Functional High-Definition Imaging of EEG Brain Dynamics

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10th EEGLAB Workshop

UCSD, La Jolla CA

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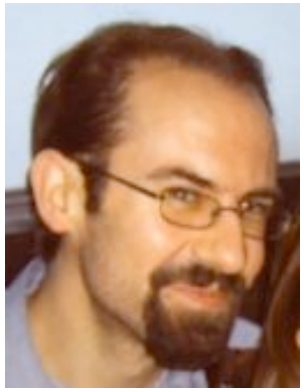
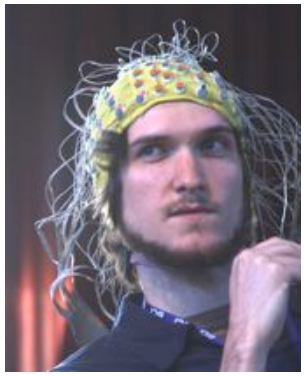
Christian Kothe



David Groppe

Jason Palmer

Julie Onton



Tim Mullen

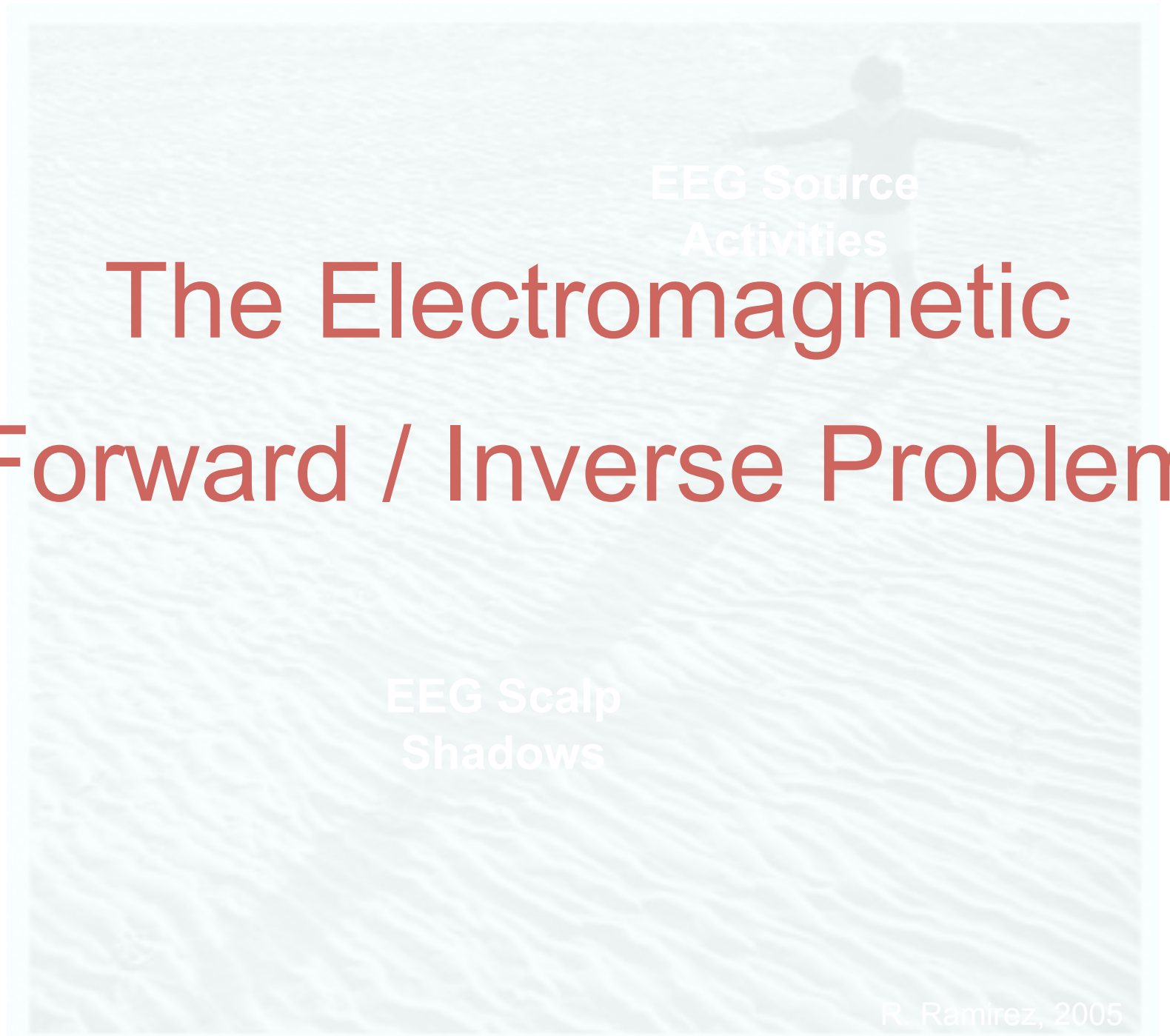
Tzyy-Ping Jung

Klaus Gramann

Tony Bell

Zeynep Akalin Acar

Nima Bigdely Shamlo



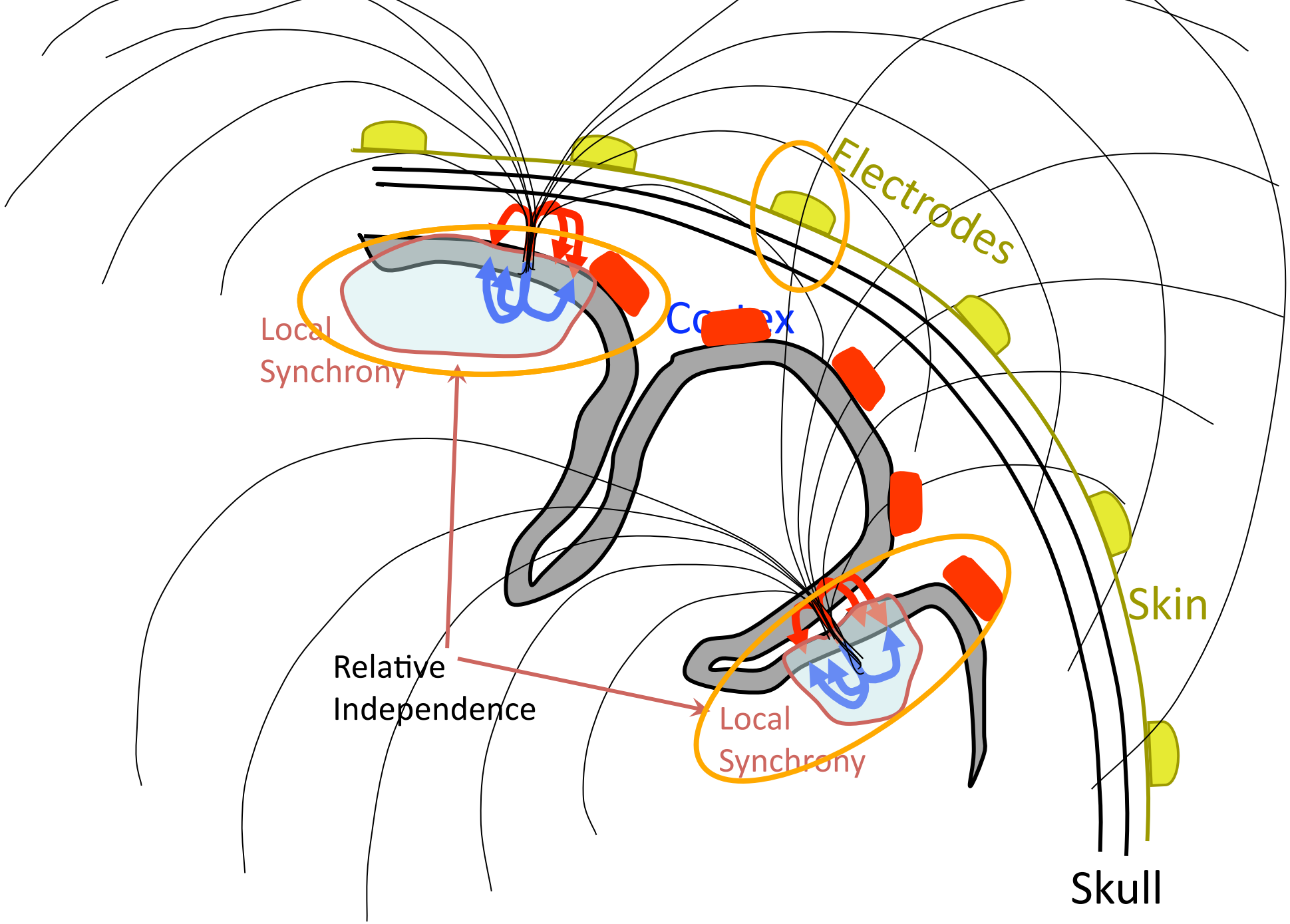
The Electromagnetic Forward / Inverse Problem

R. Ramirez, 2005


EEG Source
Activities
EEG Scalp
Shadows
R. Ramirez, 2005

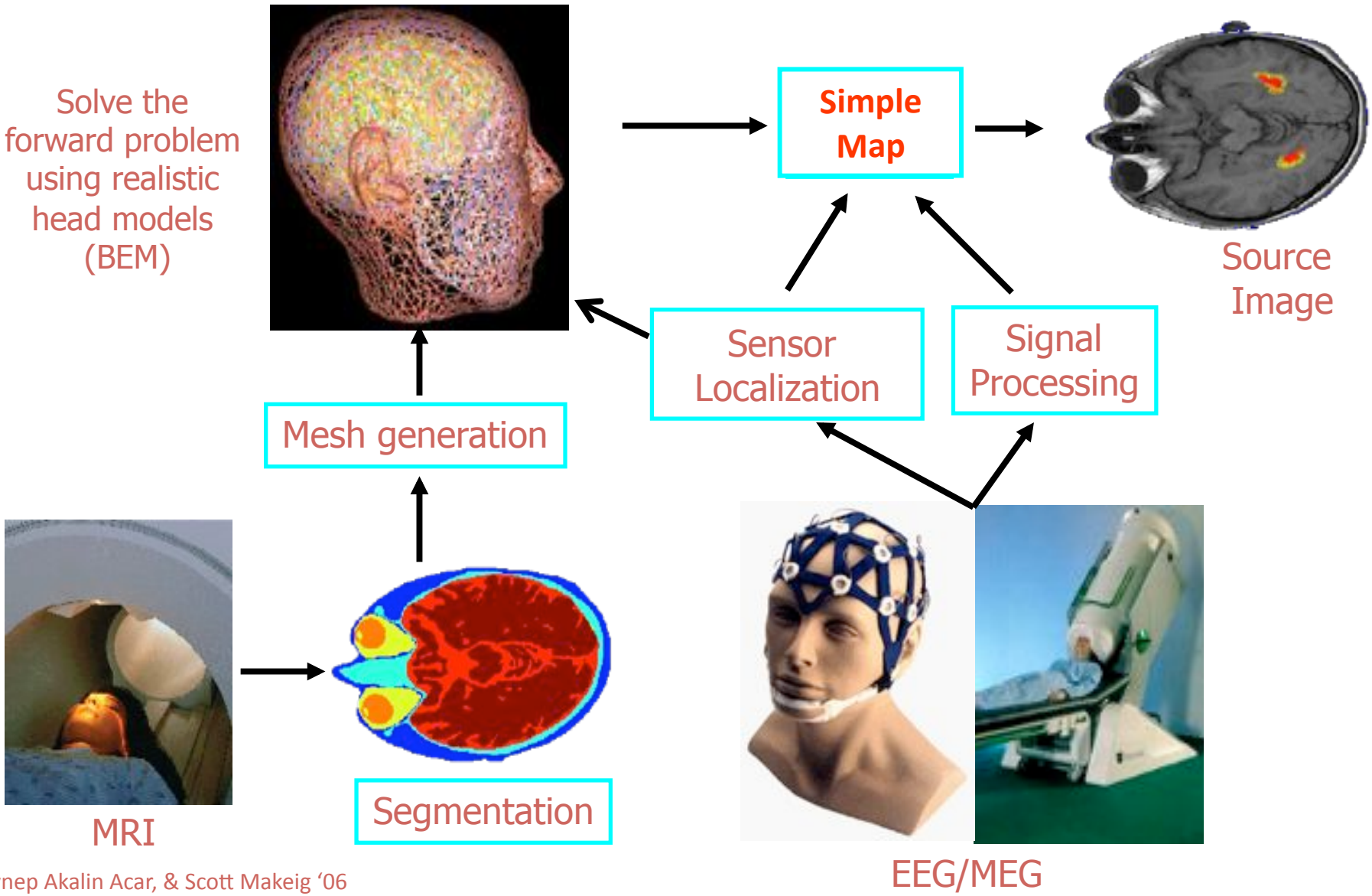
Phase cones (Freeman)

