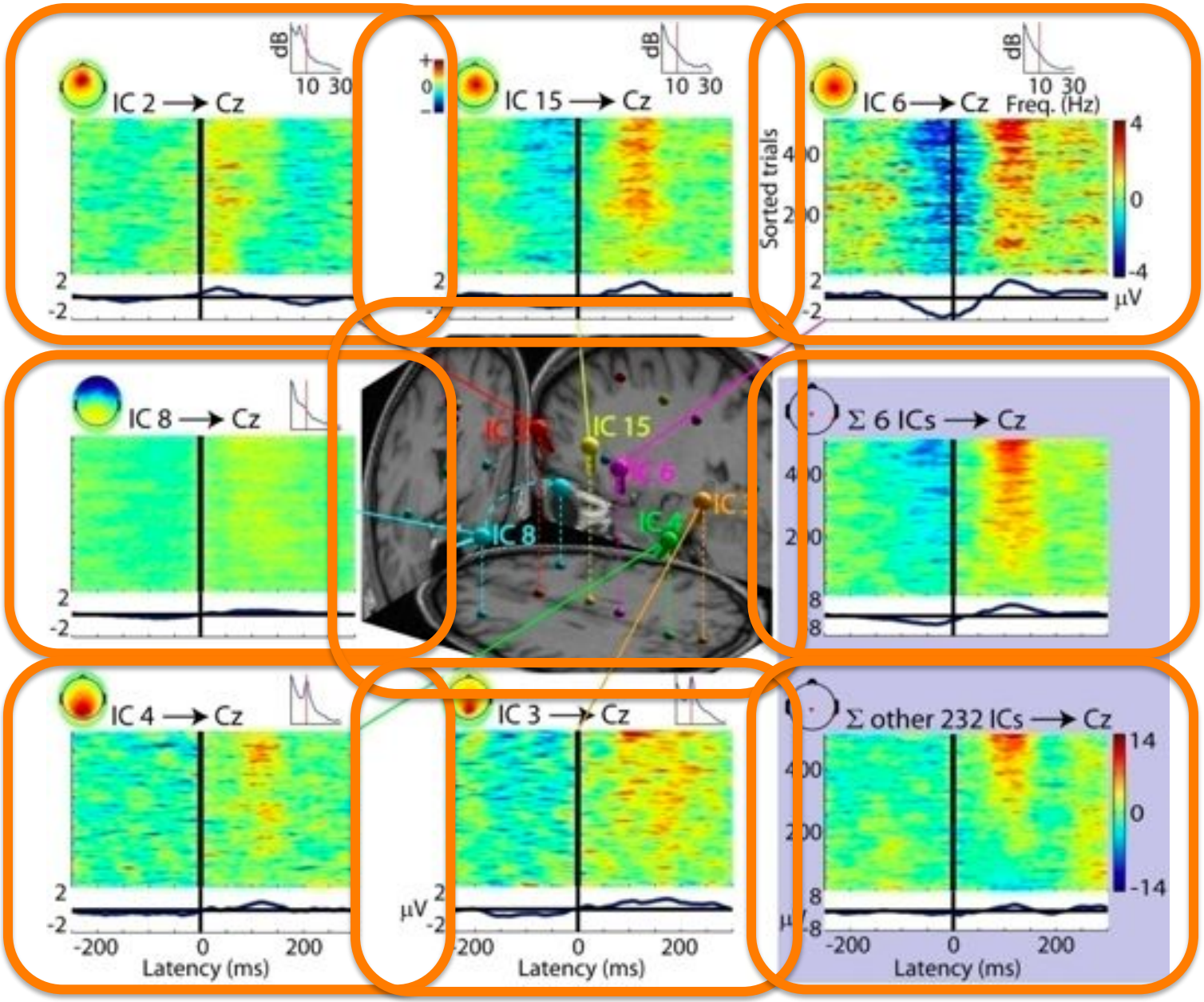
S. Makeig & J. Onton (2009)

Single-subject, single-channel case study:



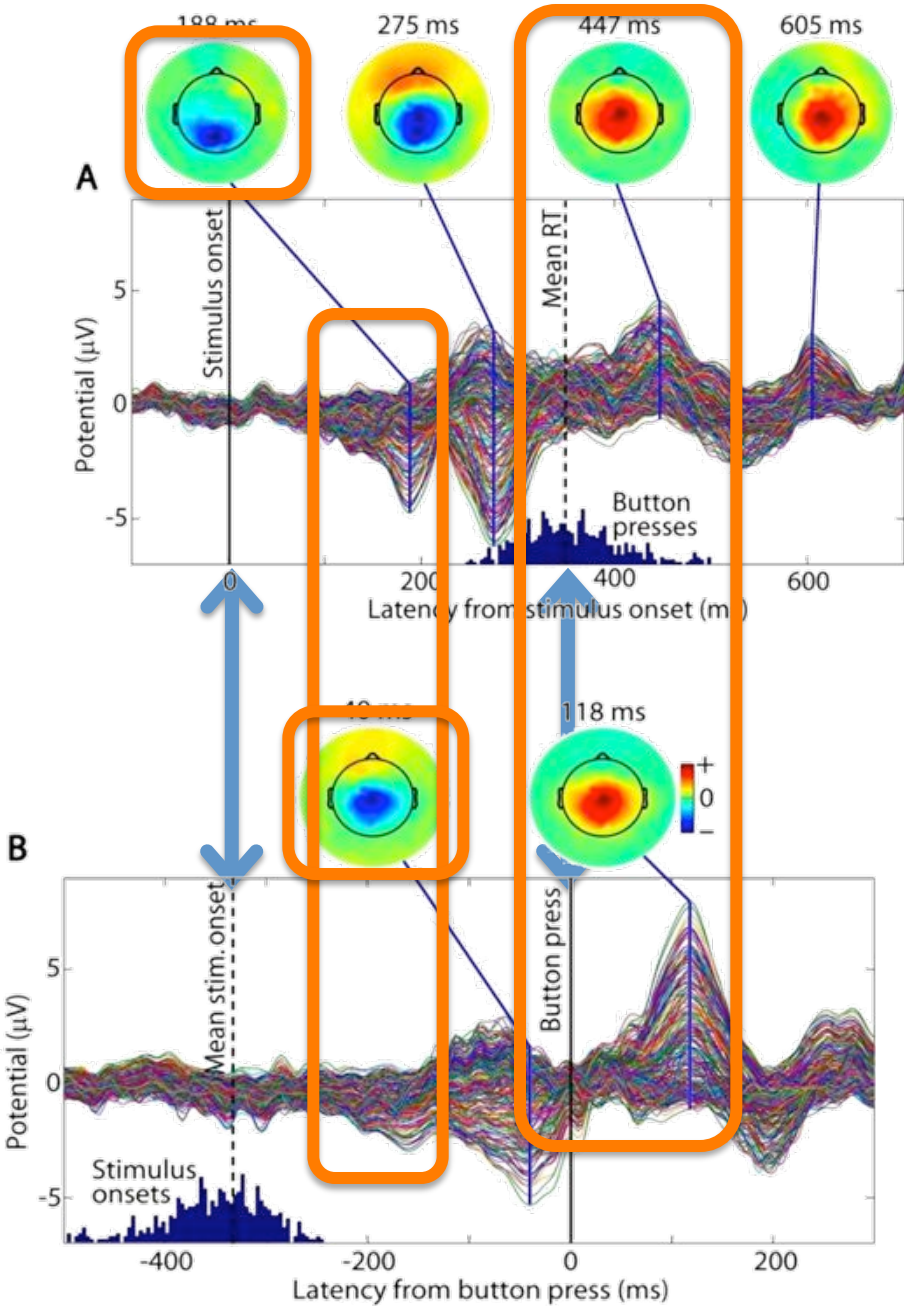
S. Makeig & J. Onton (2009)

Now, using ICA…



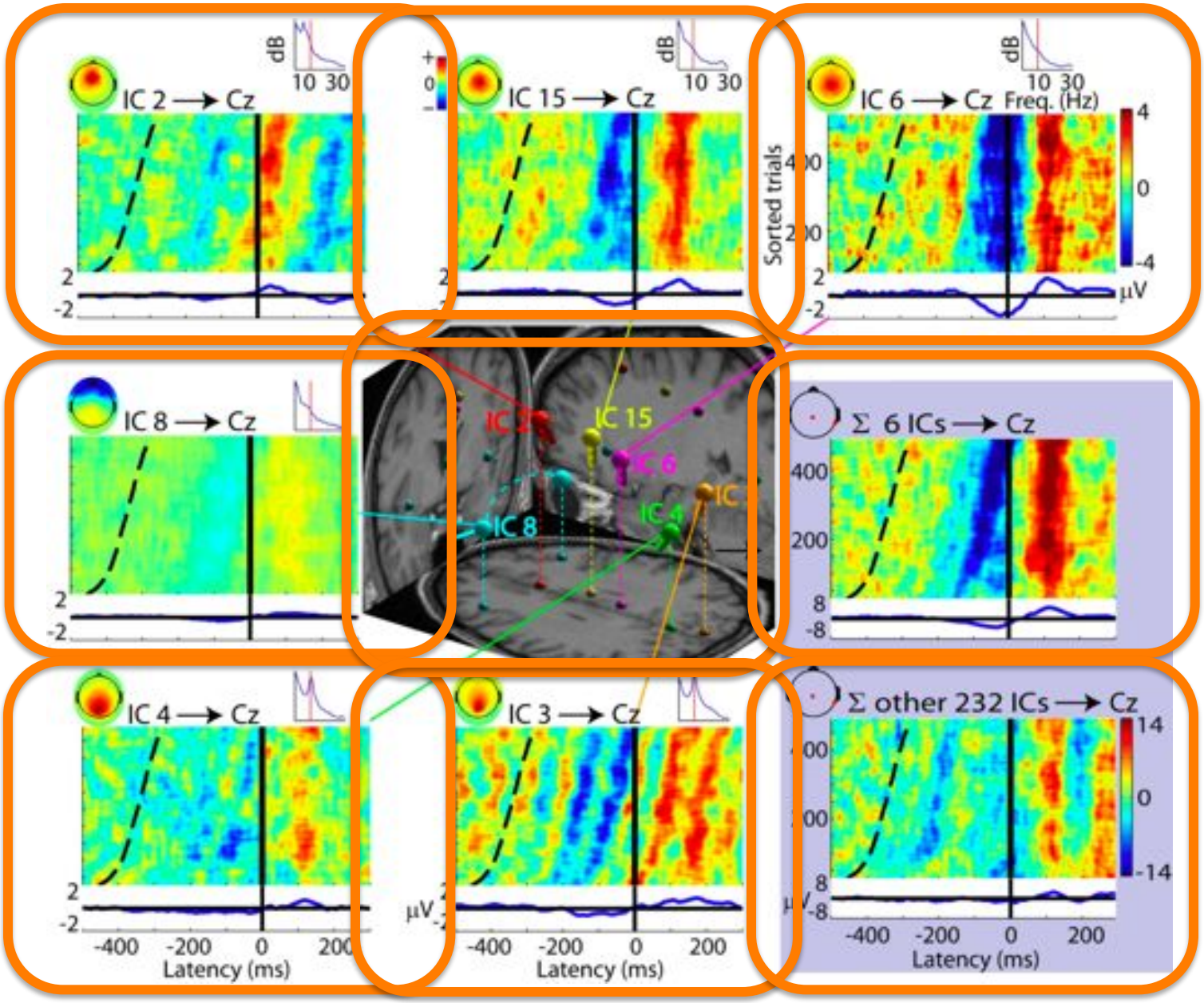
S. Makeig & J. Onton (2009)

S-T overlapping event-locked activities:



S. Makeig & J. Onton (2009)

Now, using ICA and response-locked epochs …

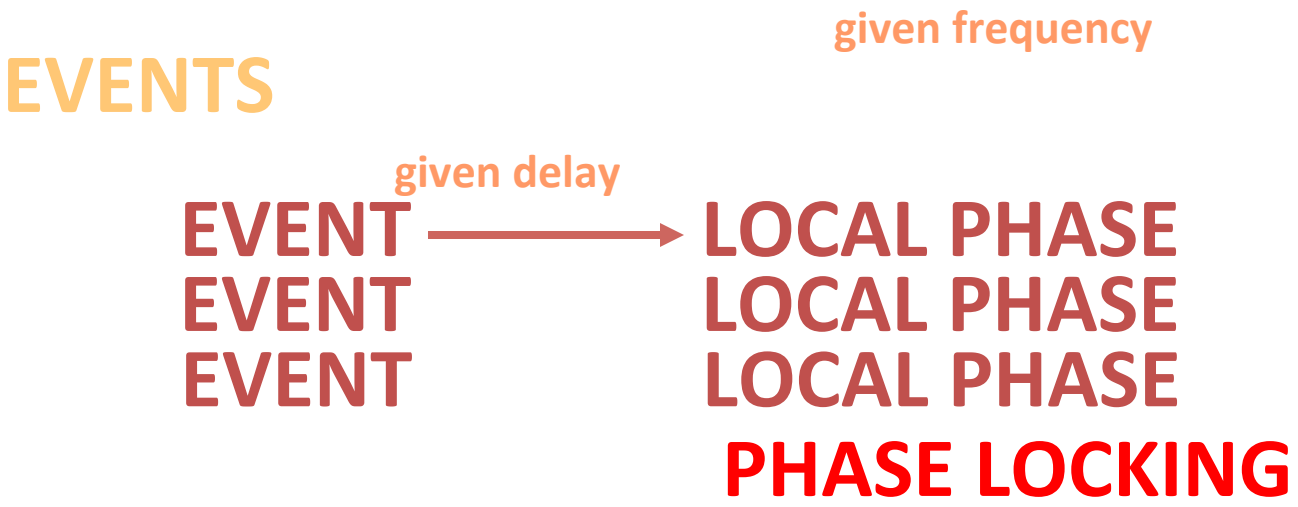


S. Makeig & J. Onton (2009)

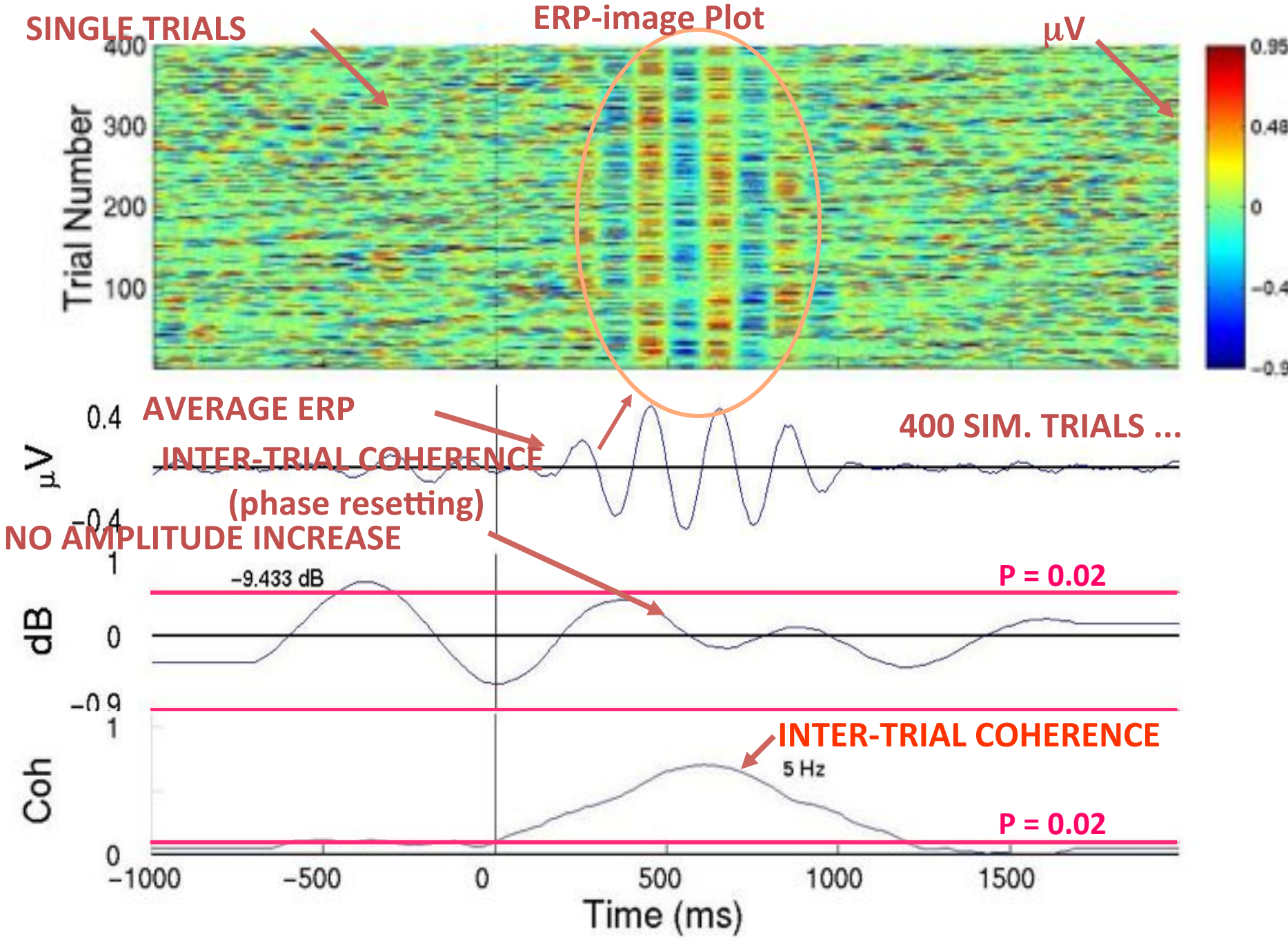
What produces event-related potential averages (ERPs)?

Inter-trial Coherence (ITC) ("phase-locking factor")

- Significant **consistency of local phase** (relative to time-locking events) of a physiological waveform **across successive trials …**