Avalanches (Plenz)



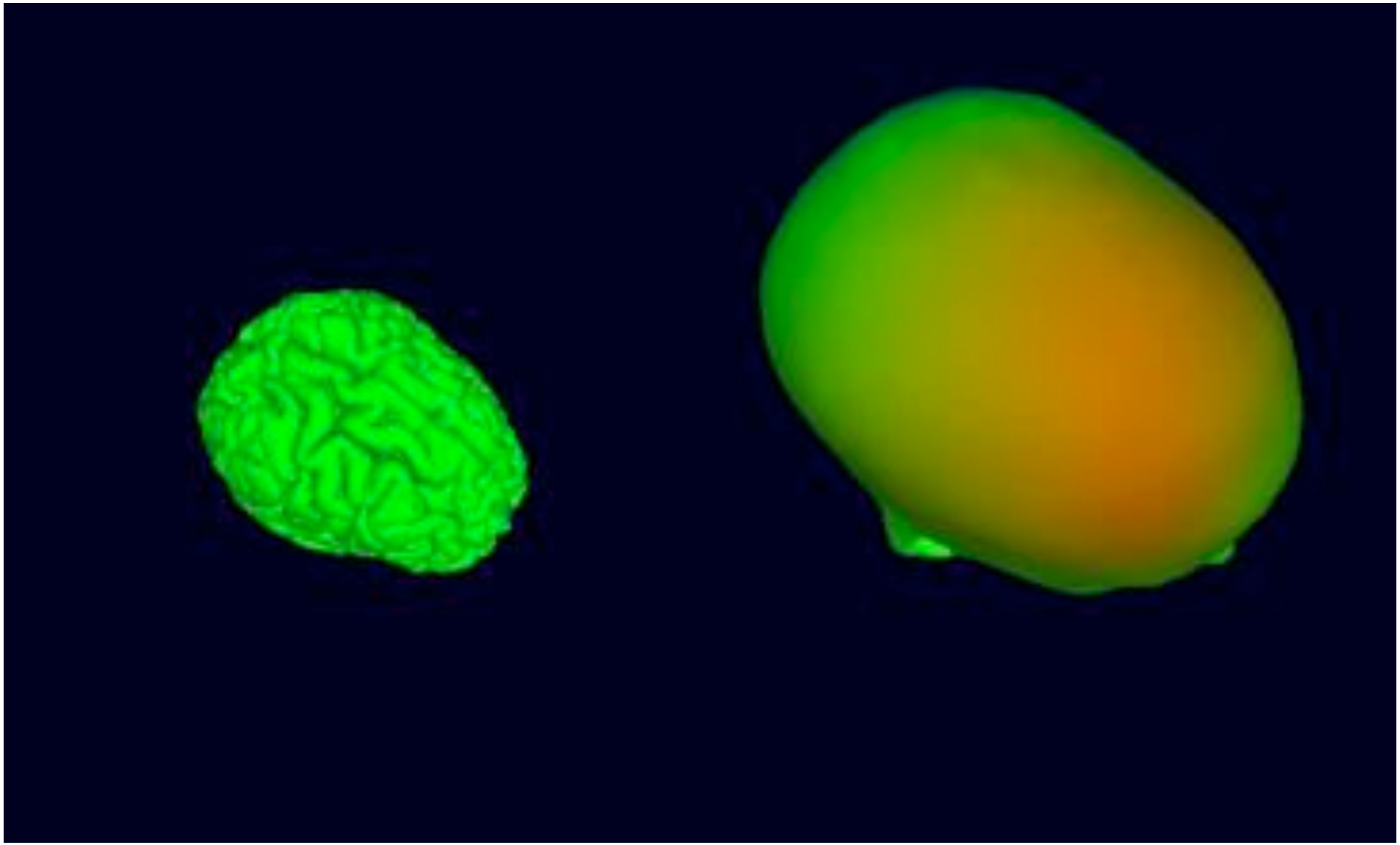
S. Makeig 2007

Electromagnetic source localization using realistic head models – the NFT toolbox



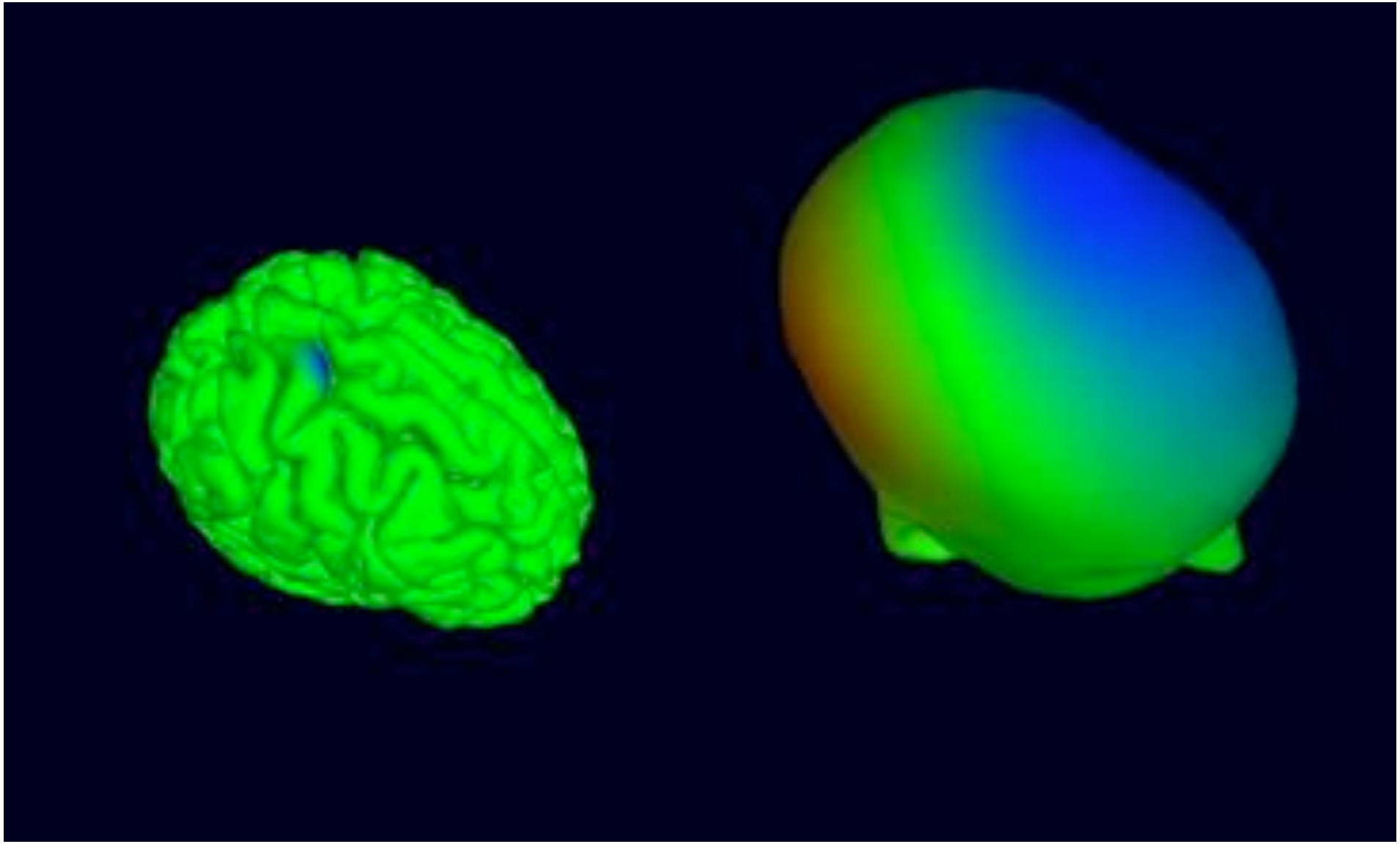
Zeynep Akalin Acar, & Scott Makeig '06

The very broad EEG point-spread function



Akalin Acar & Makeig 2010

The very broad EEG point-spread function

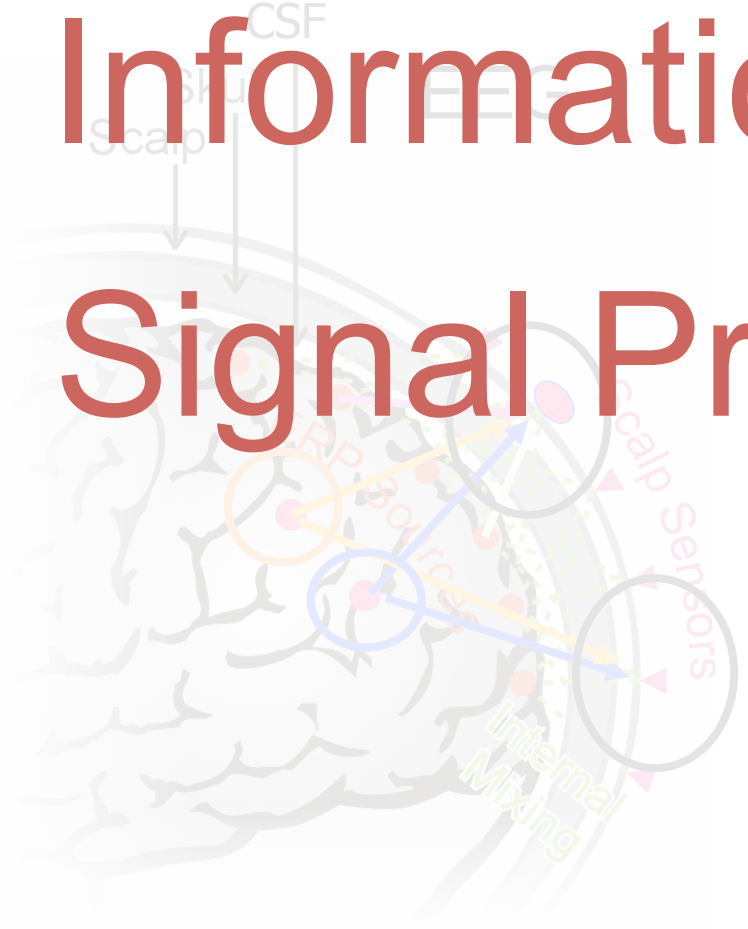


Simulated spatially labile parietal source activity

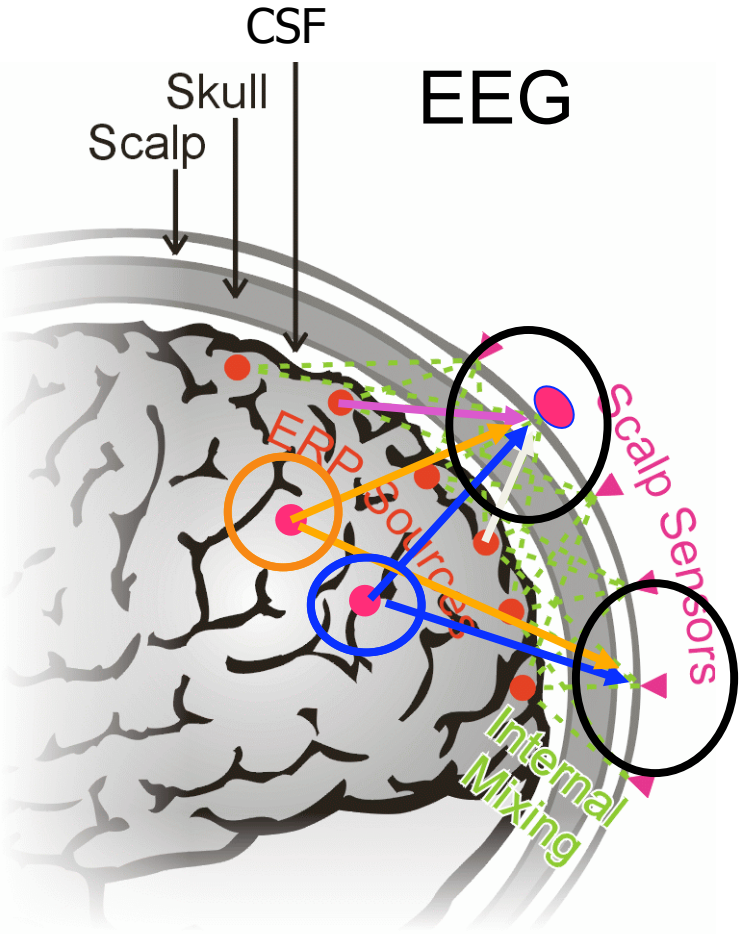
Akalin Acar & Makeig 2010