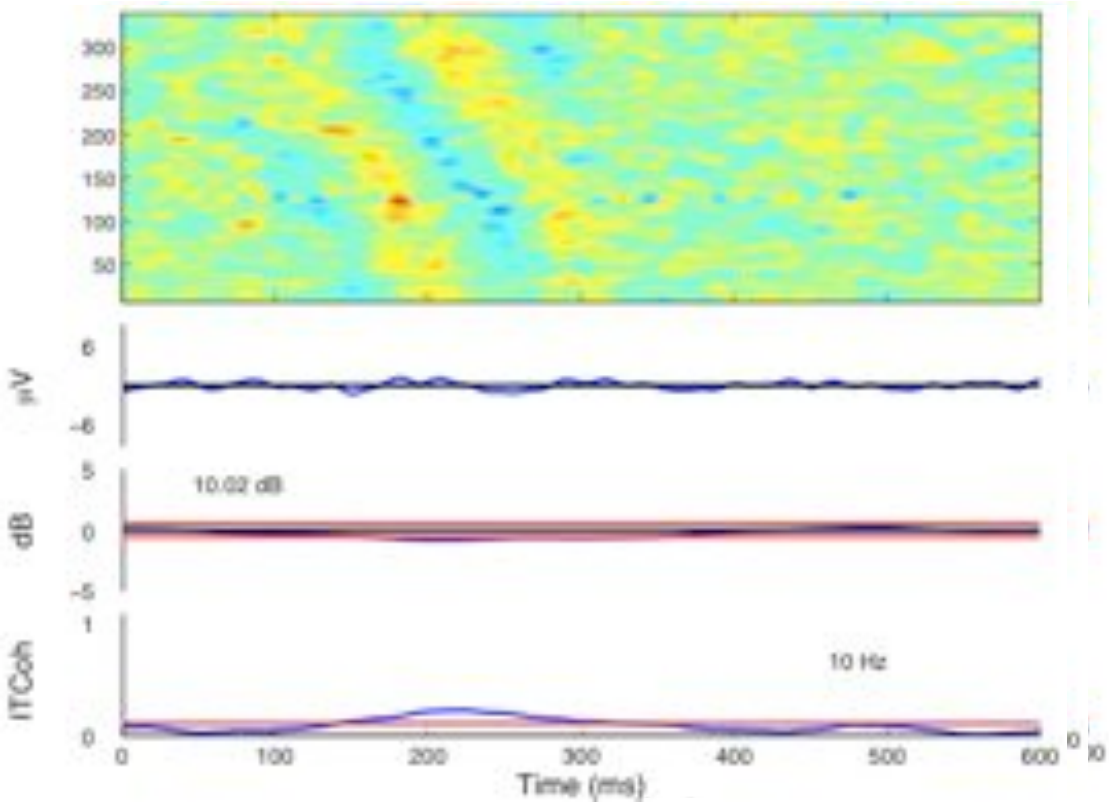


S. Makeig (2007)



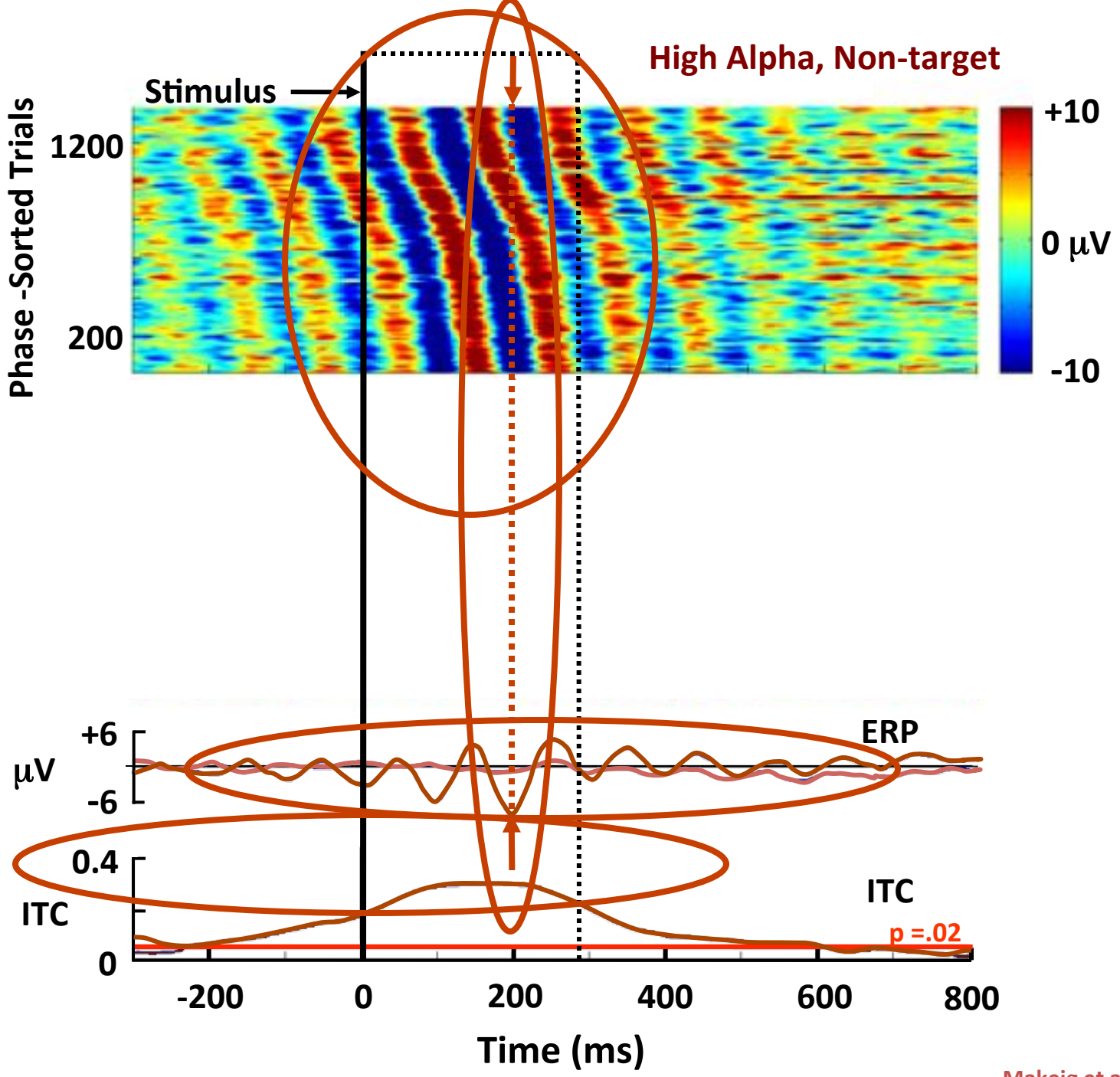
S. Makeig (2007)

Phase-locking creates the ERP



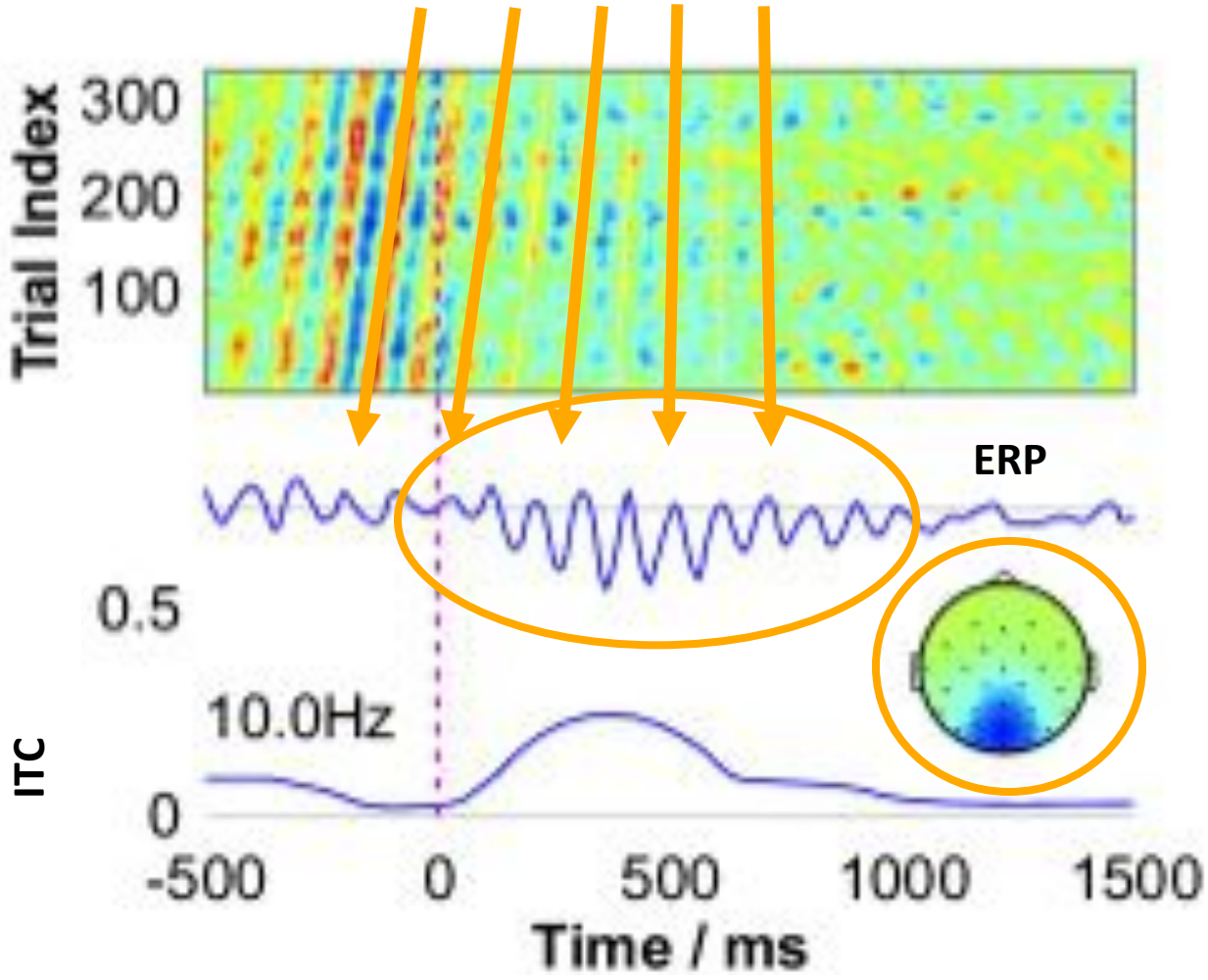
erpimage()

S. Makeig (2007)



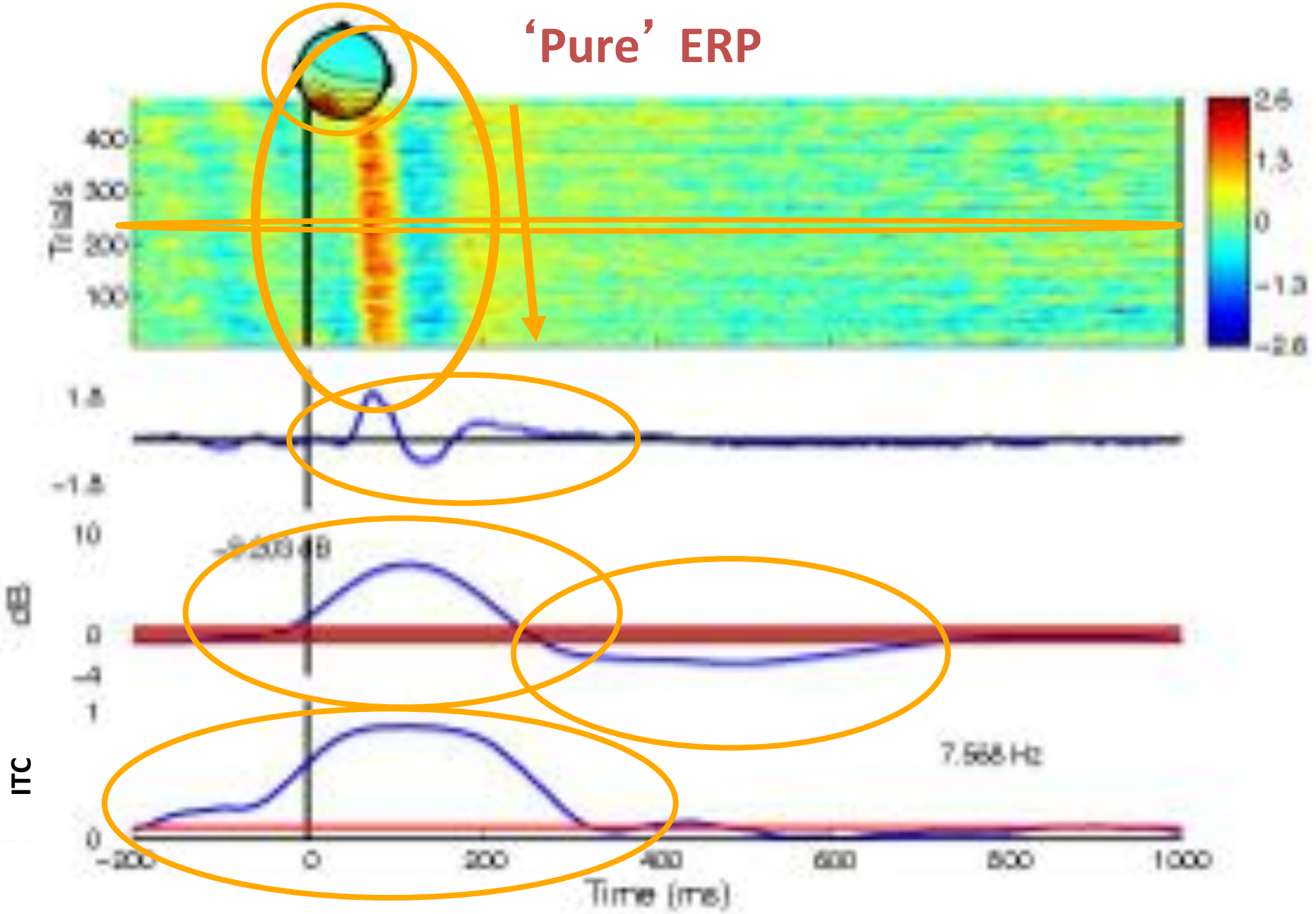
Makeig et al., *Science* 2002

“True” PPR (visual ‘alpha ringing’)



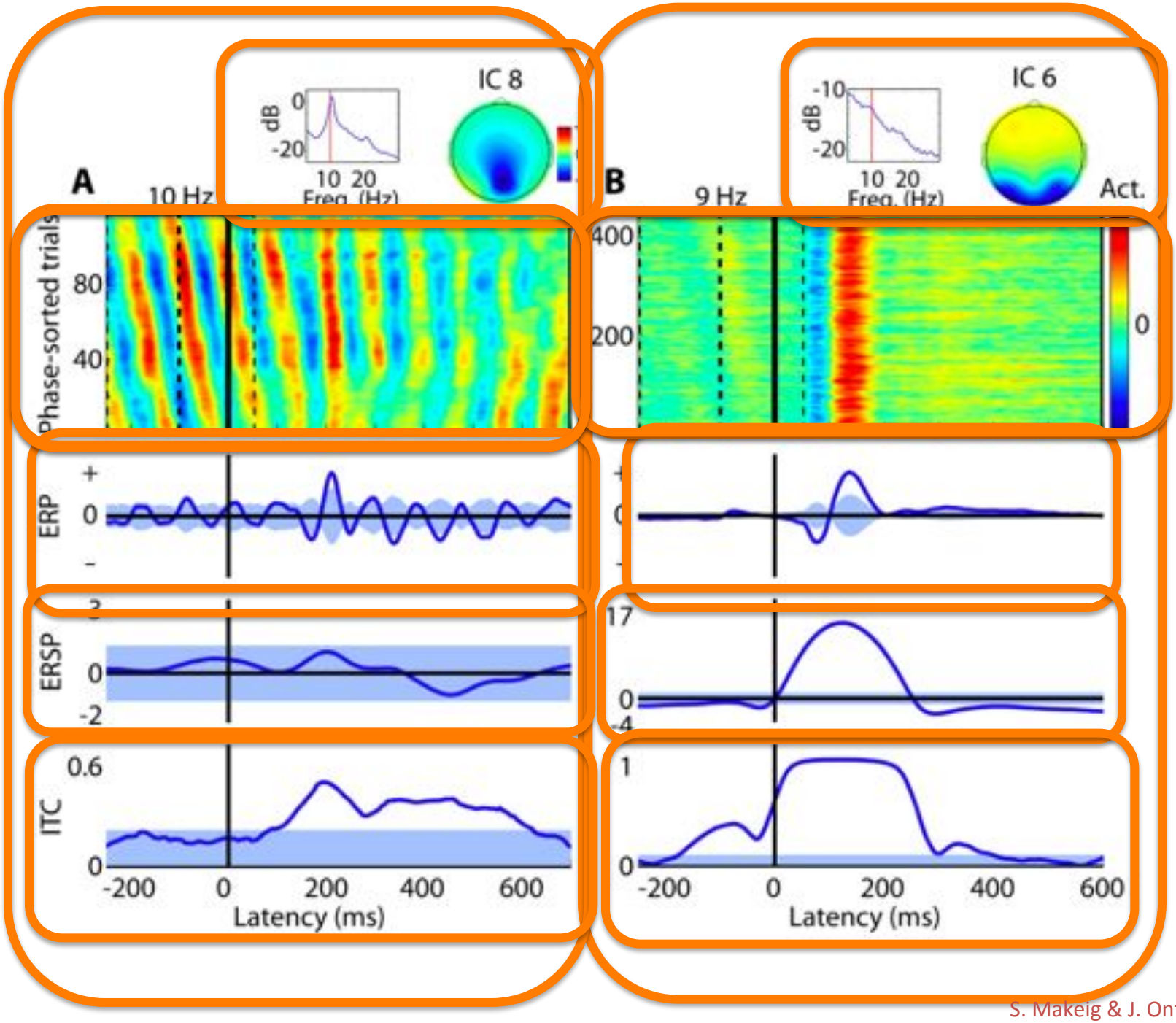
S. Enghoff, 2000

‘Pure’ ERP

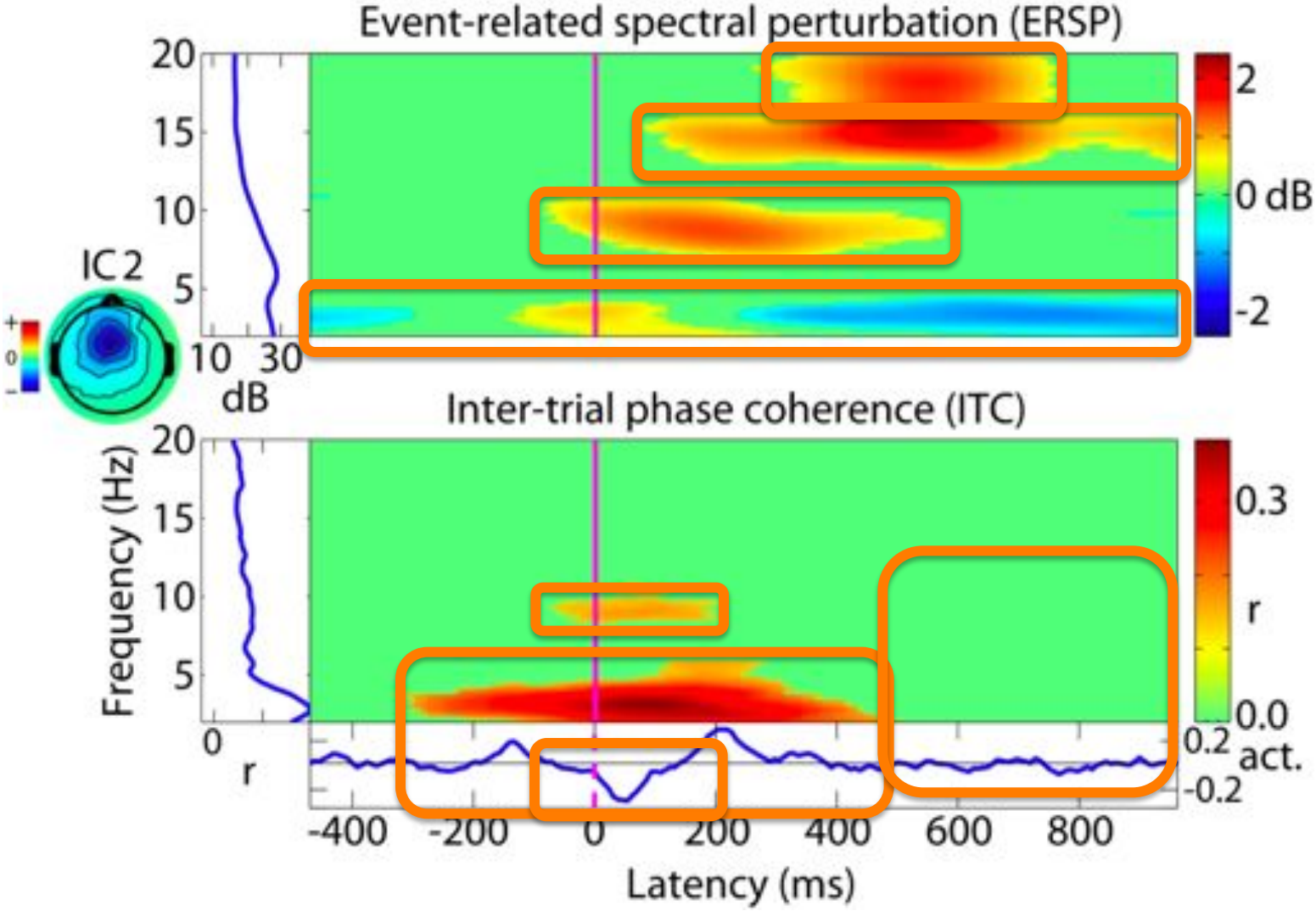


erpimage()

S. Makeig et al., TICS (2004))



S. Makeig & J. Onton (2009)

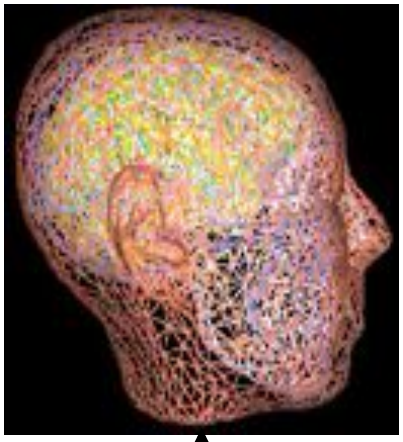


S. Makeig & J. Onton (2009)

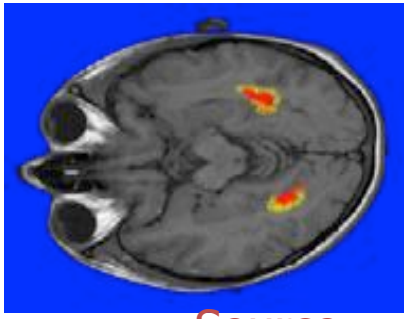
Electromagnetic source localization using realistic head models

BUT how to find a 'simple' map representing the projection of a single cortical source?