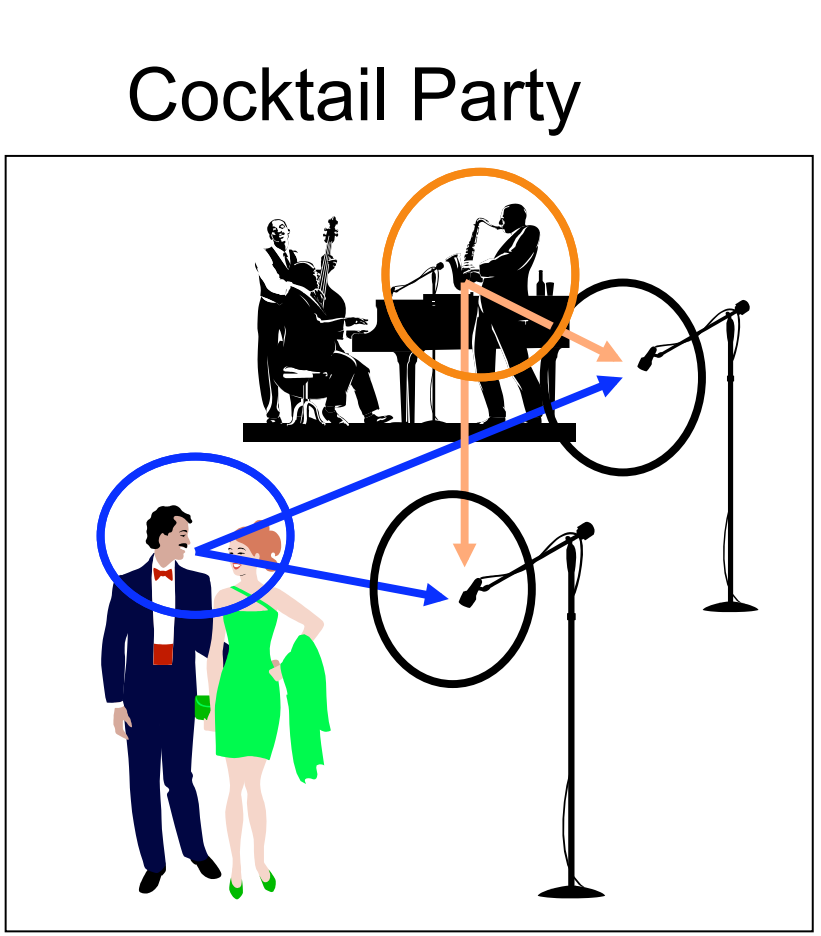
Blind EEG Source Separation by ICA

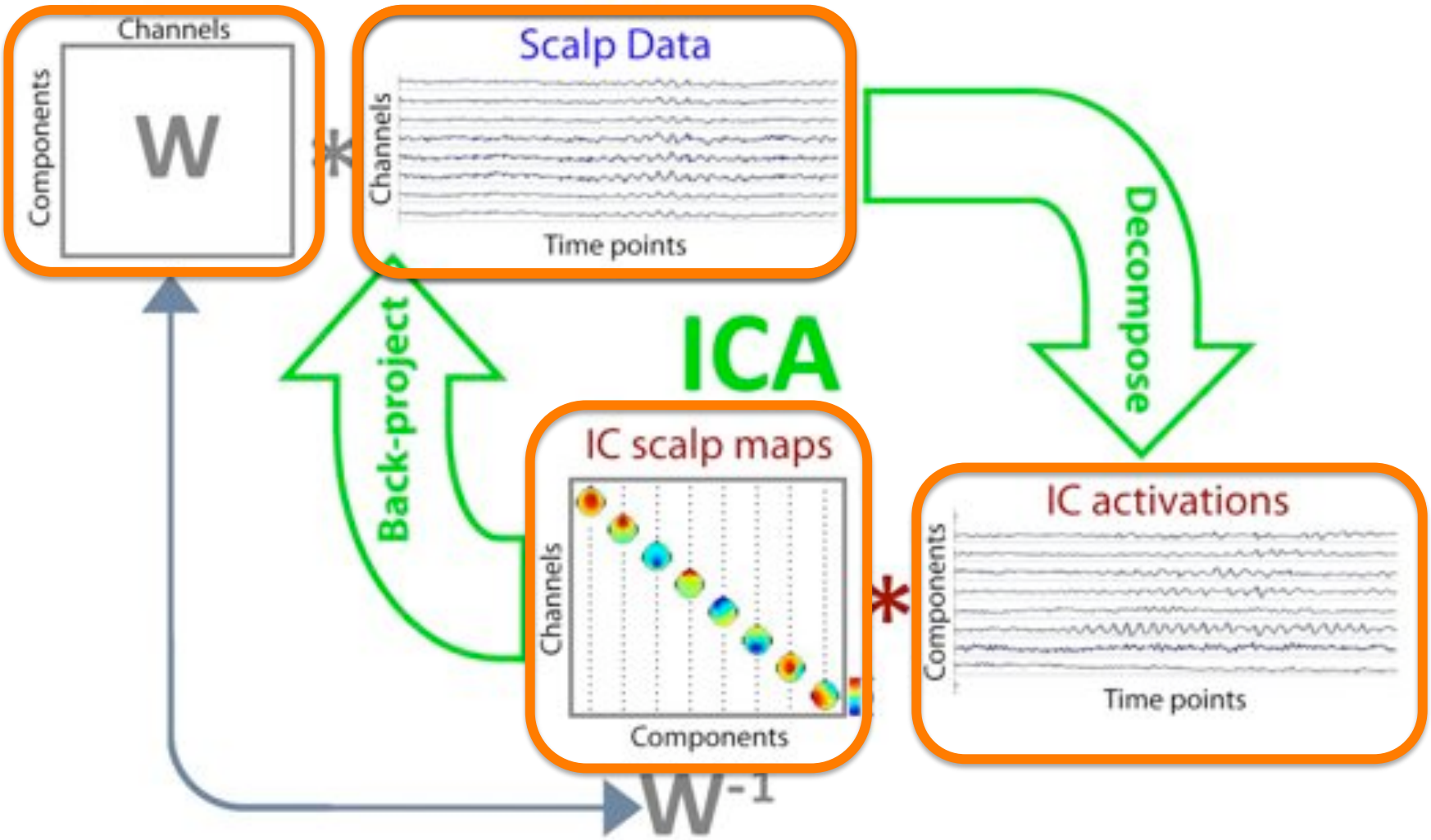
Information-based Signal Processing



Blind EEG Source Separation by ICA






Channels
Components
W
*
Scalp Data
Channels
Time points
Decompose
ICA
Back-project
IC scalp maps
Channels
Components
*
IC activations
Components
Time points
W-1