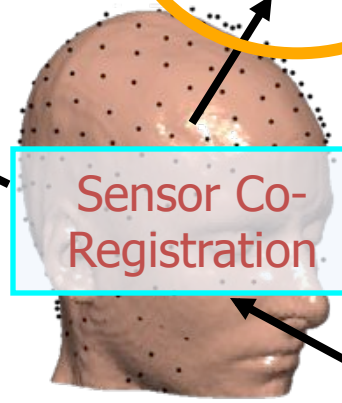
Solve the forward problem using realistic head models (BEM)



Simple Map



Source Image

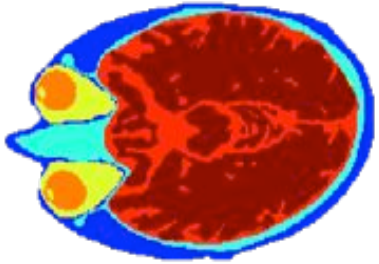


Sensor Co-Registration

Signal Processing

Mesh generation

MRI

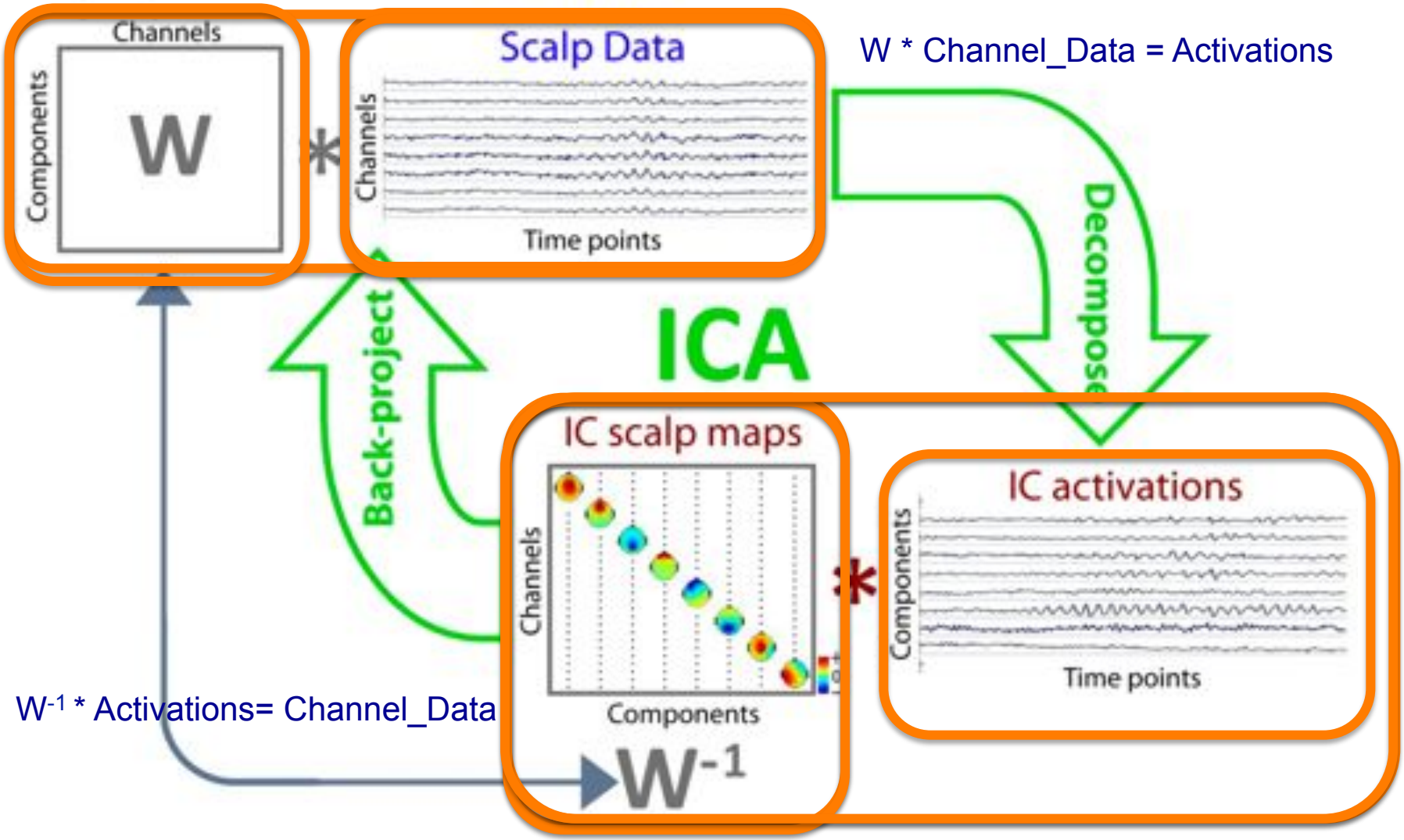


Segmentation

EEG/MEG

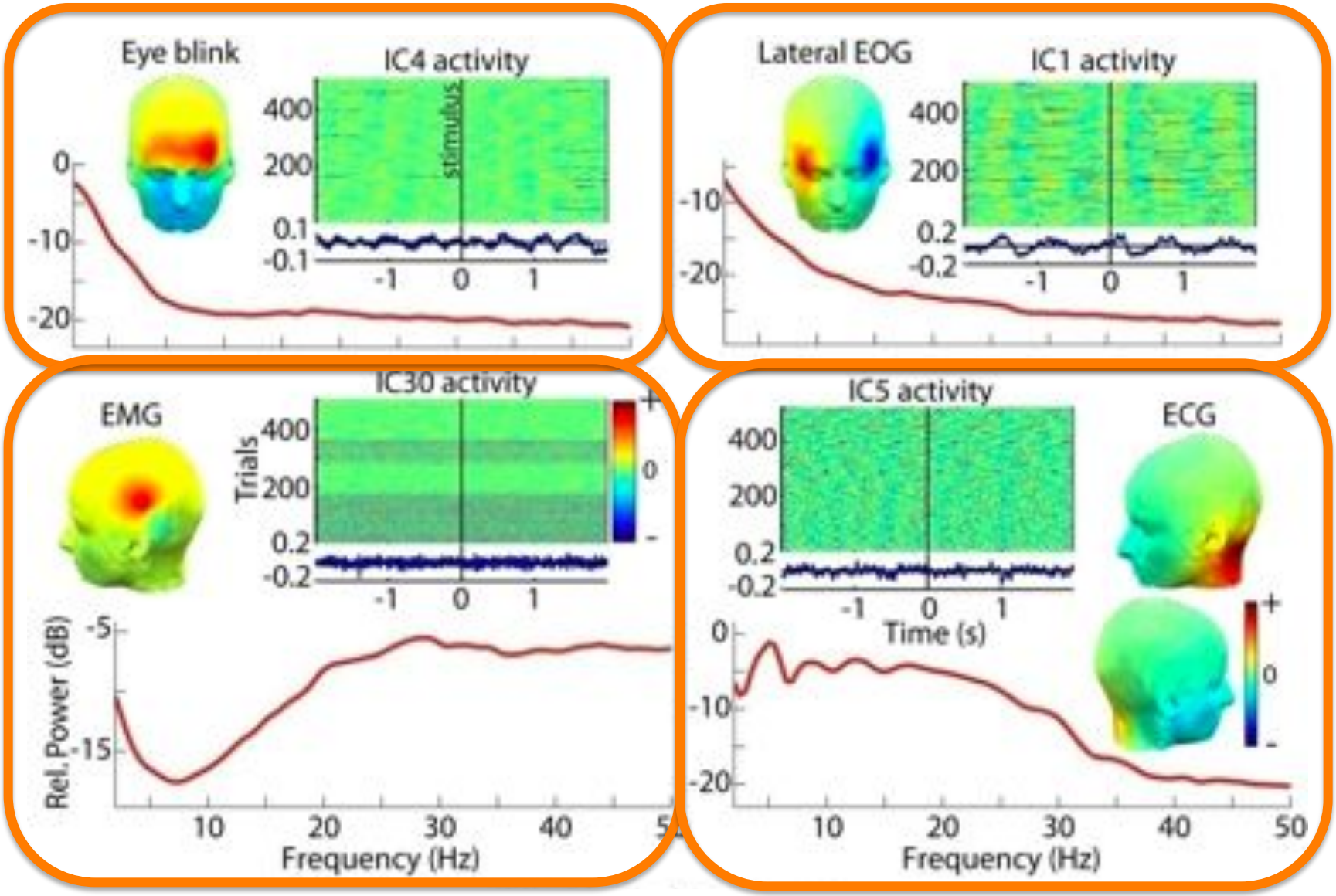
Zeynep Akalin Acar, & Scott Makeig '11

ICA is a linear data decomposition method



Makeig & Onton, 2011

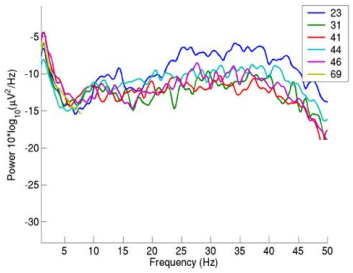
ICA finds Non-Brain Independent Component (IC) Processes …

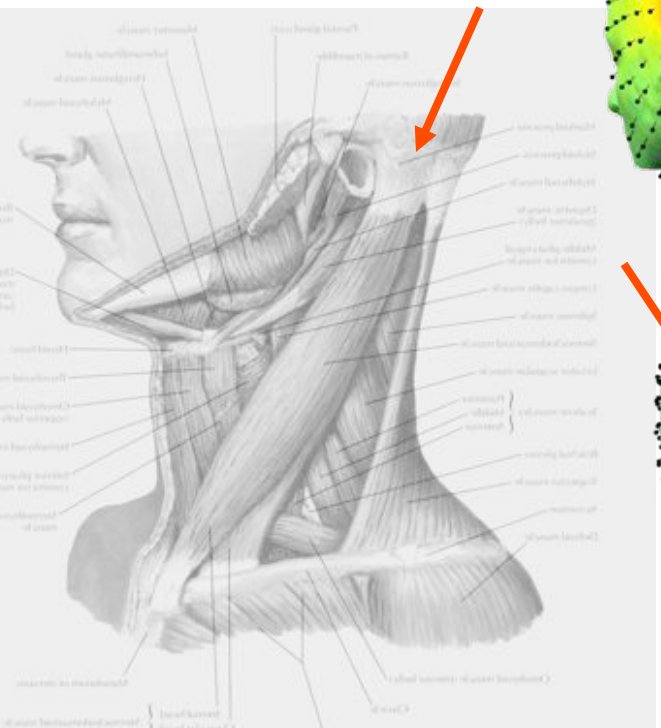


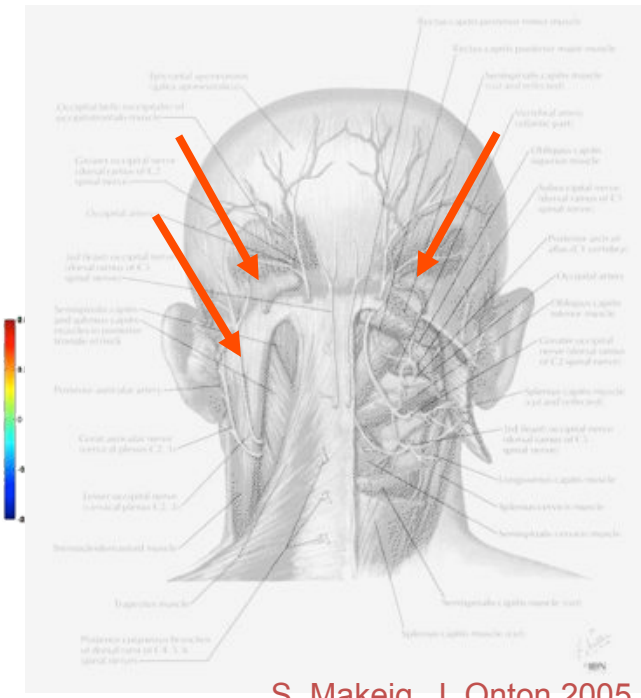
… separates them from the remainder of the data …

J. Onton & S. Makeig 2006

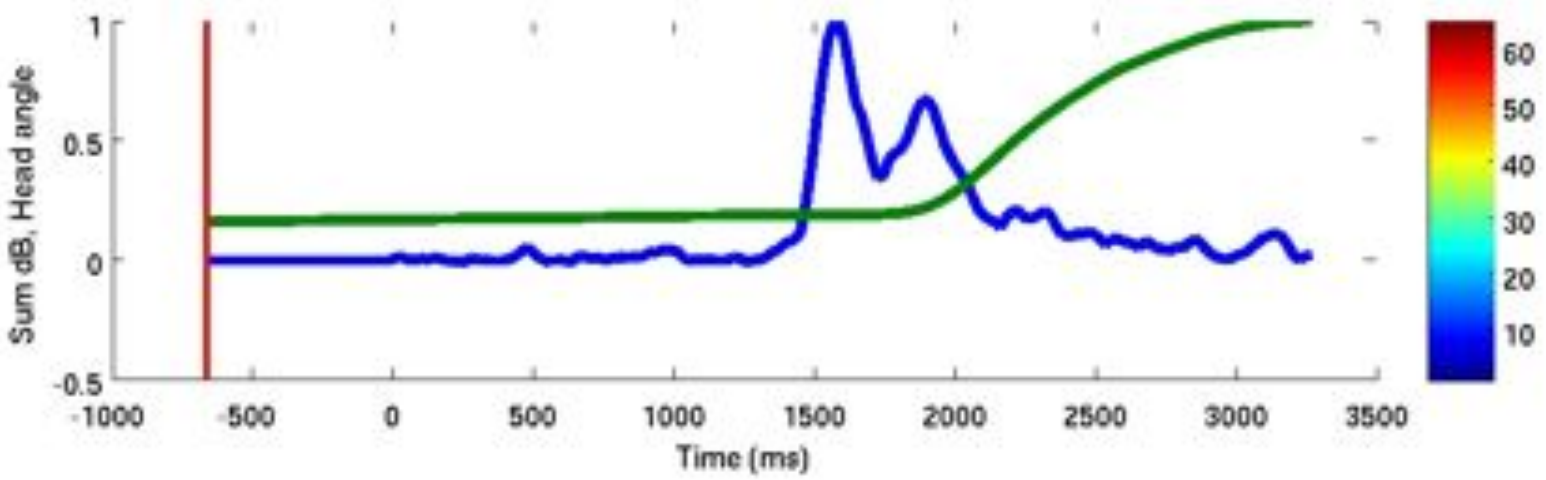
Independent muscle signals



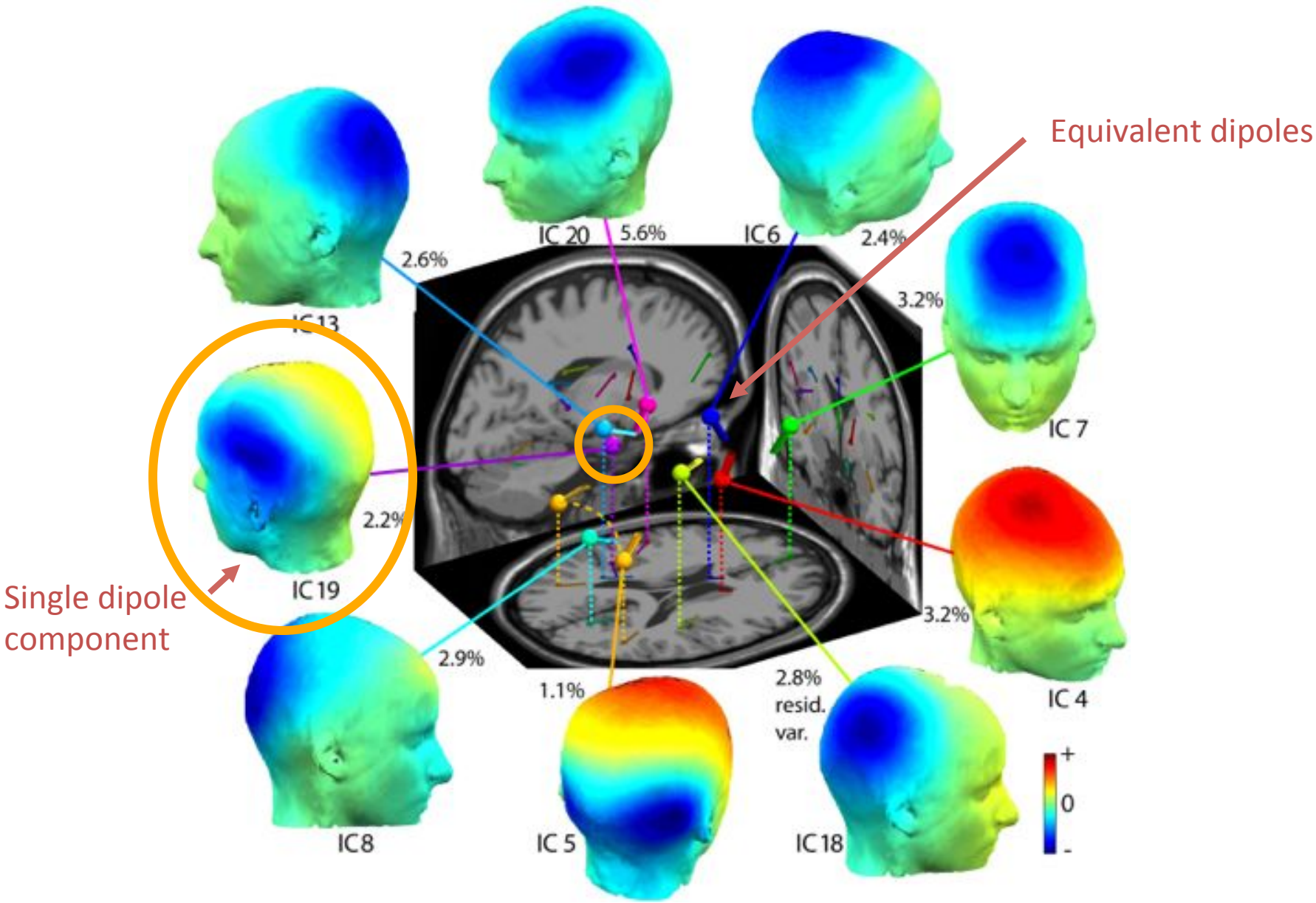




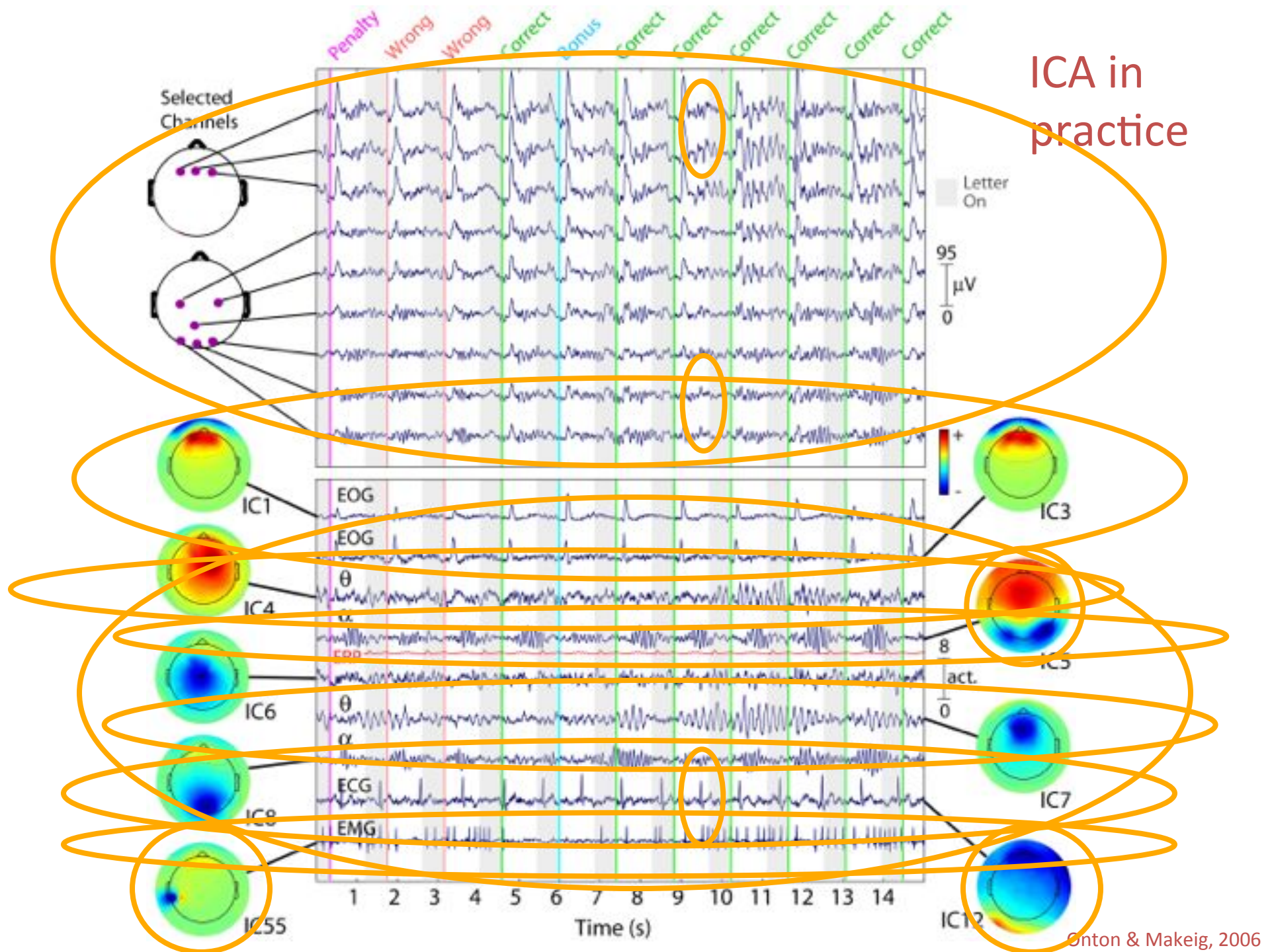
S. Makeig, J. Onton 2005


Sum dB, Head angle
1
0.5
0
-0.5
-1000
-500
0
500
1000
1500
2000
2500
3000
3500
Time (ms)
60
50
40
30
20
10

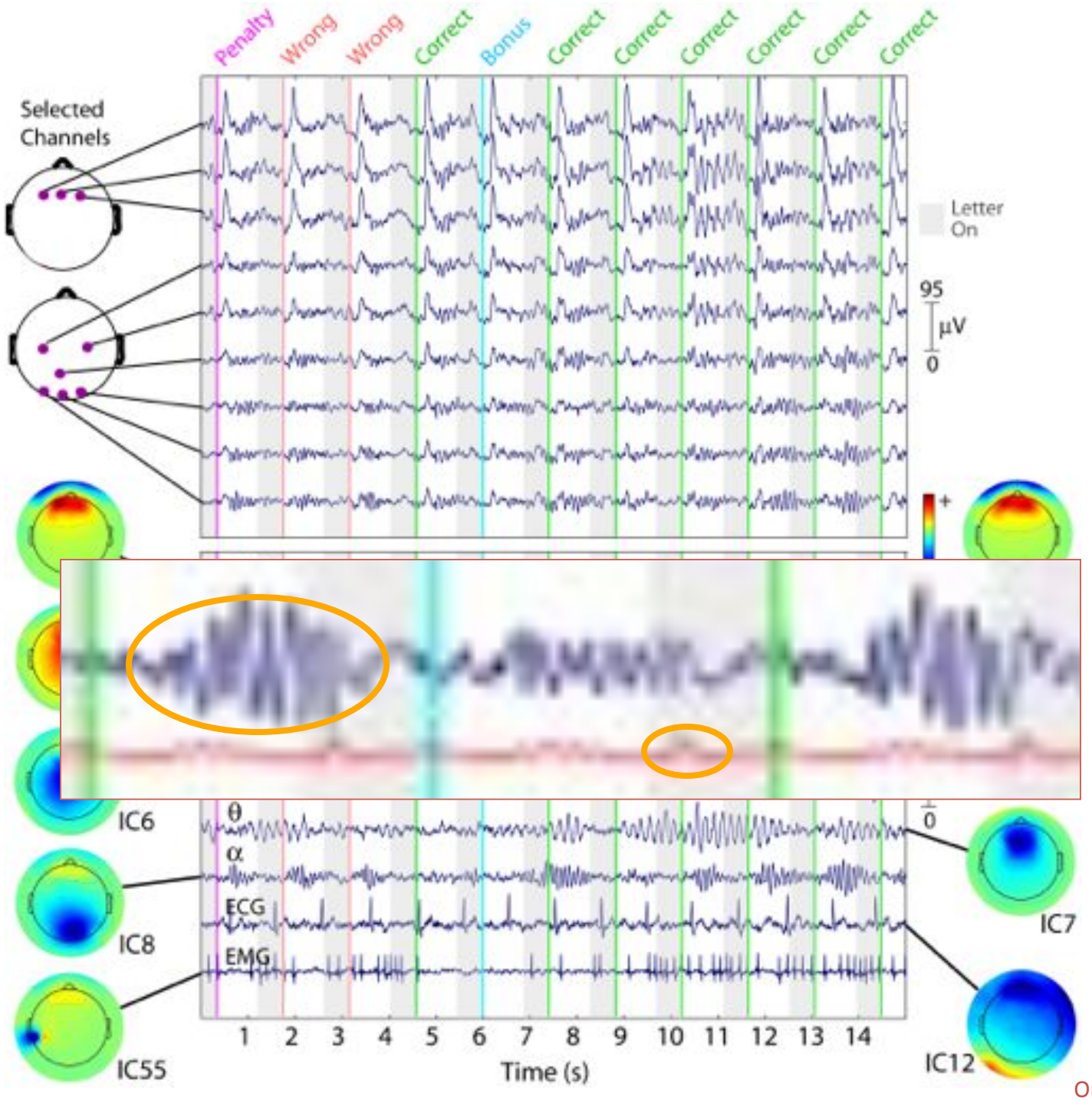
ICA also separates cortical brain IC processes



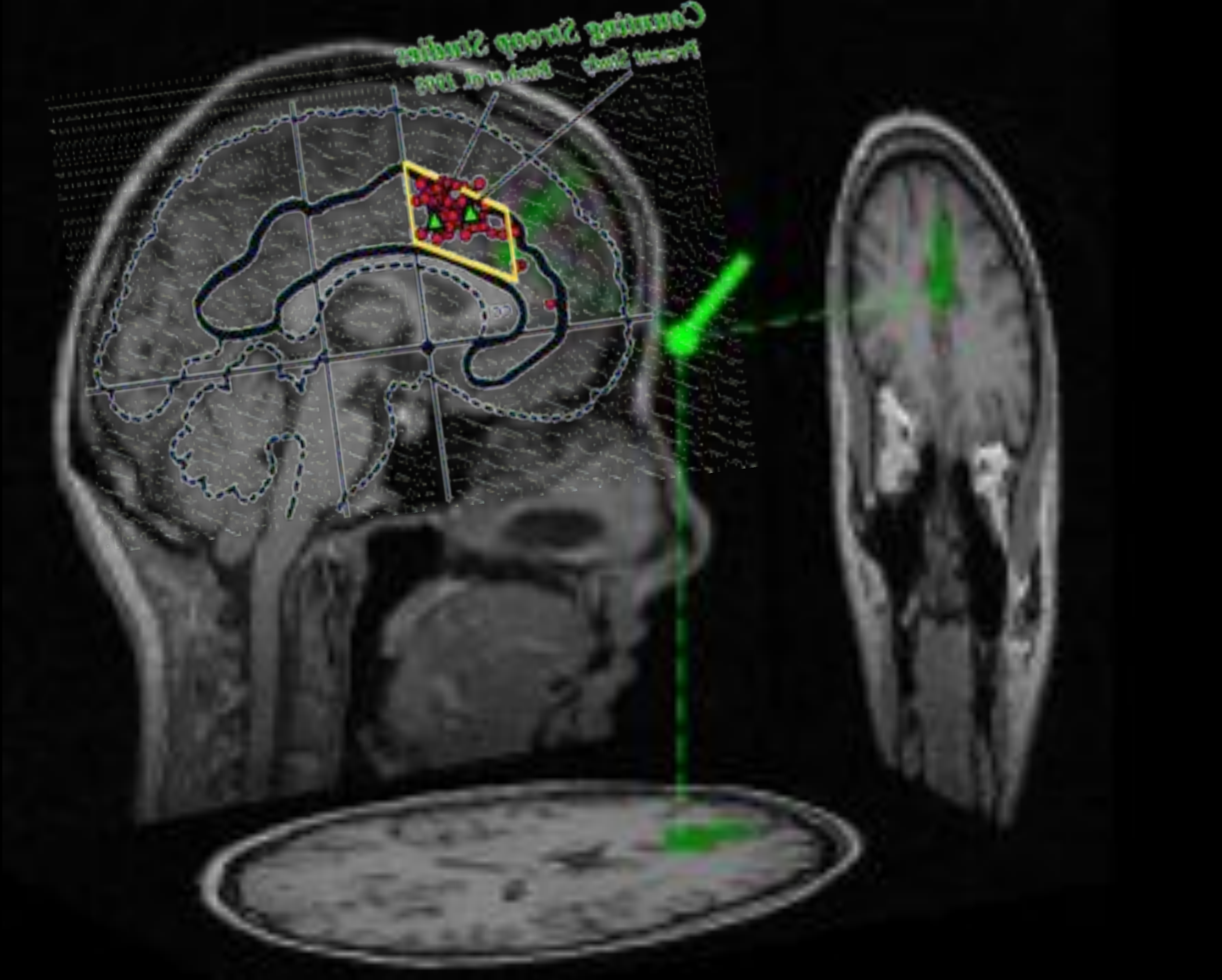
Julie Onton & S. Makeig (2006)



Onton & Makeig, 2006



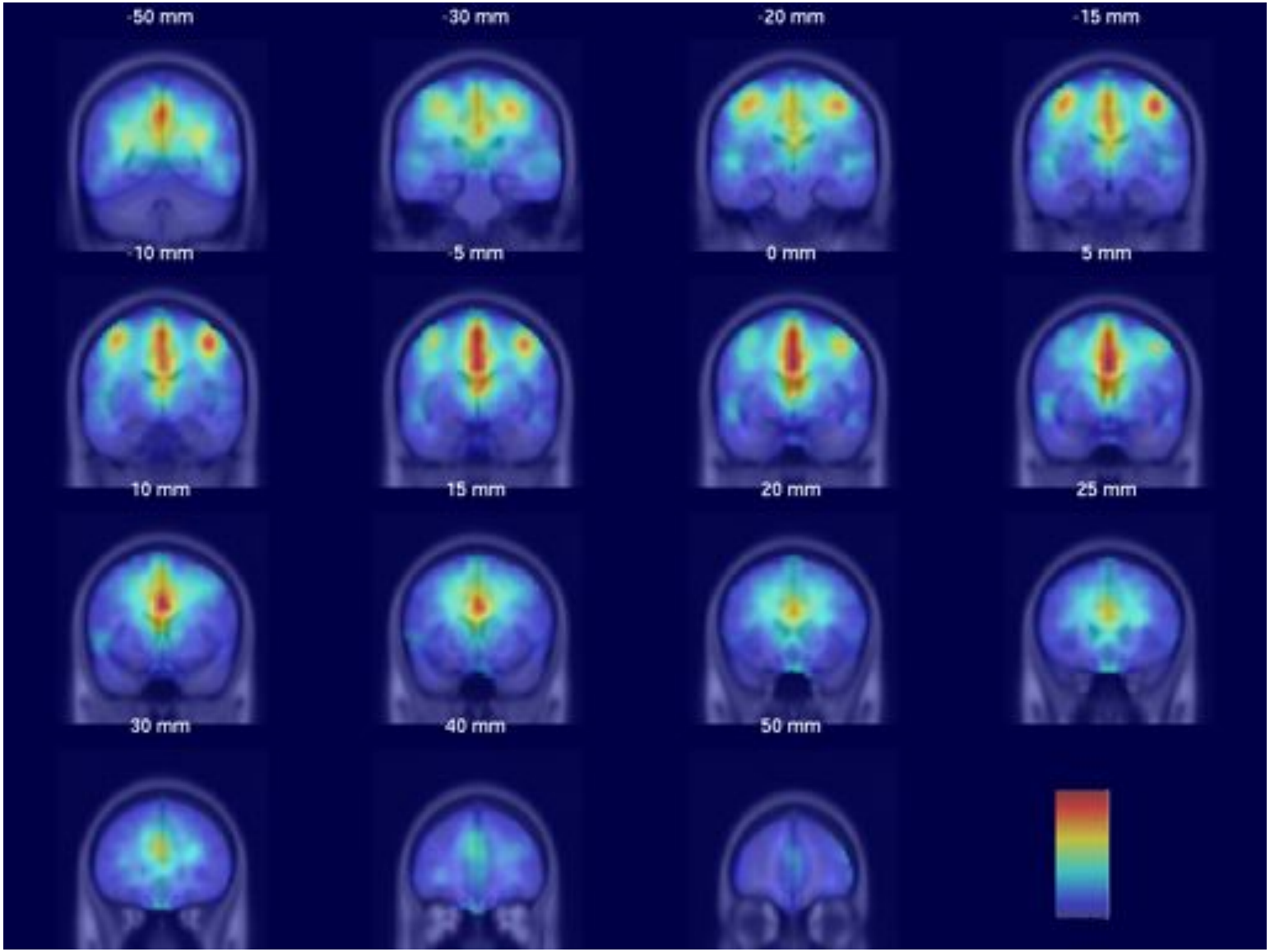
Onton, Makeig (2006)


Counting Stroop Studies
Present Study

Does the spatial distribution of independent components depend on the task the subject performs?

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

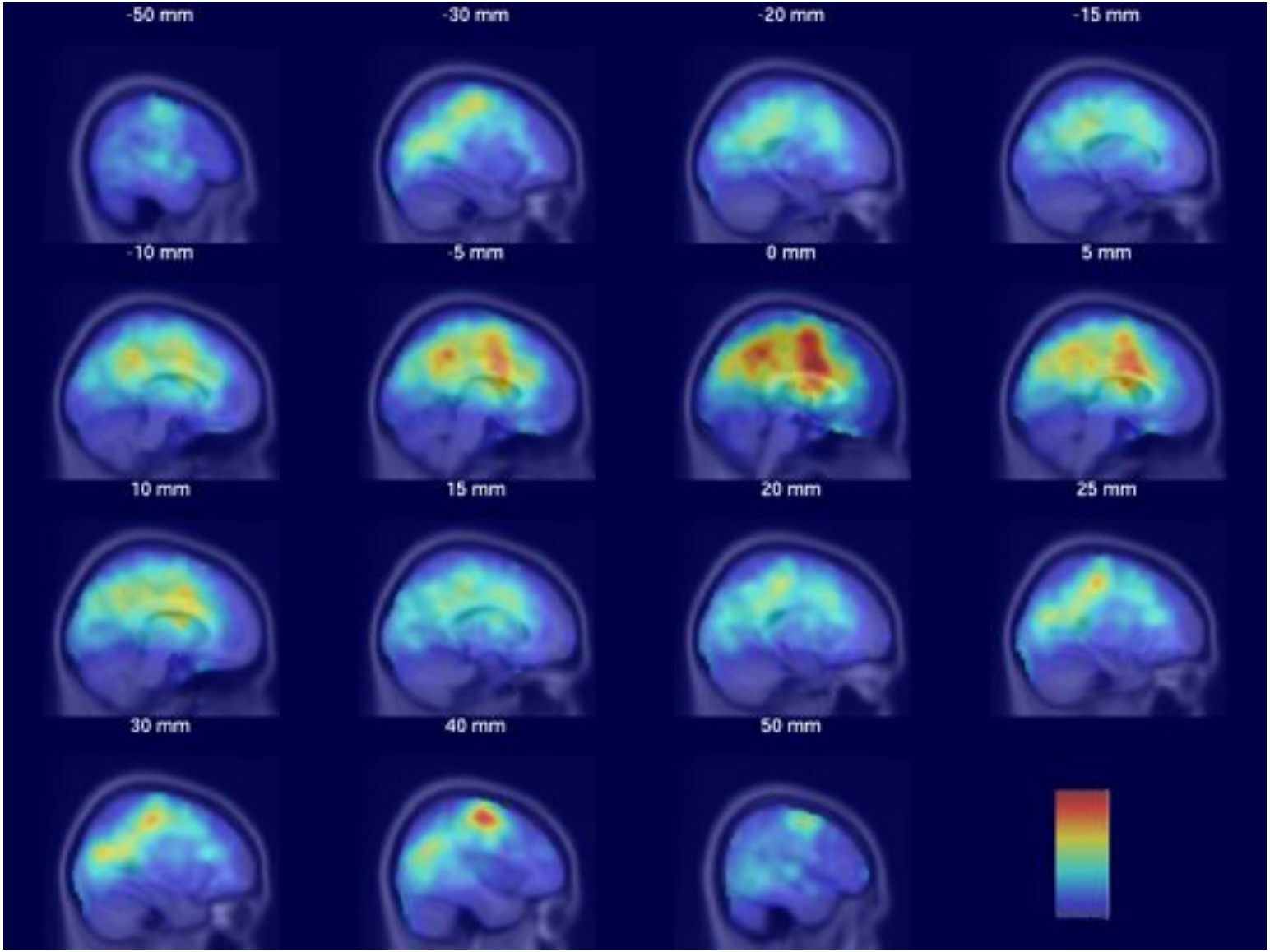
Dipole Density – 200k IC Equivalent Dipoles



>> dipoledensity()