Independent Component Analysis of Electroencephalographic Data

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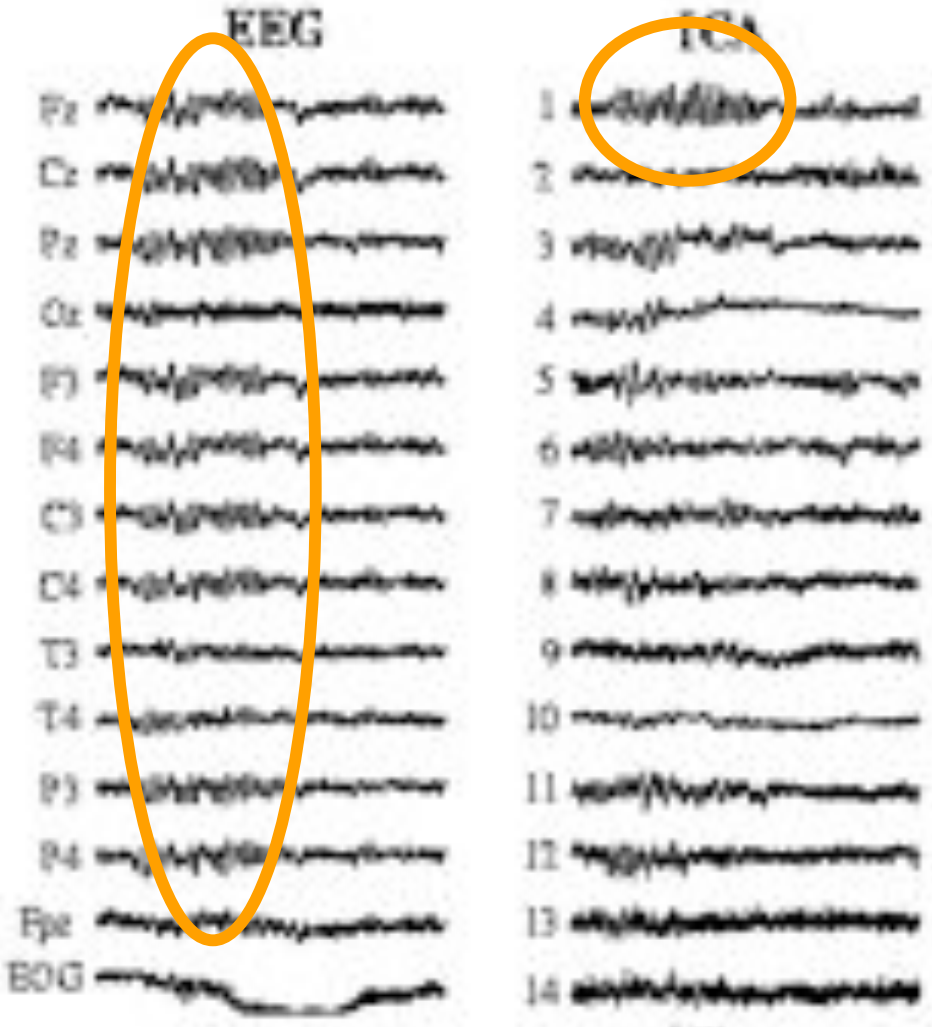
Abstract

Separation of the electroencephalographic (EEG) and electromyographic (EMG) data collected from any point on the human scalp includes activity generated within a large brain area. While spatial smoothing of EEG data by volume conduction does not involve significant time delays, human, suggesting that the Independent Component Analysis (ICA) algorithm of Bell and Sejnowski [1] is suitable for performing blind source separation on EEG data. The ICA algorithm separates the problem of source identification from that of source localization. First results of applying the ICA algorithm to EEG and event-related potential (ERP) data collected during a normal and auditory detection task show: (1) ICA training is insensitive to different random seeds. (2) ICA may be used to segregate obvious artifactual EEG components [eye and muscle noise, eye movements] from other sources. (3) ICA is capable of isolating overlapping EEG phenomena, including alpha and theta bursts and spatially separate ERP components, to improve ICA decomposition. (4) Nonstationarities in EEG and behavioral states can be tracked using ICA via changes in the amount of residual correlation between ICA filtered output channels.