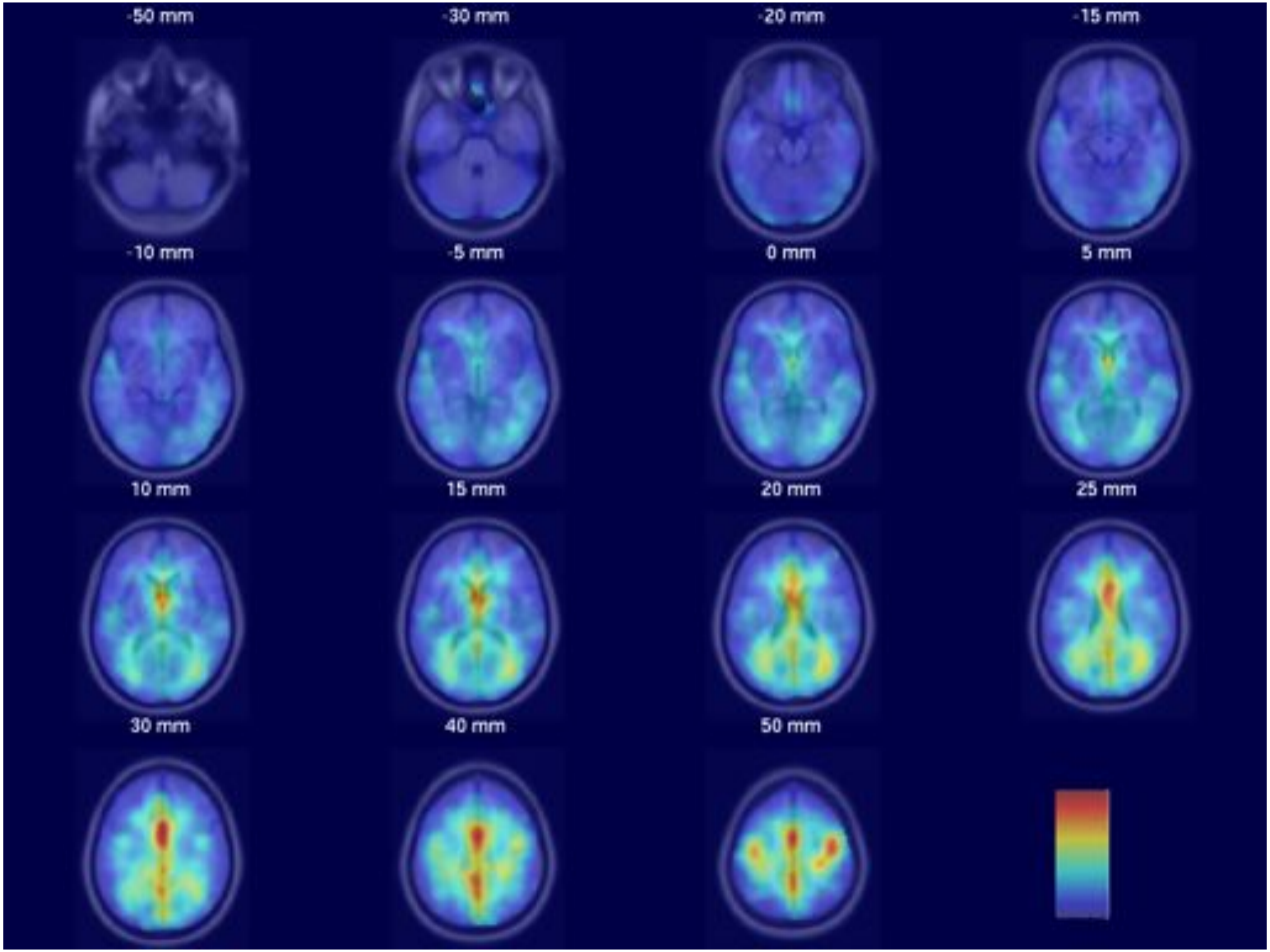
N. Bigdely-Shamlo, 2011

Dipole Density – 200k IC Equivalent Dipoles



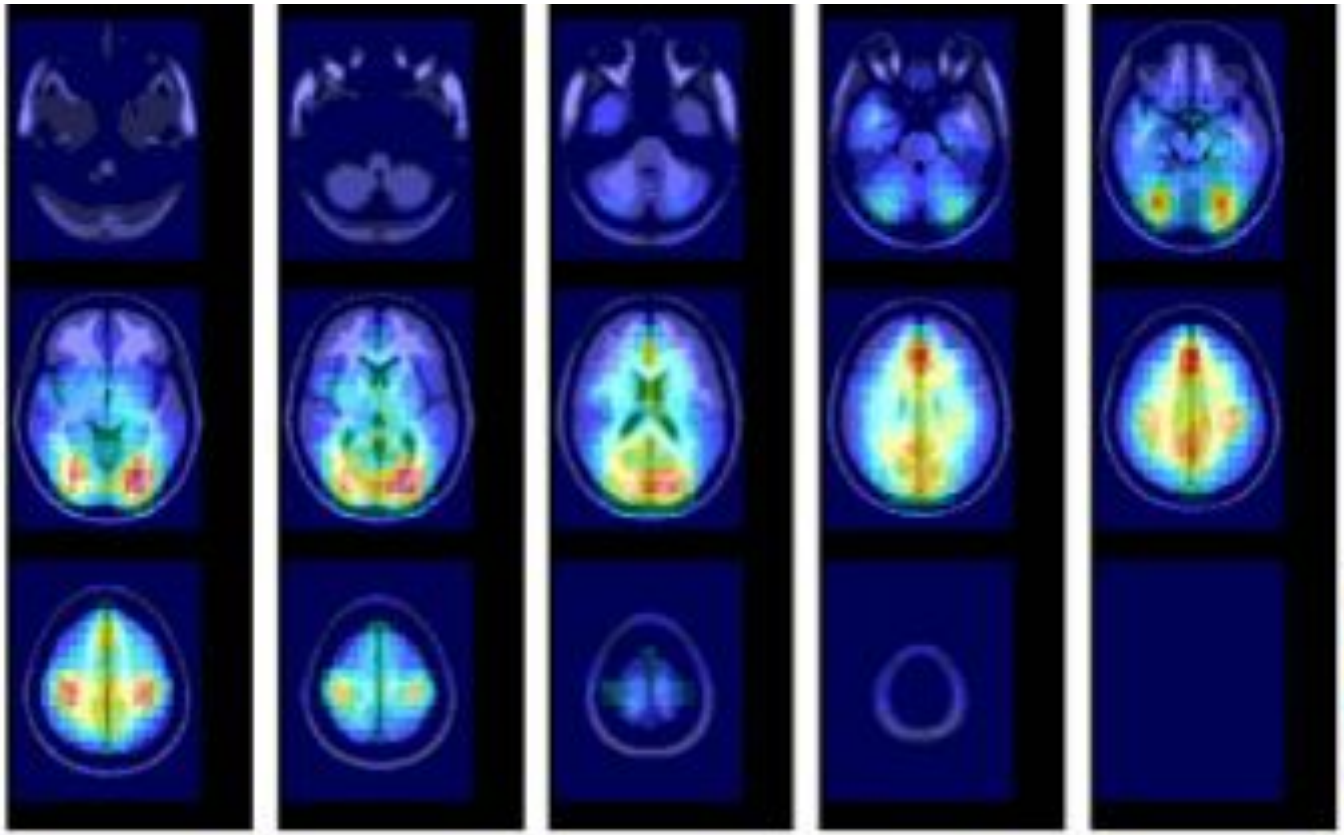
N. Bigdely-Shamlo, 2011

Dipole Density – 200k IC Equivalent Dipoles



N. Bigdely-Shamlo, 2011

Equivalent dipole density



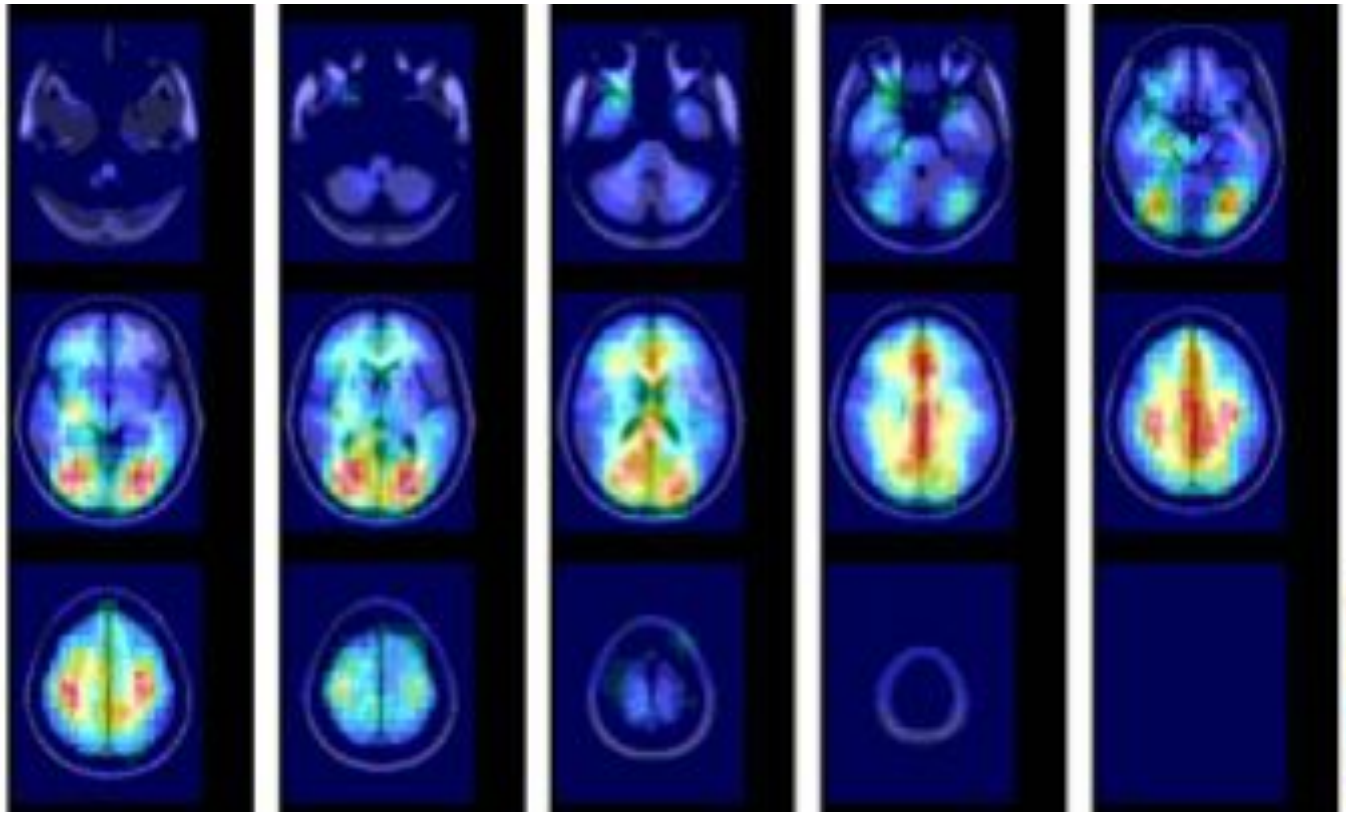
Sternberg letter memory task

>> dipoledensity()

Onton et al., 2

Onton et al., ‘05

Equivalent dipole density



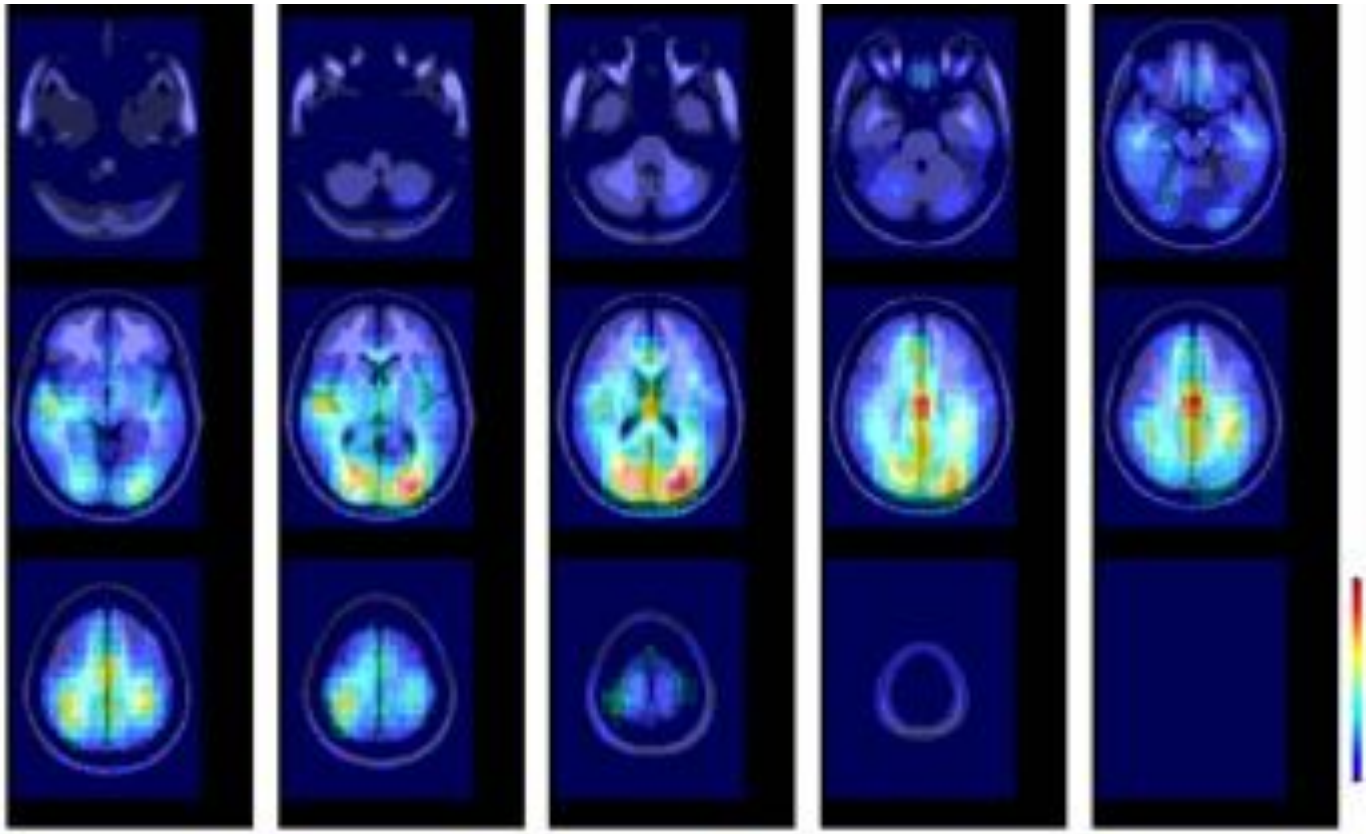
Letter twoback with feedback

>> **dipoledensity**()

Onton et al., 2

Onton et al., ‘05

Equivalent dipole density



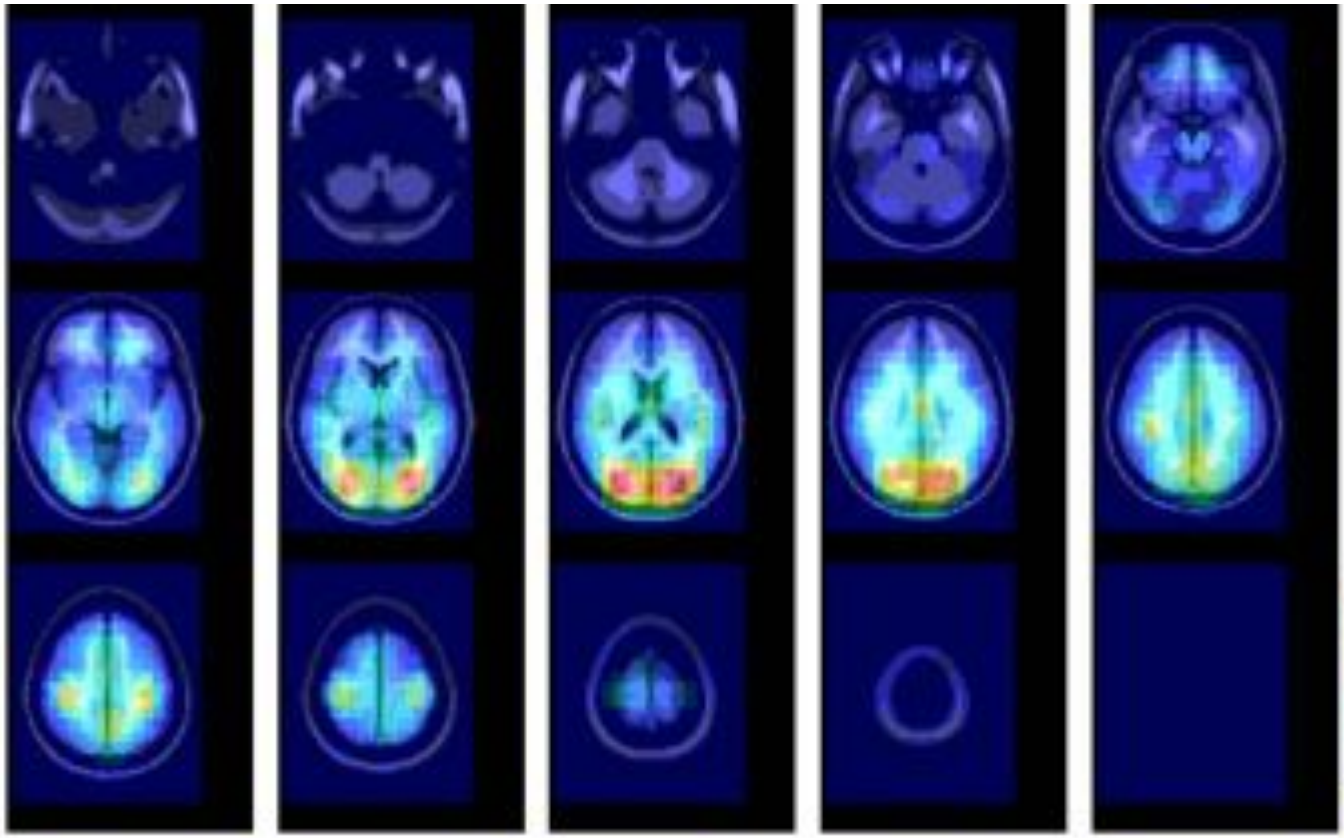
Auditory oddball plus novel sounds

>> dipoledensity()

Onton et al., 2

Onton et al., ‘05

Equivalent dipole density



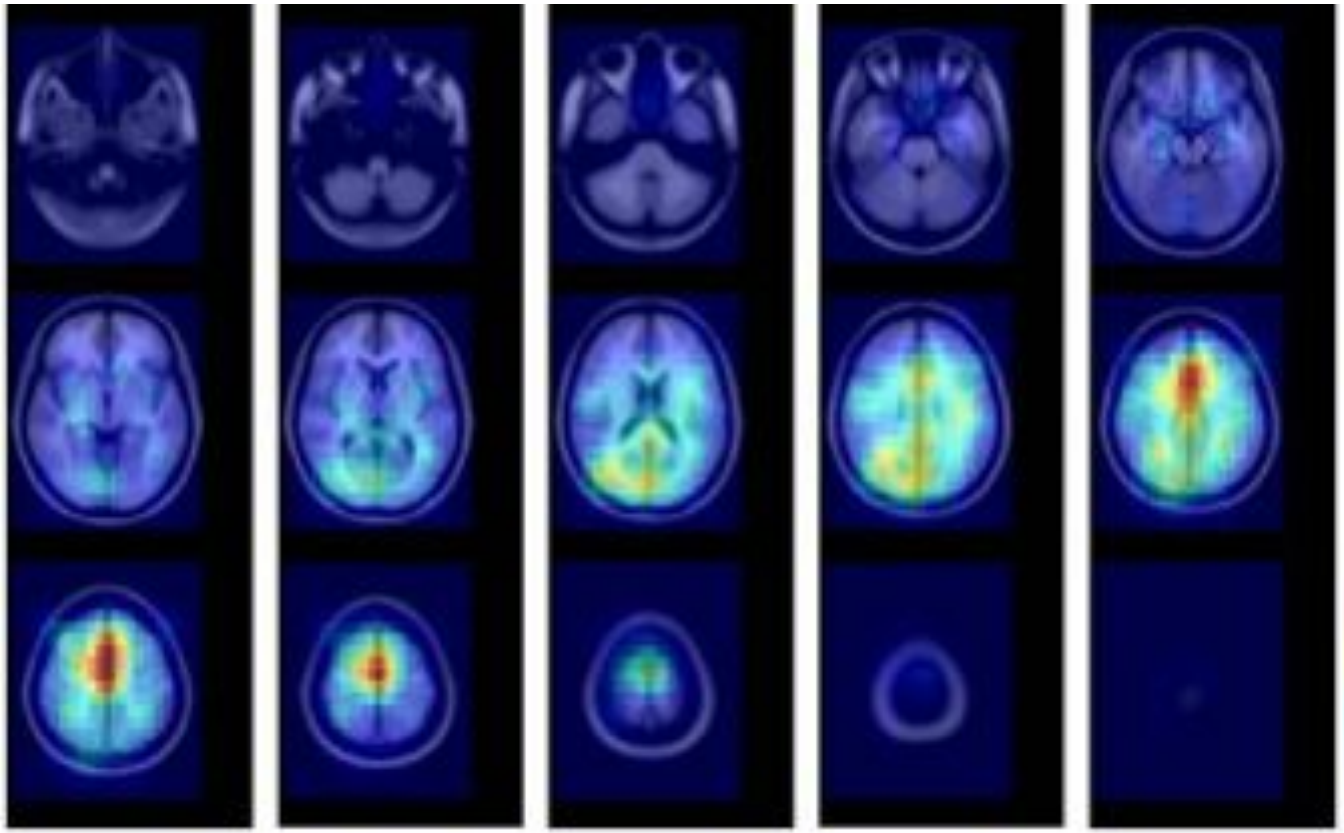
Emotion imagery task

>> dipoledensity()

Onton et al., 2

Onton et al., ‘05

Equivalent dipole density Exp I



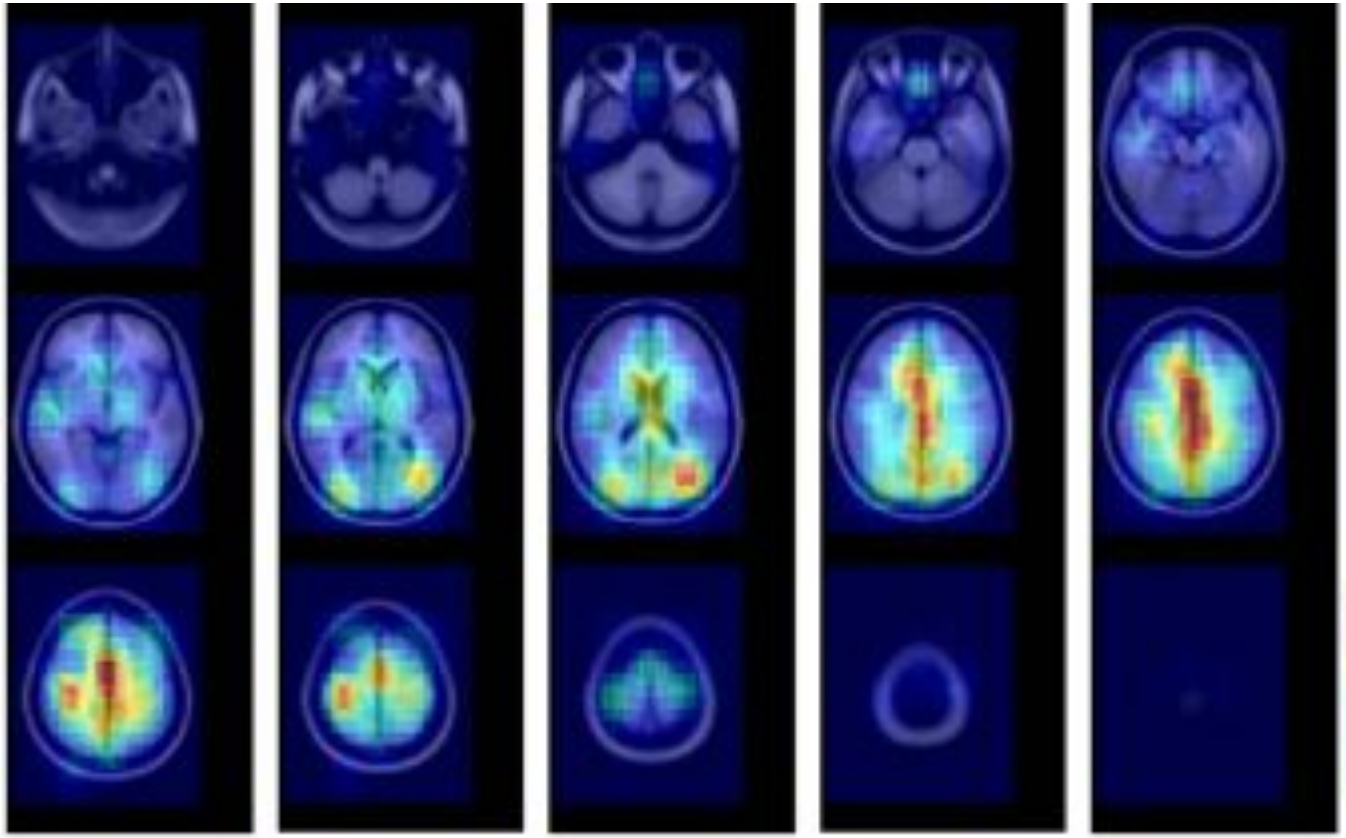
Word memory (old/new) task

>> dipoledensity()

Onton et al., 2

Onton et al., ‘05

Equivalent dipole density Exp II



Visually cued button press task

>> dipoledensity()