Makeig et al., NIPS, 1995

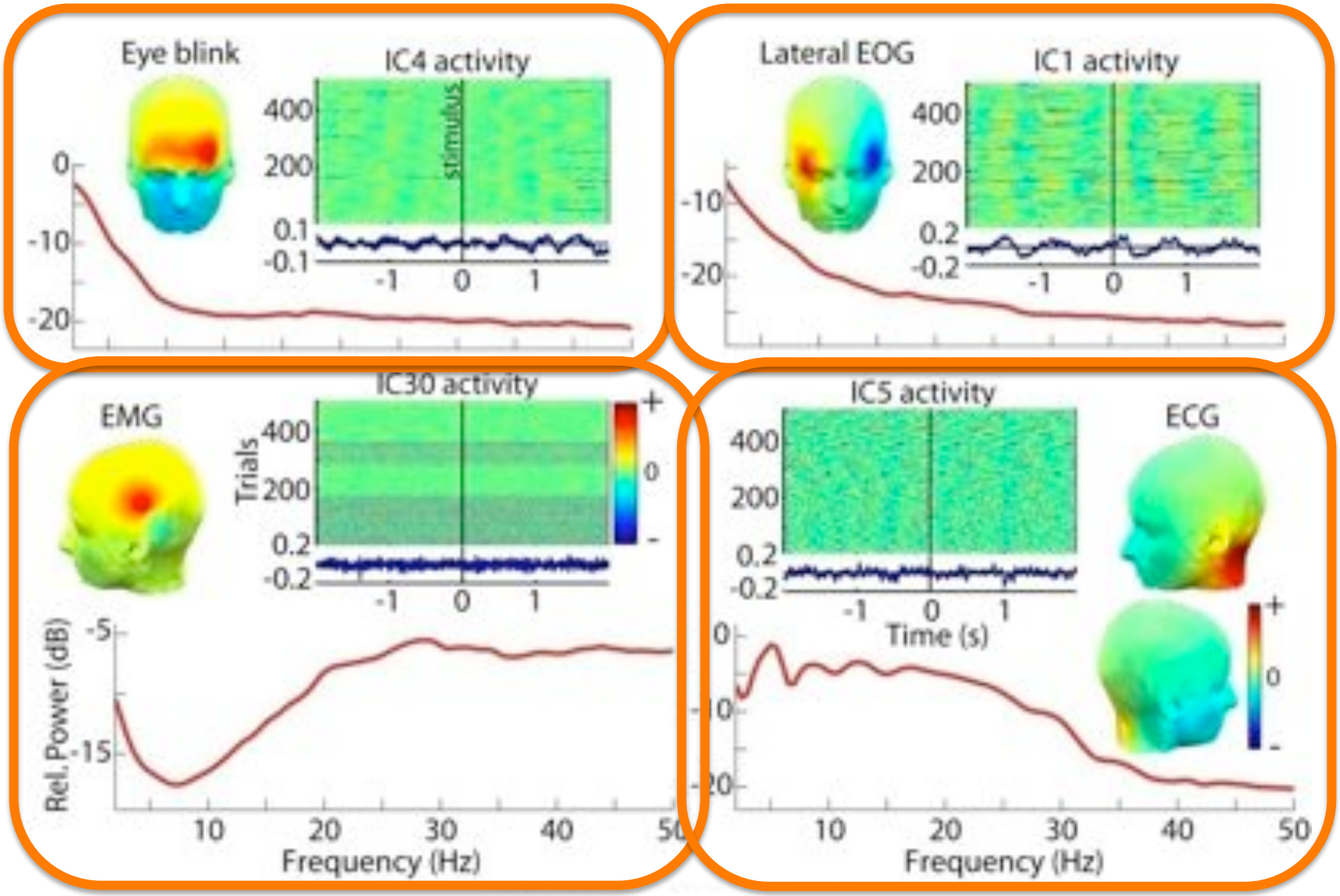


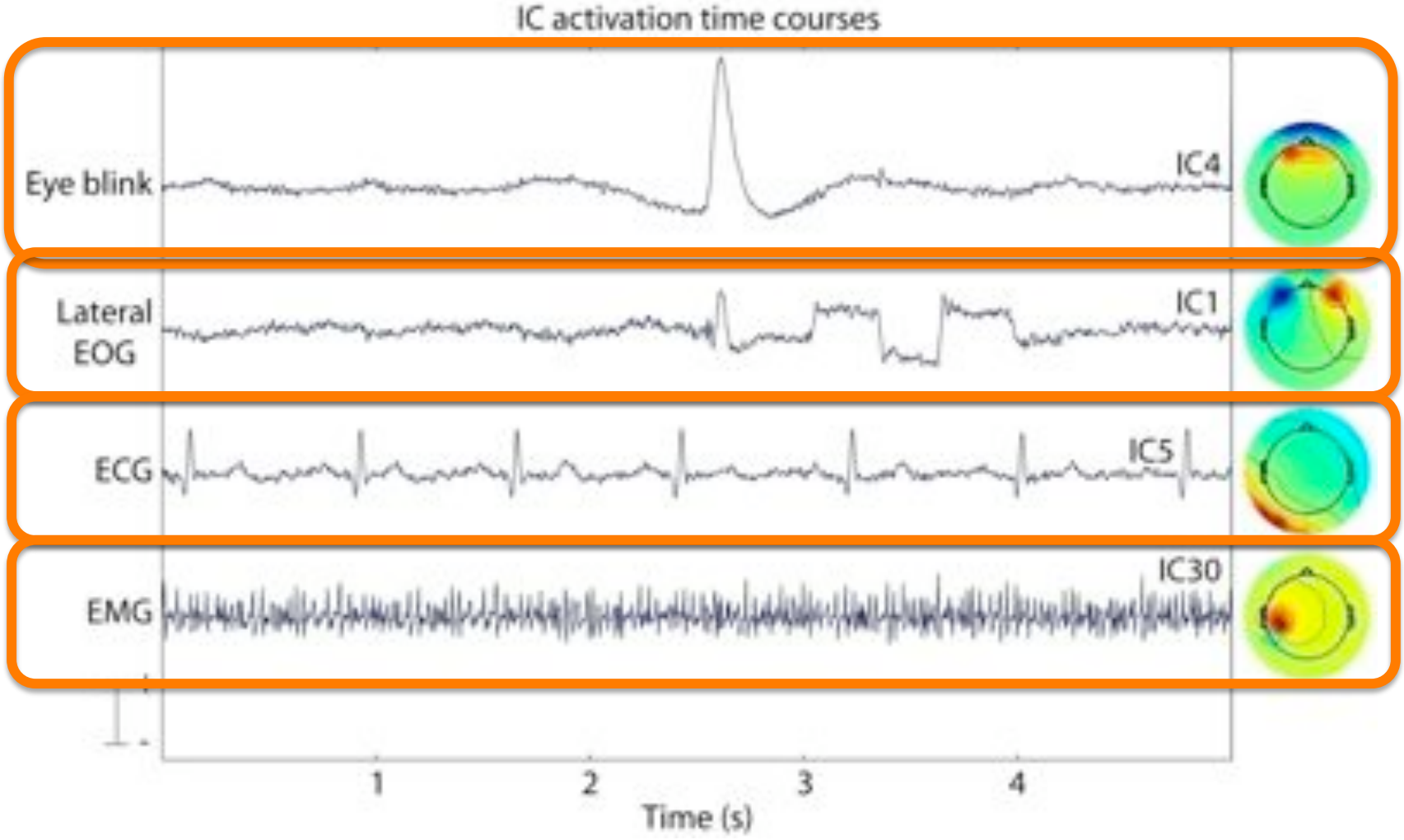
S. Makeig et al. (1995)

1

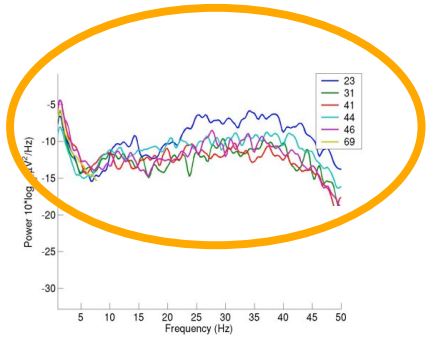
"ICA may be used to segregate obvious artificial EEG component (line and muscle noise, eye movements) from other sources."