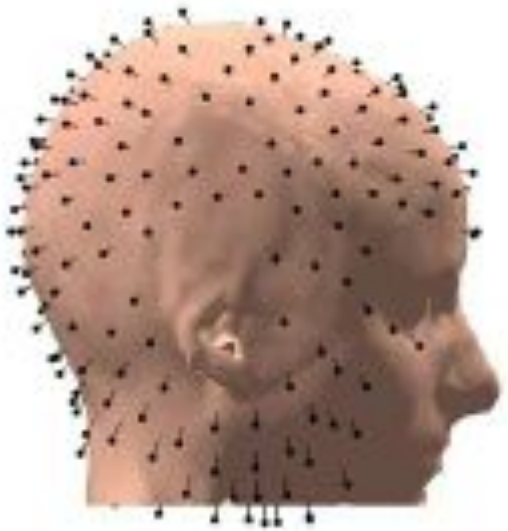
Onton et al., 2

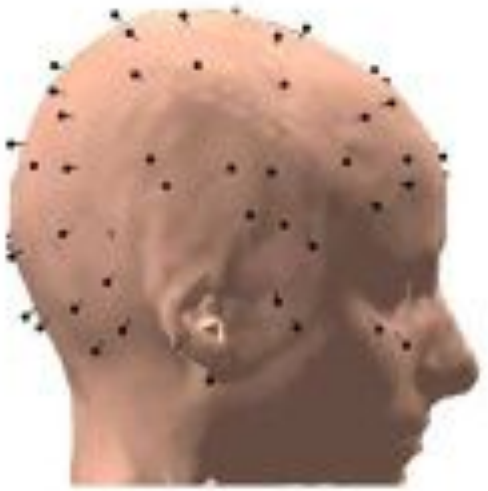
Onton et al., '05

… Some caveats

In this preliminary *dipoledensity()* study …

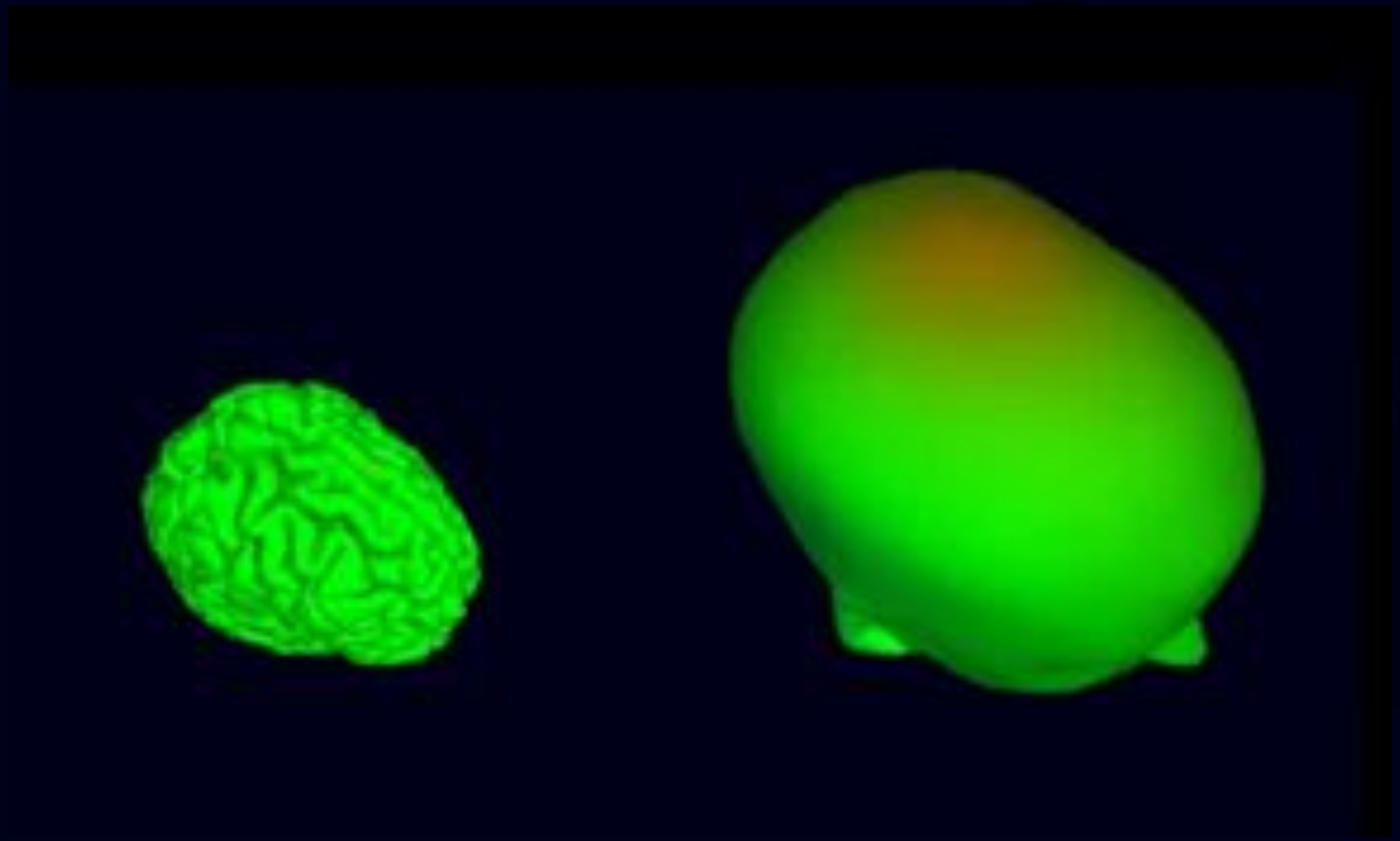
- The electrode locations were not individualized.
- MR images were not available → co-registration crude.
- Single versus dual-dipole model selection was subjective.
- Different electrode montages → possible location effects





Onton, 2005

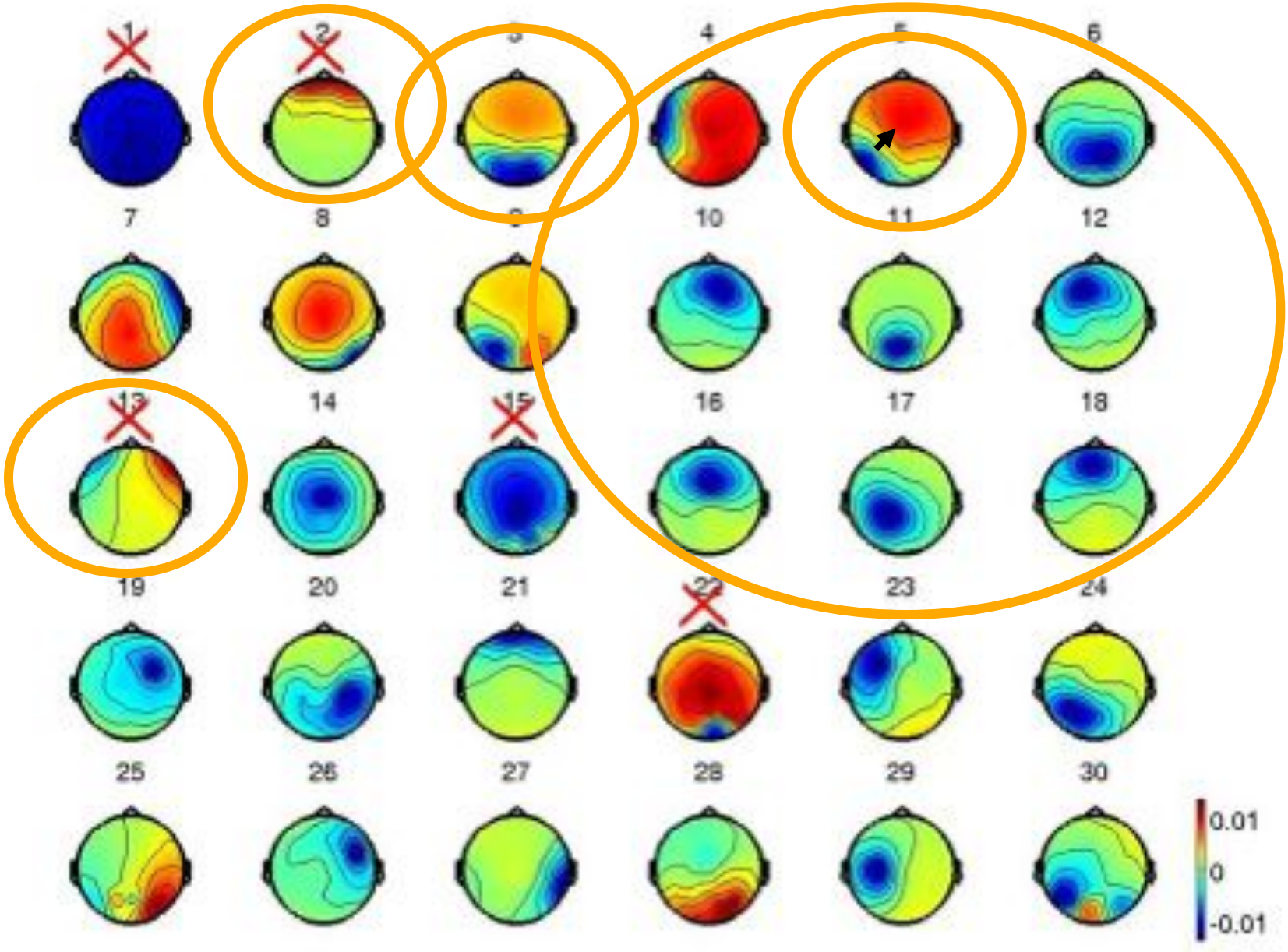
The very broad EEG point-spread function



Simulated cm^2-scale multi-source activity, and its EEG projection

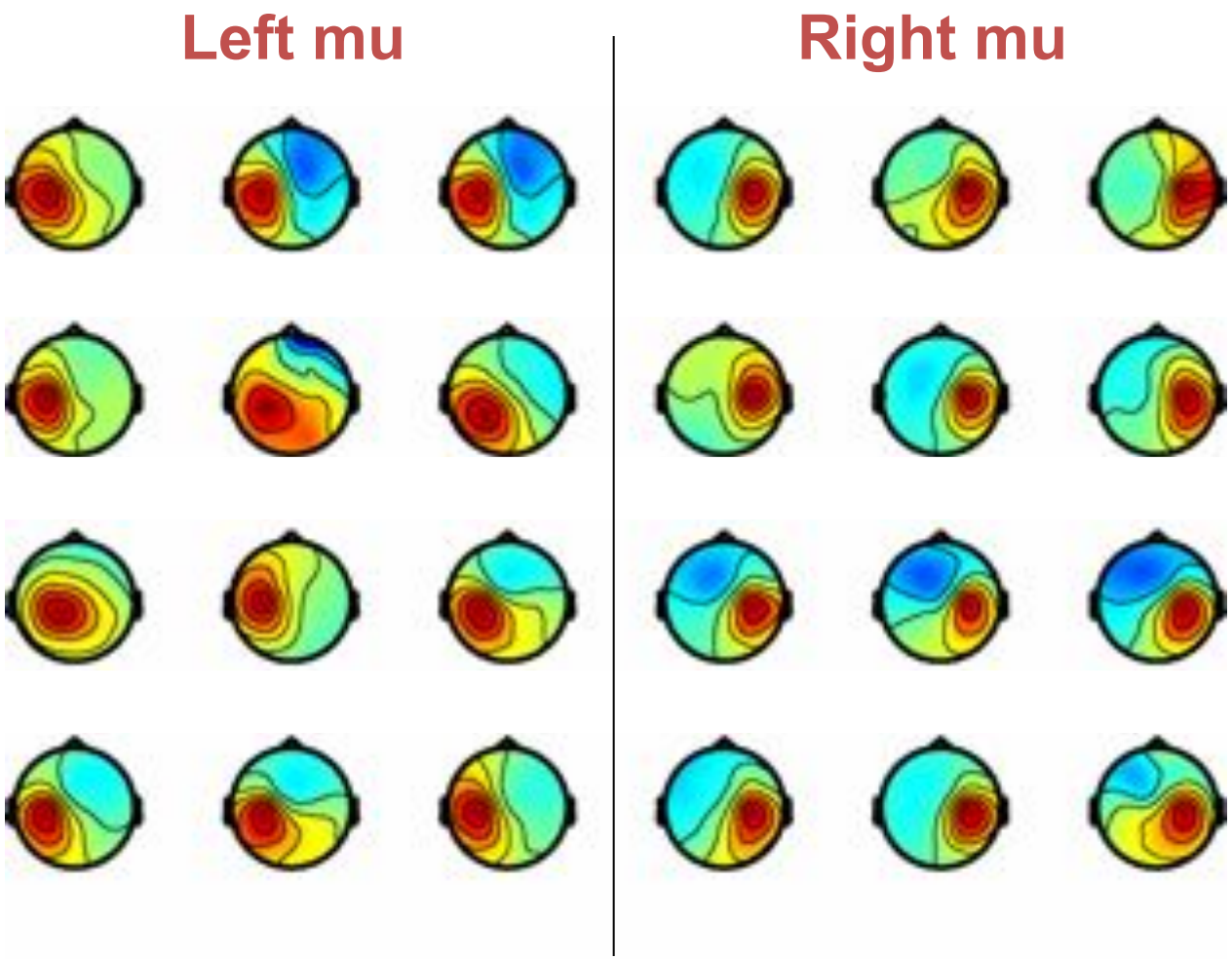
Akalin Acar & Makeig 2010

Largest 30 independent components (single subject)



Makeig, 2007

Clustering ICA components by eye



Makeig et al., *unpublished*

So how to cluster components?

The same problems hold for clustering independent components

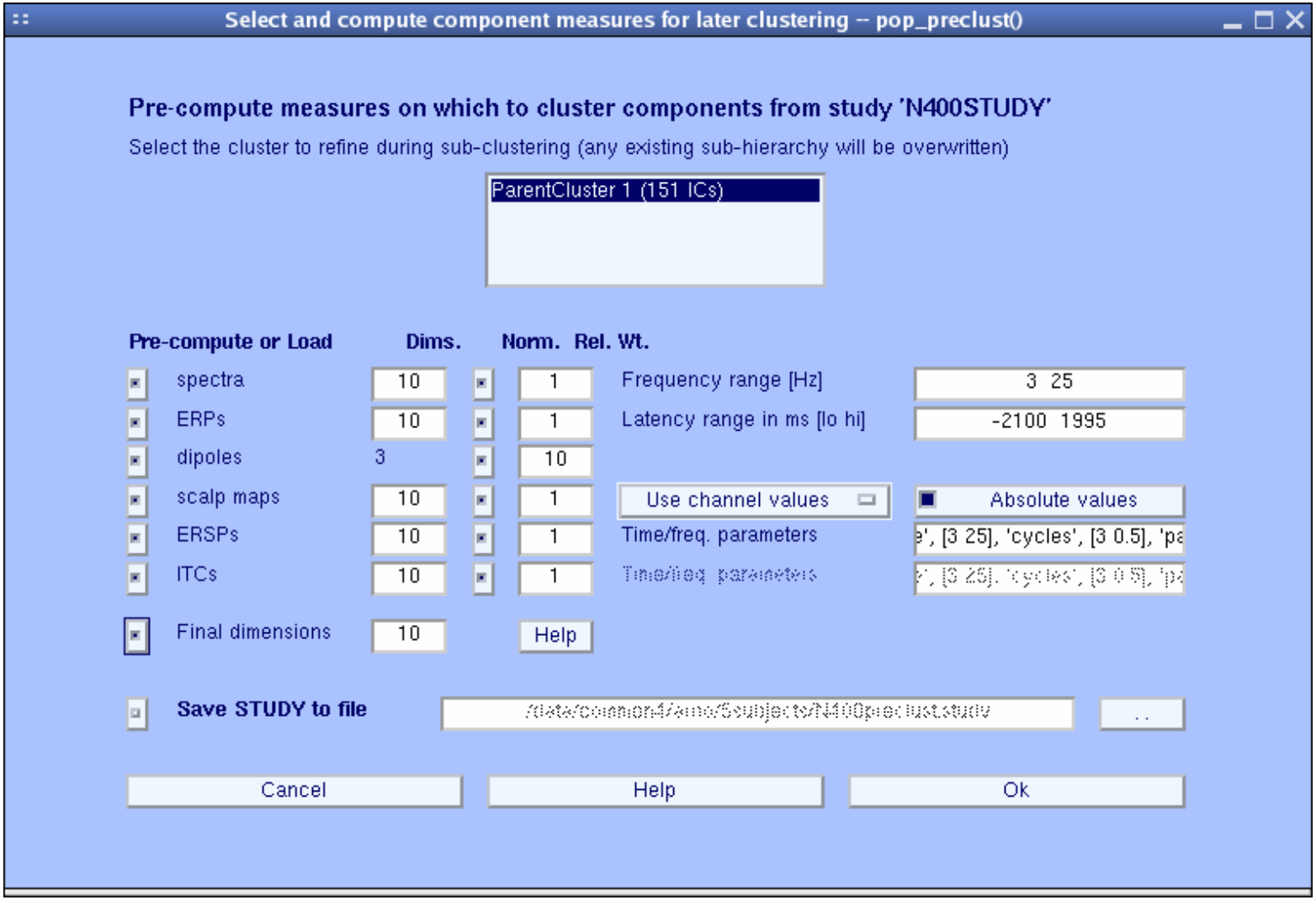
Across Ss, components don't even have "the same" scalp maps!

→ Are "the same" components found across subjects?

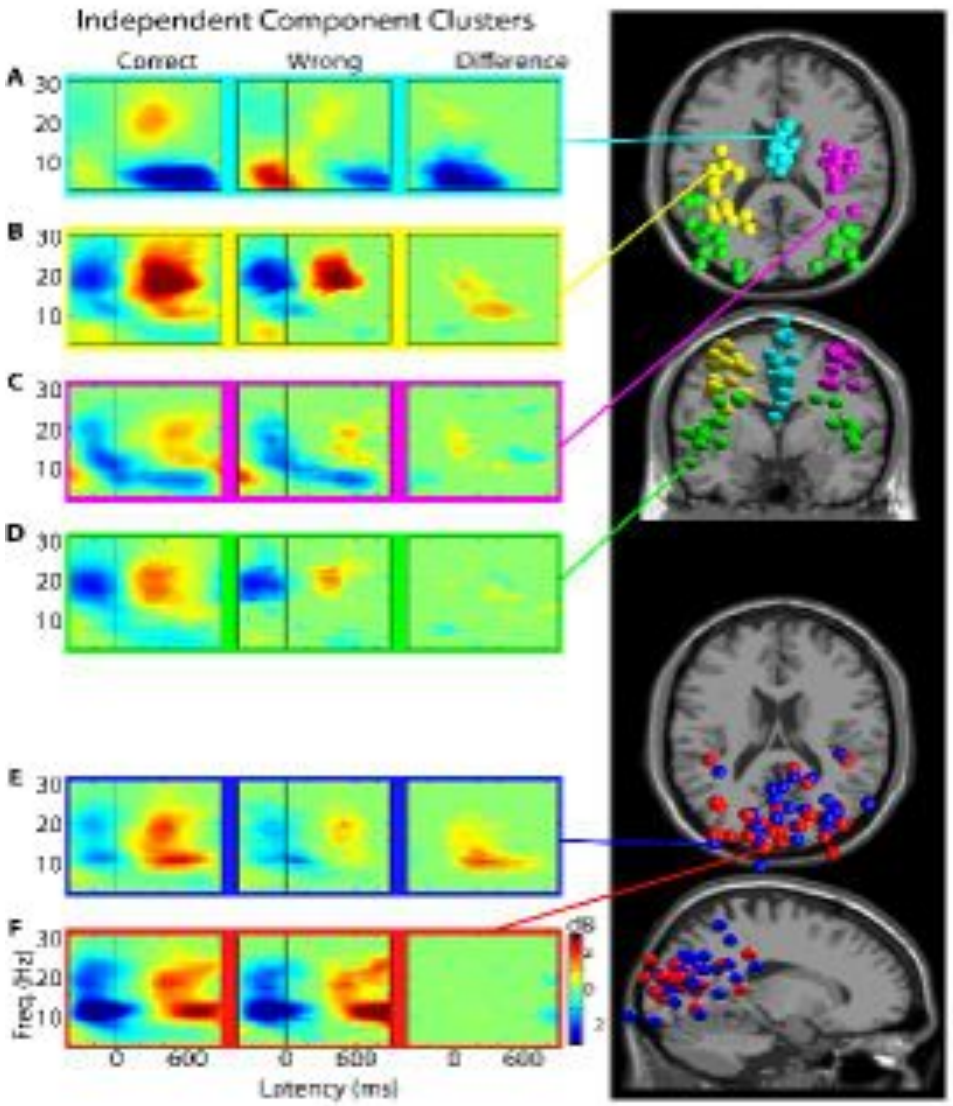
- What should define "the same" (i.e., "component equivalence")?
  - Similar scalp maps?
  - Similar cortical or 3-D equivalent dipole locations?
  - Similar activity power spectra?
  - Similar ERPs?
  - Similar ERSPs?
  - Similar ITCs?
  - OR …, Similar *combinations* of the above? …

Makeig, 2007

EEGLAB IC Clustering



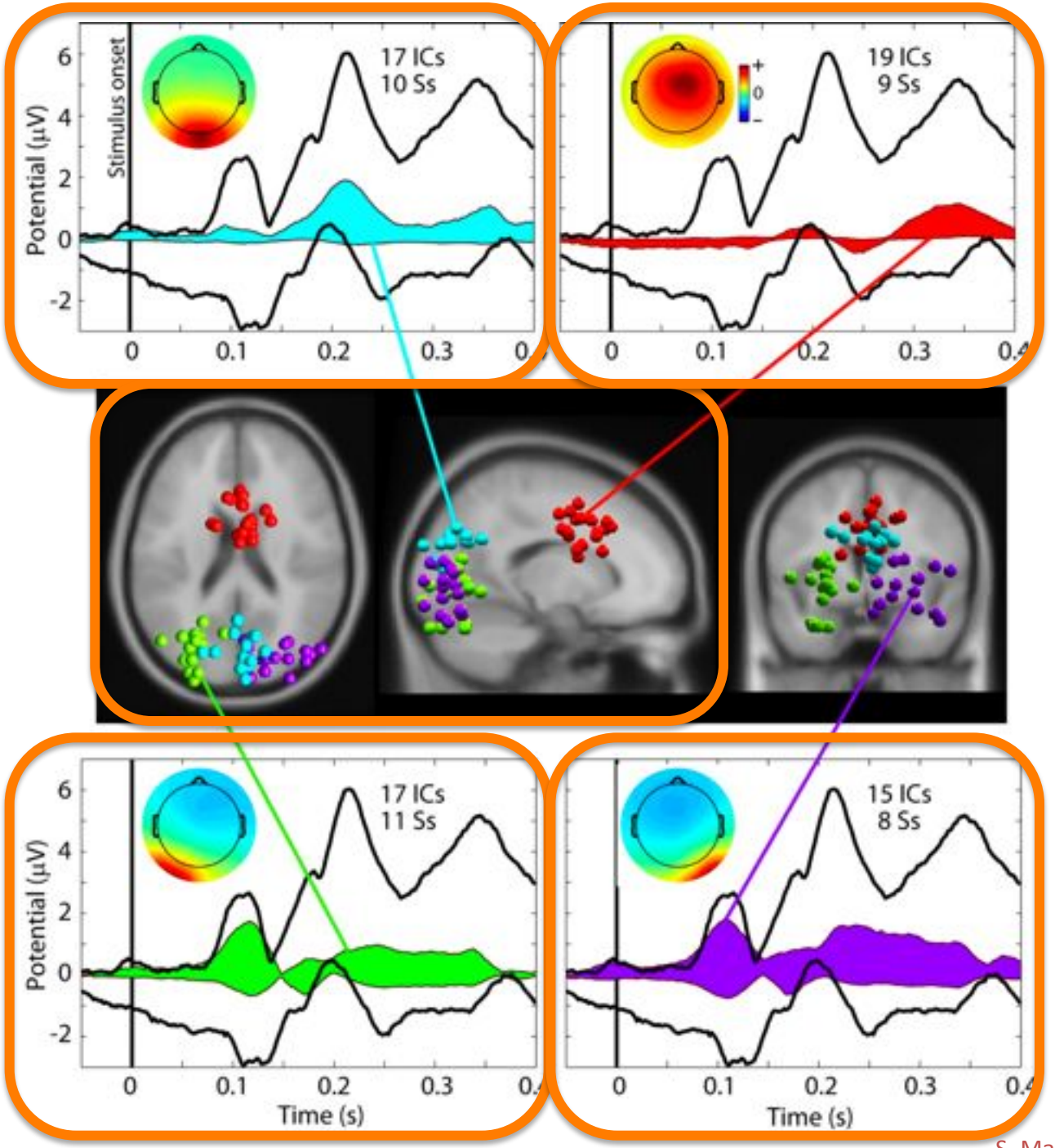
Study IC Clustering



Sometime clusters are spatially separate AND have distinct responses.

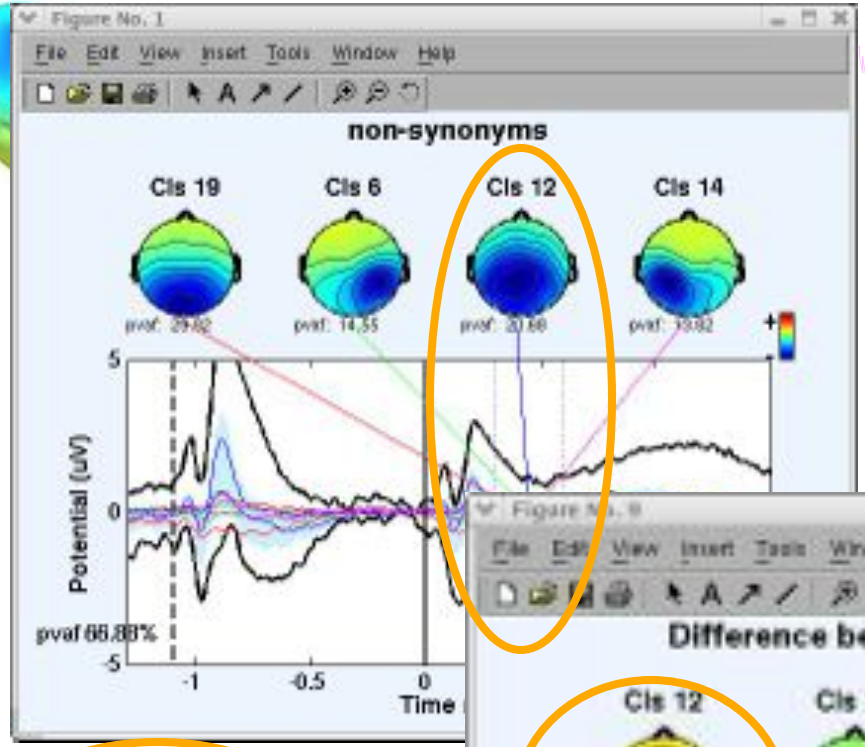
In other cases, they have similar responses or they overlap spatially.

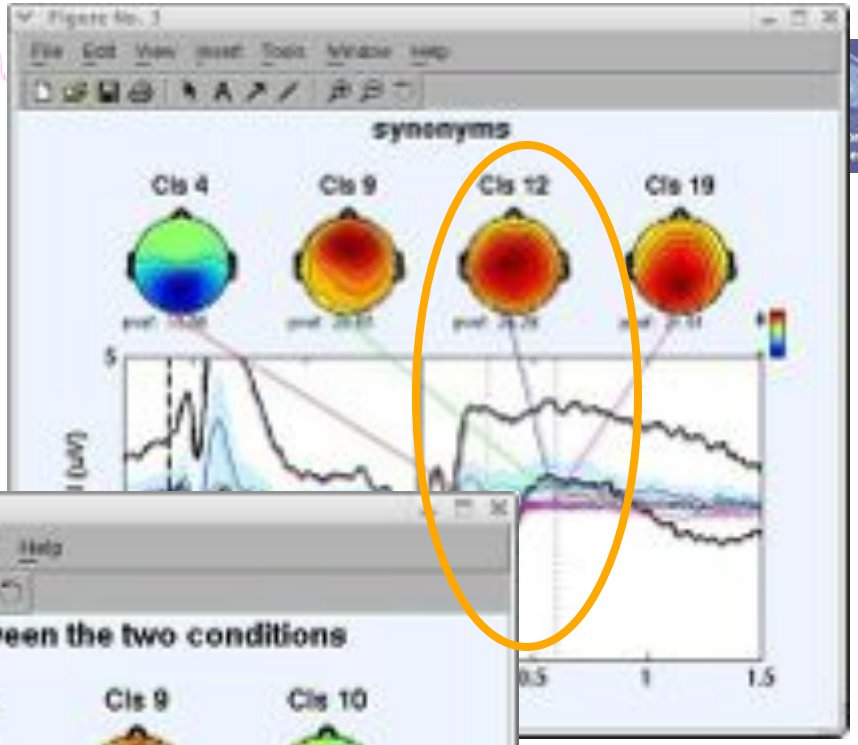
Onton & Makeig, 2007

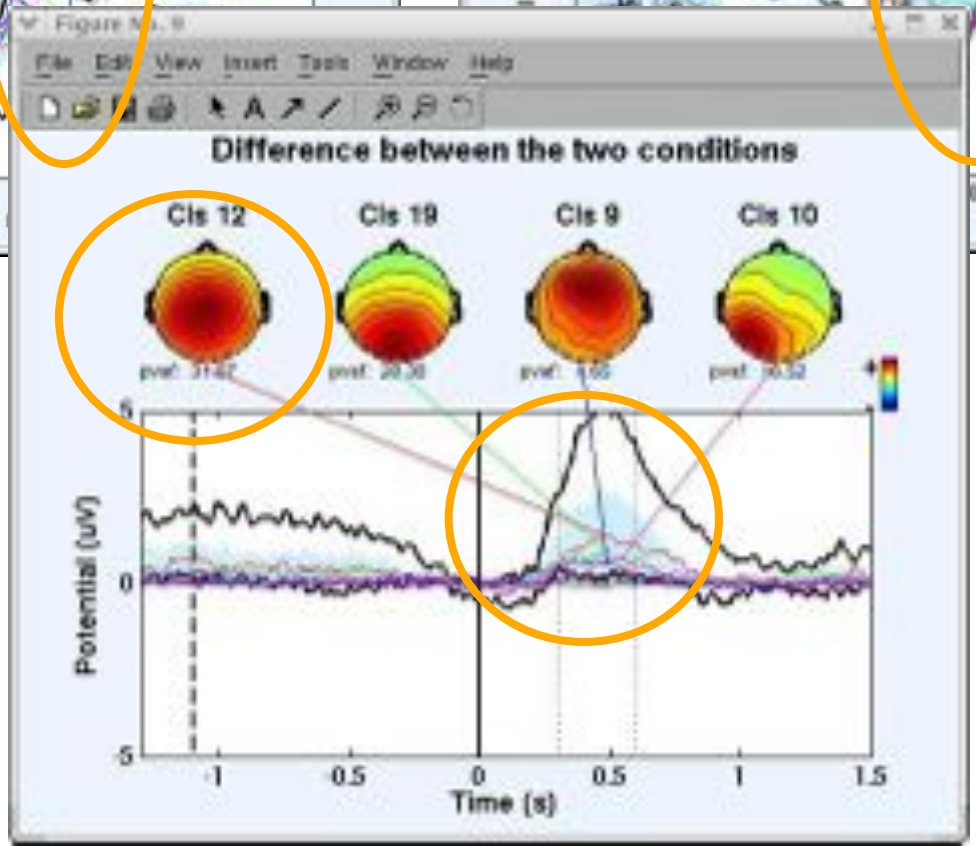


S. Makeig & J. Onton (2009)

Cluster ERP contributions - clust_envtopo()







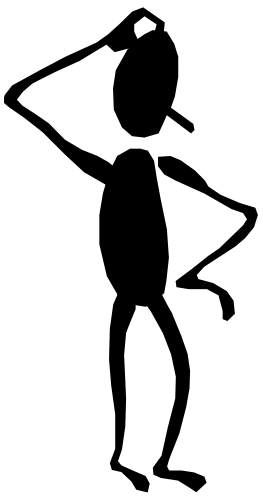
clust_envtopo(STUDY, ALLEEG, 'clusters', [], 'subclus',[3 7 18 20], 'env_erp', 'all', 'vert', -1100, 'baseline', [-200 0], 'diff', [2 1], 'limits', [-1300 1500 -5 5], 'only_precomp', 'on', 'clustnums' , -4, 'limcontrib', [300 600]);

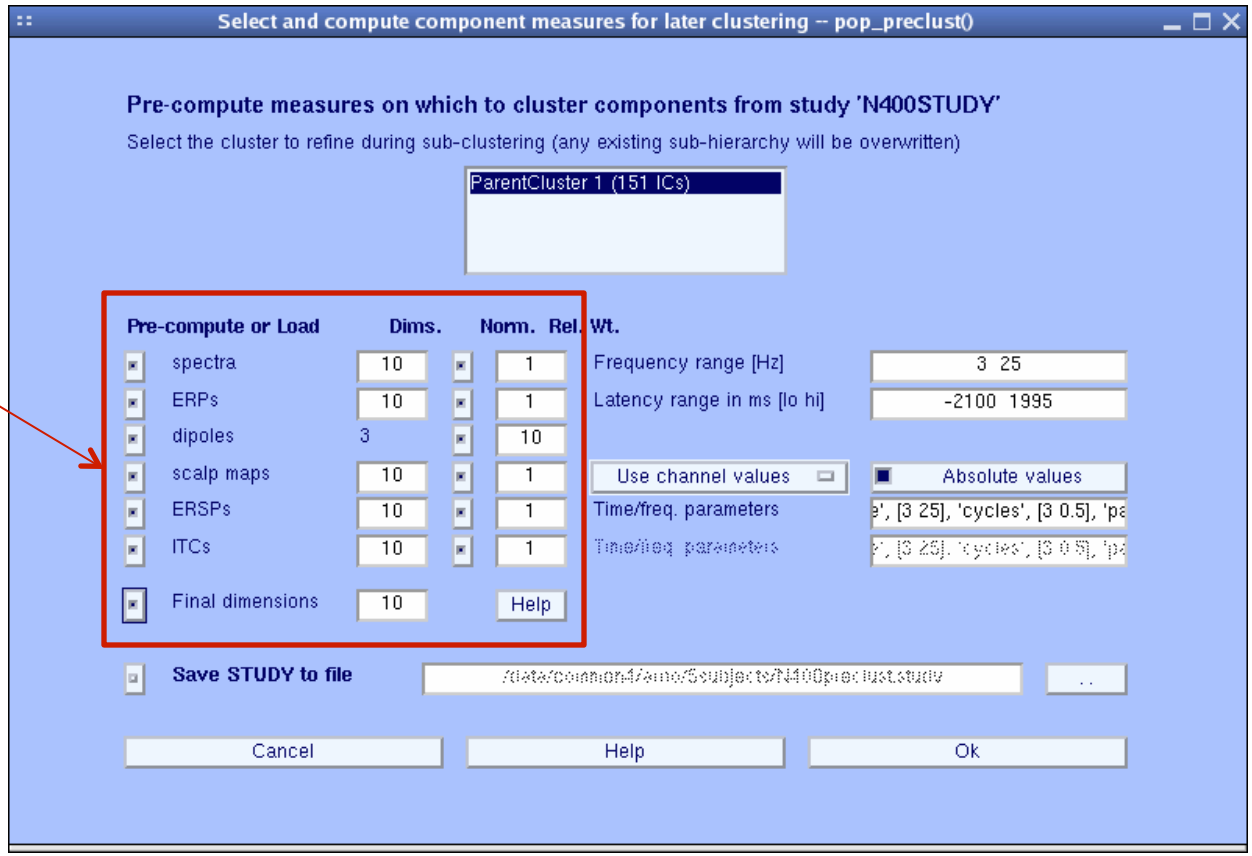
Makeig, 2007

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 original clustering has ~12 parameters





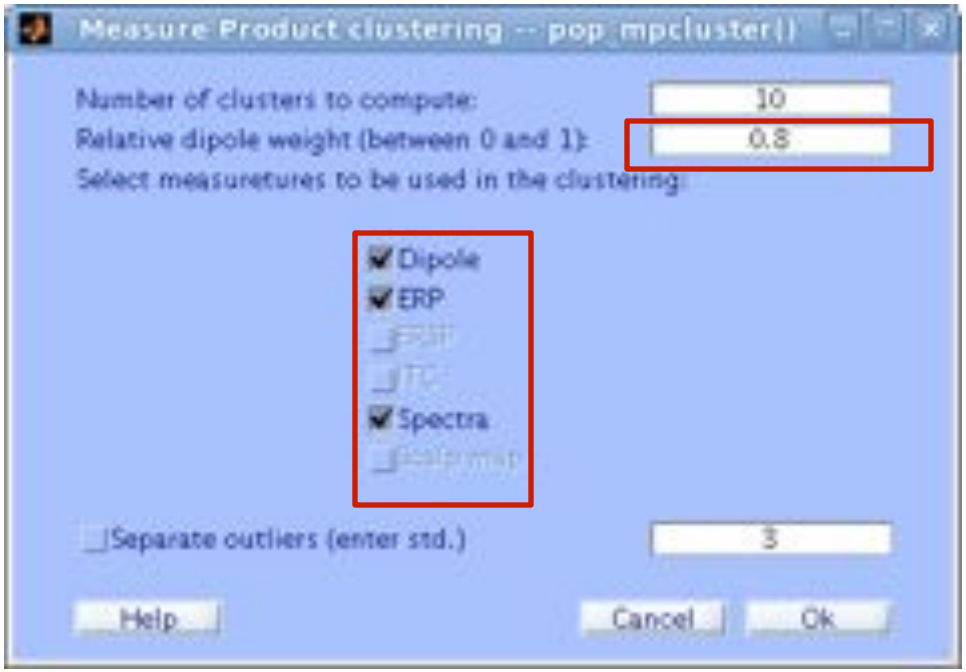
N. Bigdely-Shamlo, 2010

Study IC Clustering: New Developments

The Affinity Clustering method

(EEGLAB plug-in by Nima Bigdely Shamlo)

only has one pre-clustering parameter.



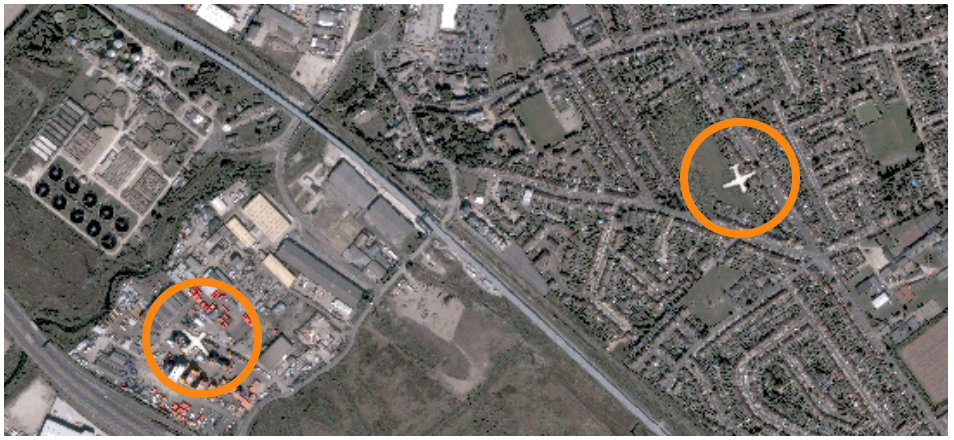
Of course, one still has to select a subset of measures and the number of clusters….

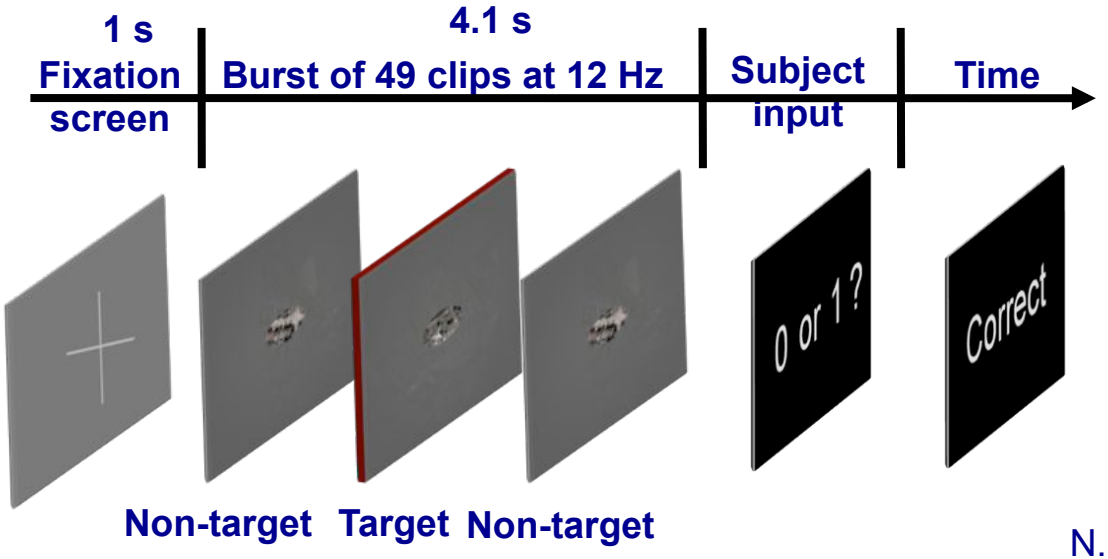
N. Bigdely-Shamlo, 2010

Measure Projection: RSVP Example

Rapid Serial Visual Presentation Experiment

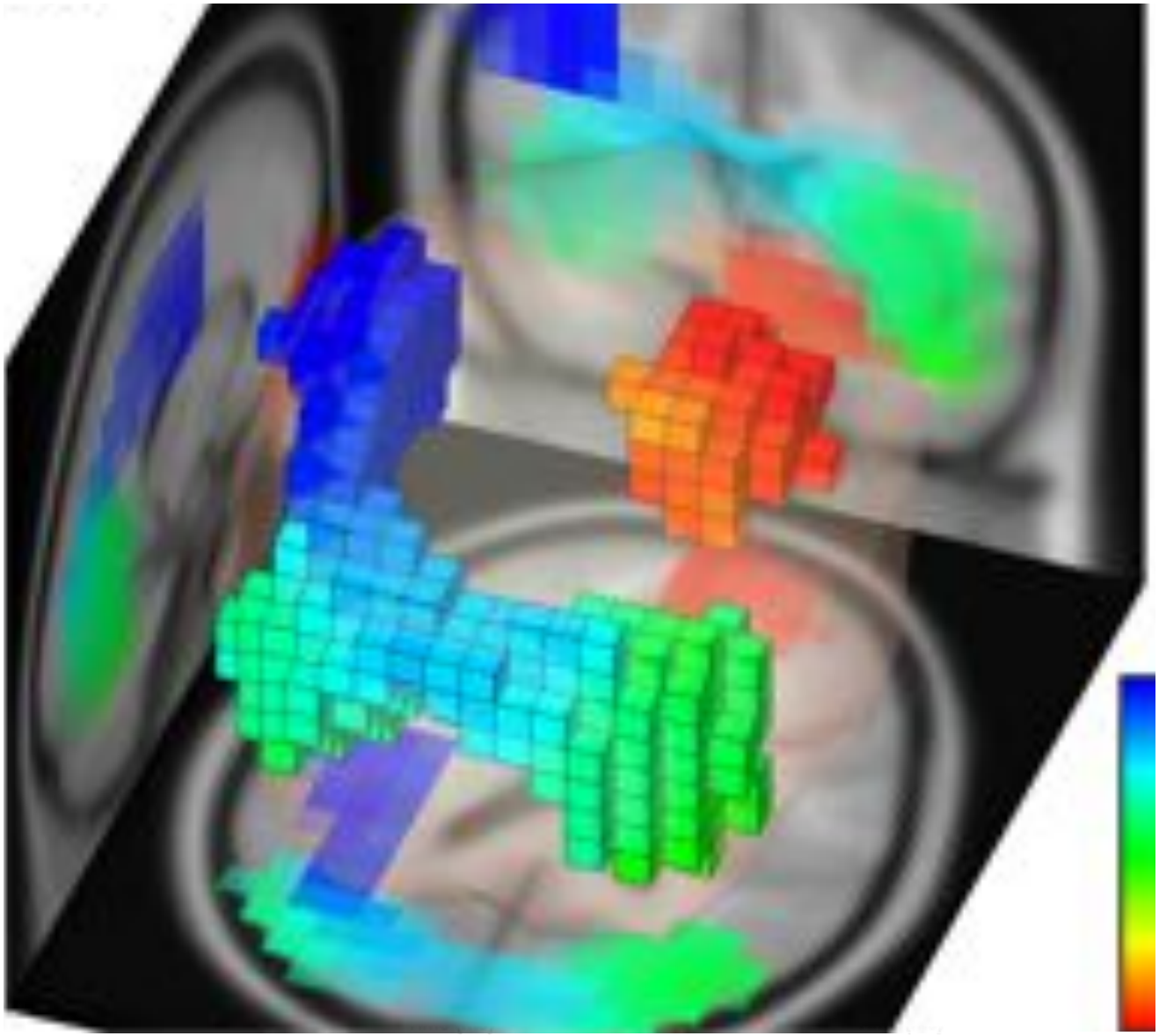
- 8 subjects
- 15 Sessions
- Visual target detection
- 257 components with equiv. dipoles inside the brain





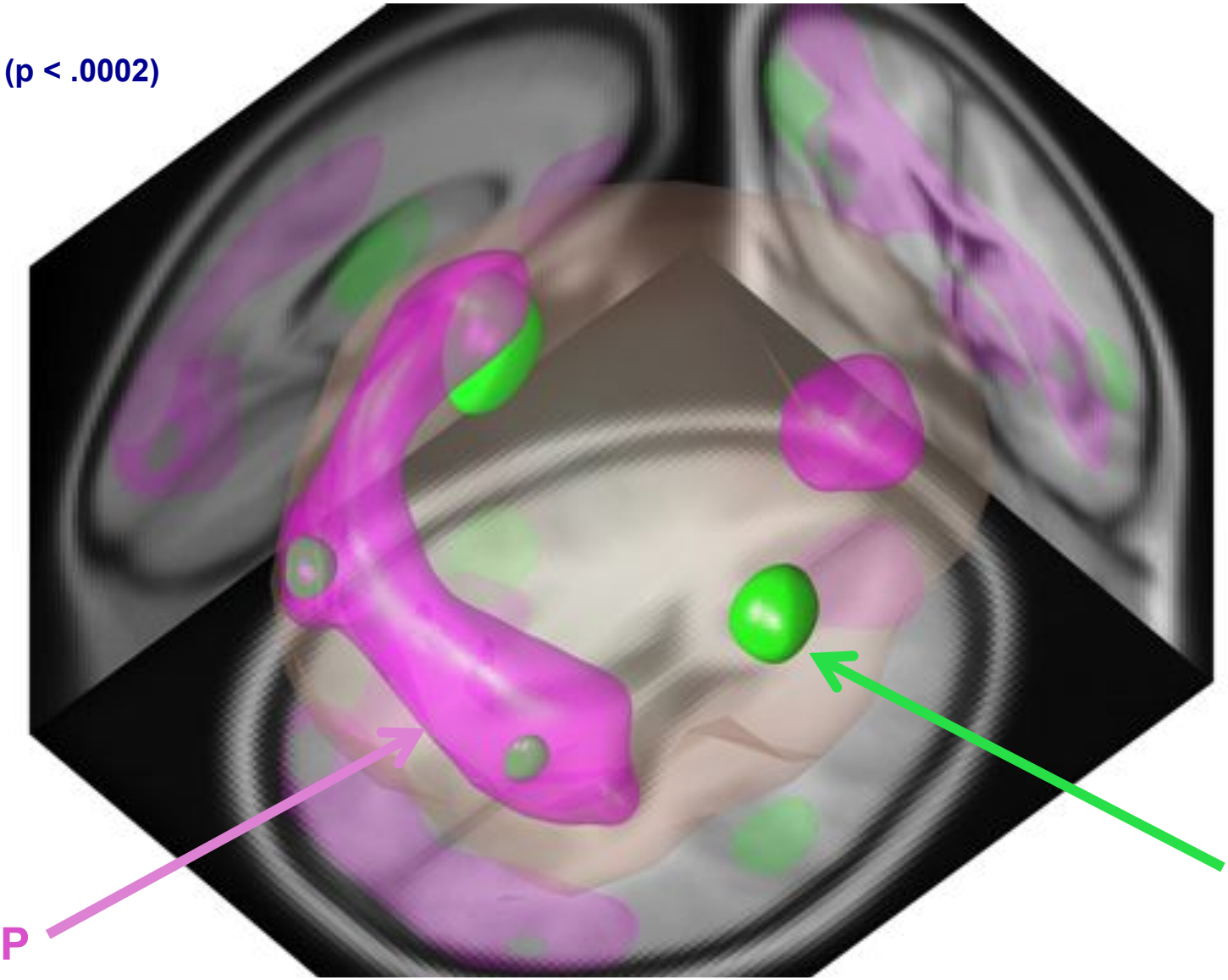
N. Bigdely-Shamlo, 2011

Measure Projection: RSVP Example



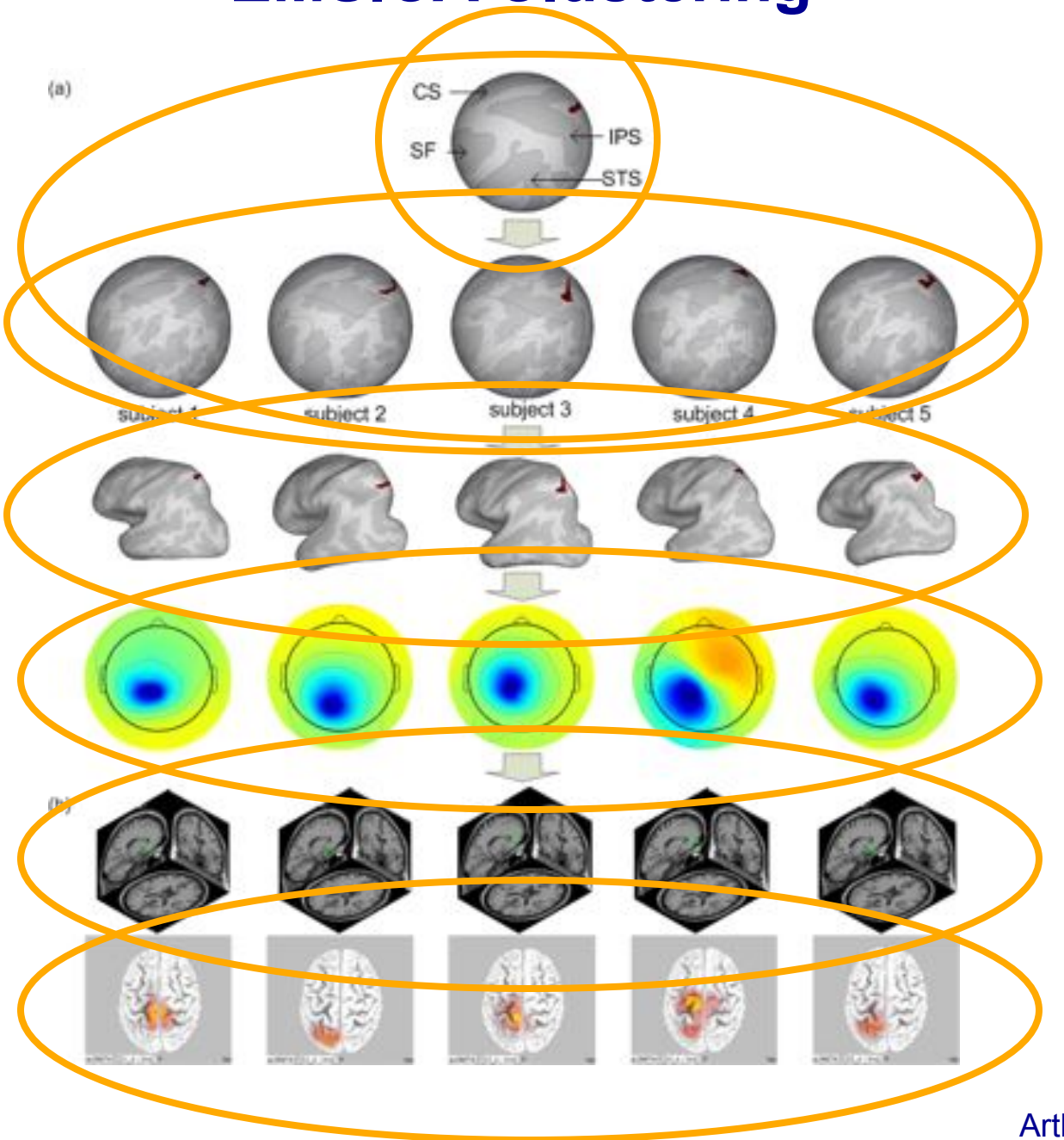
N. Bigdely-Shamlo, 2011

Measure Projection: RSVP Example



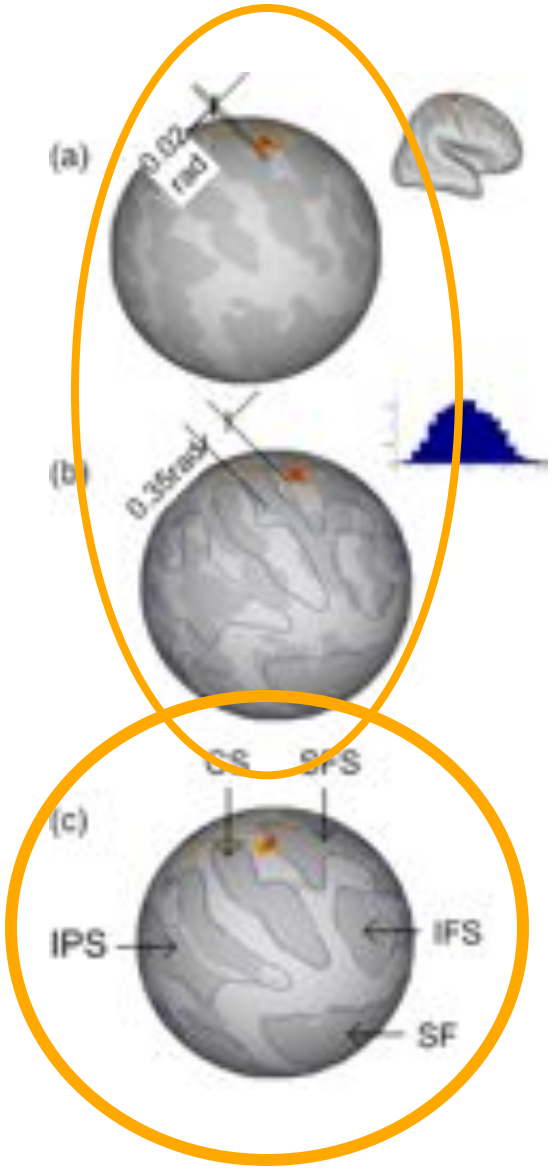
N. Bigdely-Shamlo, 2011

EMSICA Clustering



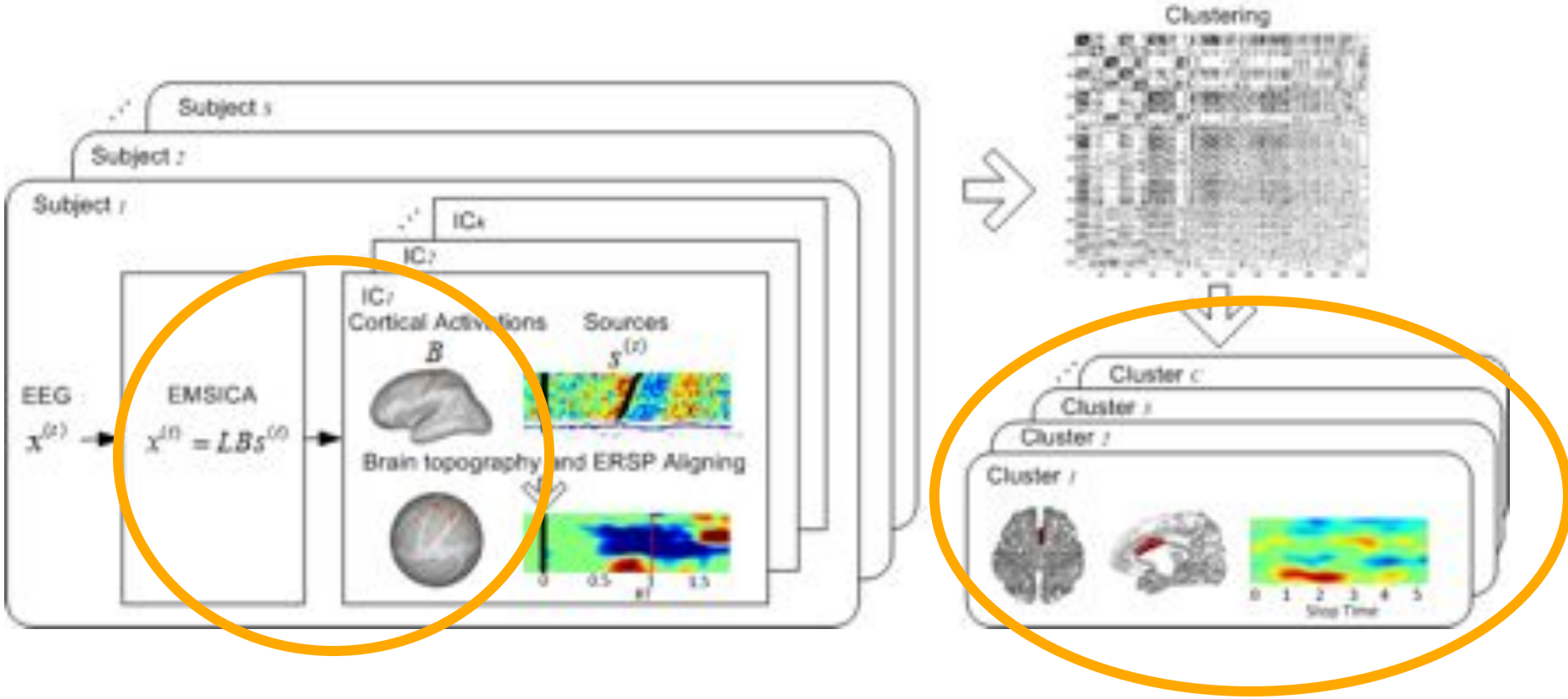
Arthur Tsai et al., 2012

EMSICA Clustering

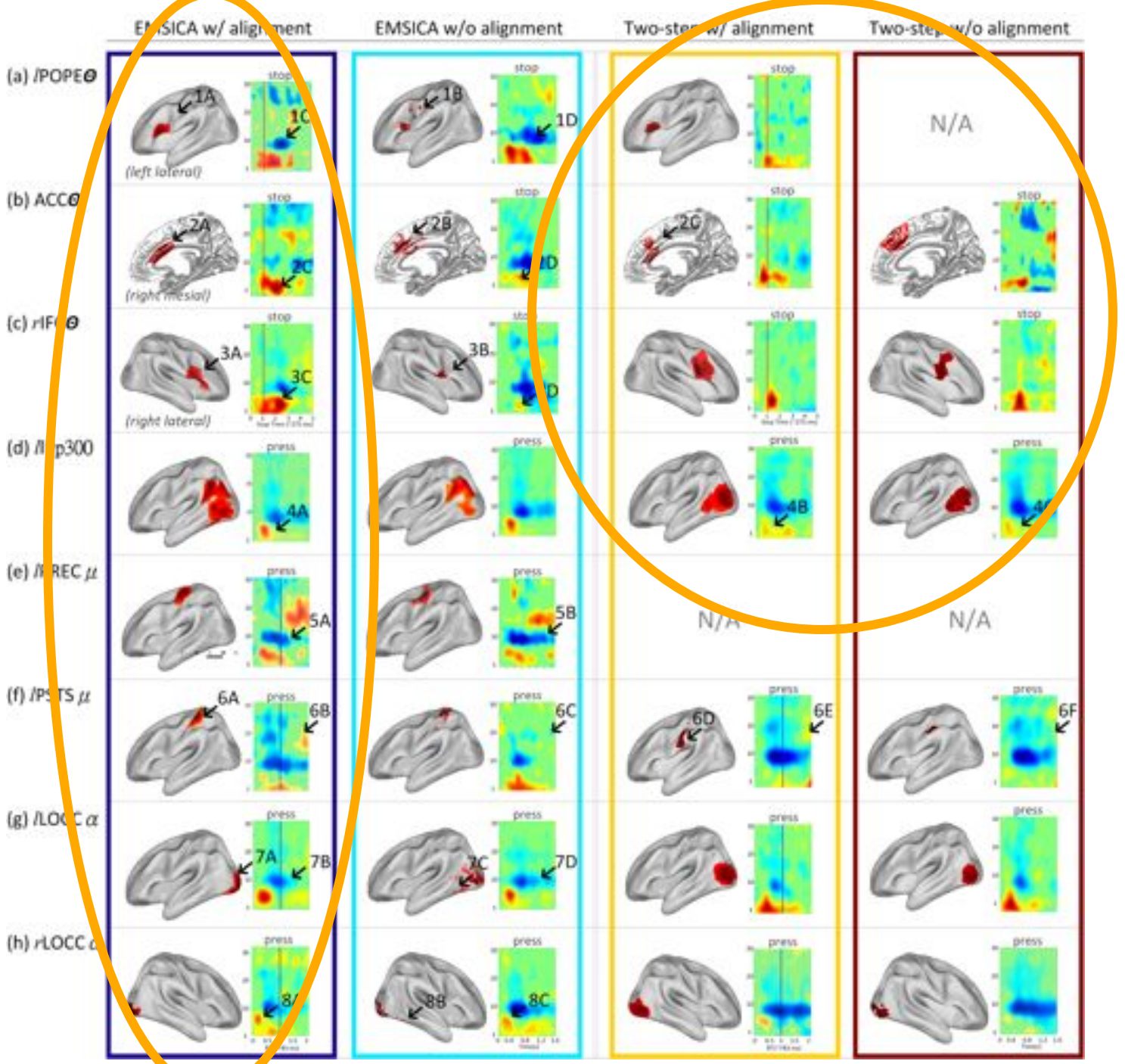


Arthur Tsai et al., 2012

EMSICA Clustering



Arthur Tsai et al., 2012



Arthur Tsai et al., 2012