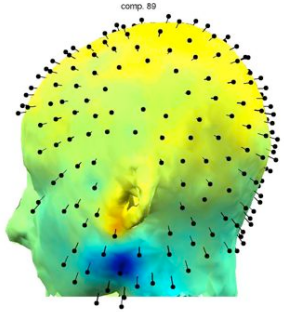
- Makeig et al., 1996

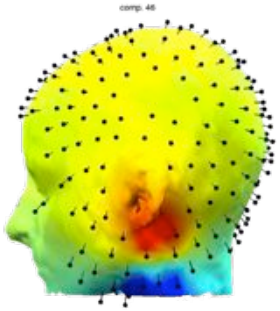

Eye blink
IC4 activity
stimulus
400
200
0.1
-0.1
0
-10
-20
-1
0
1
Lateral EOG
IC1 activity
400
200
0.2
-0.2
-10
-20
EMG
IC30 activity
Trials
+
0
-
Rel. Power (dB)
-5
-15
10
20
30
40
50
Frequency (Hz)
IC5 activity
ECG
Time (s)

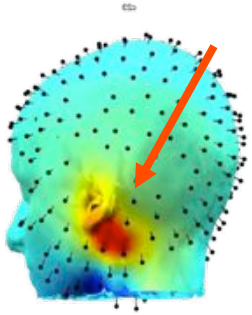

IC activation time courses
Eye blink
IC4
Lateral EOG
IC1
ECG
IC5
EMG
IC30
1
2
3
4
Time (s)

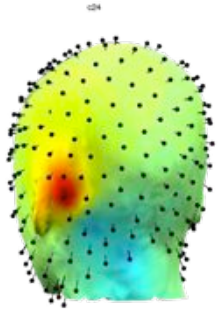
Independent muscle components

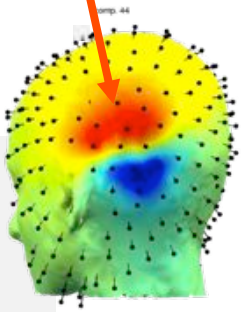


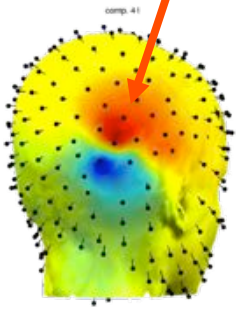


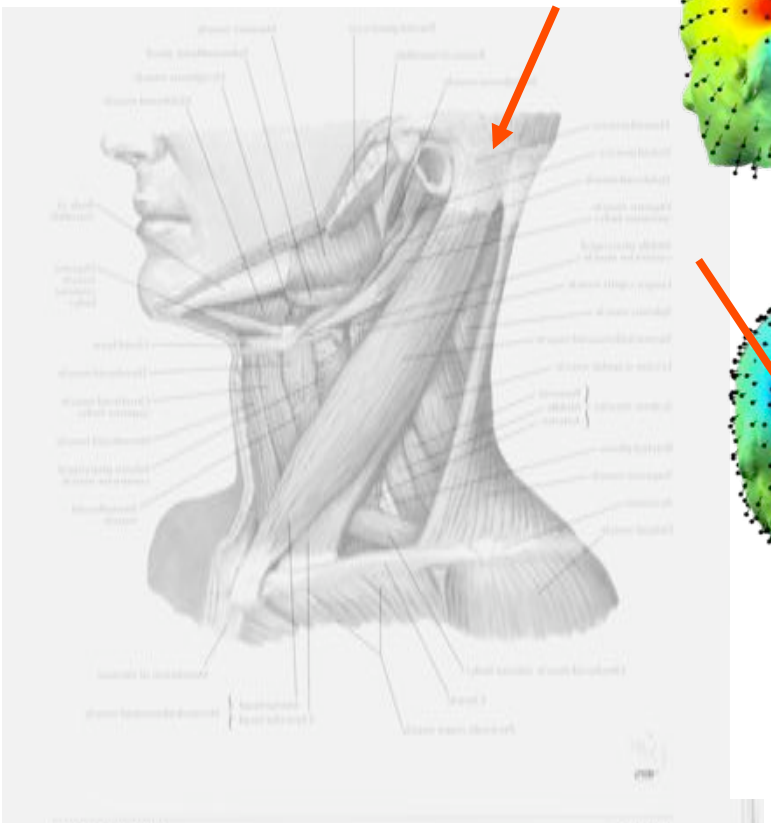


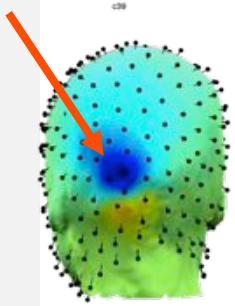


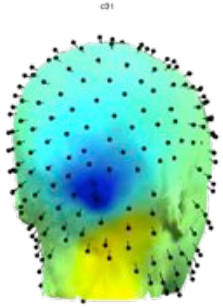


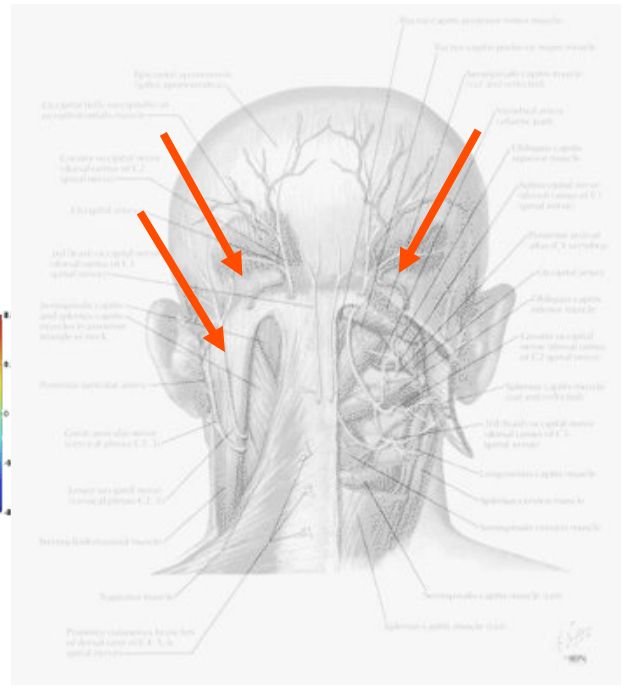












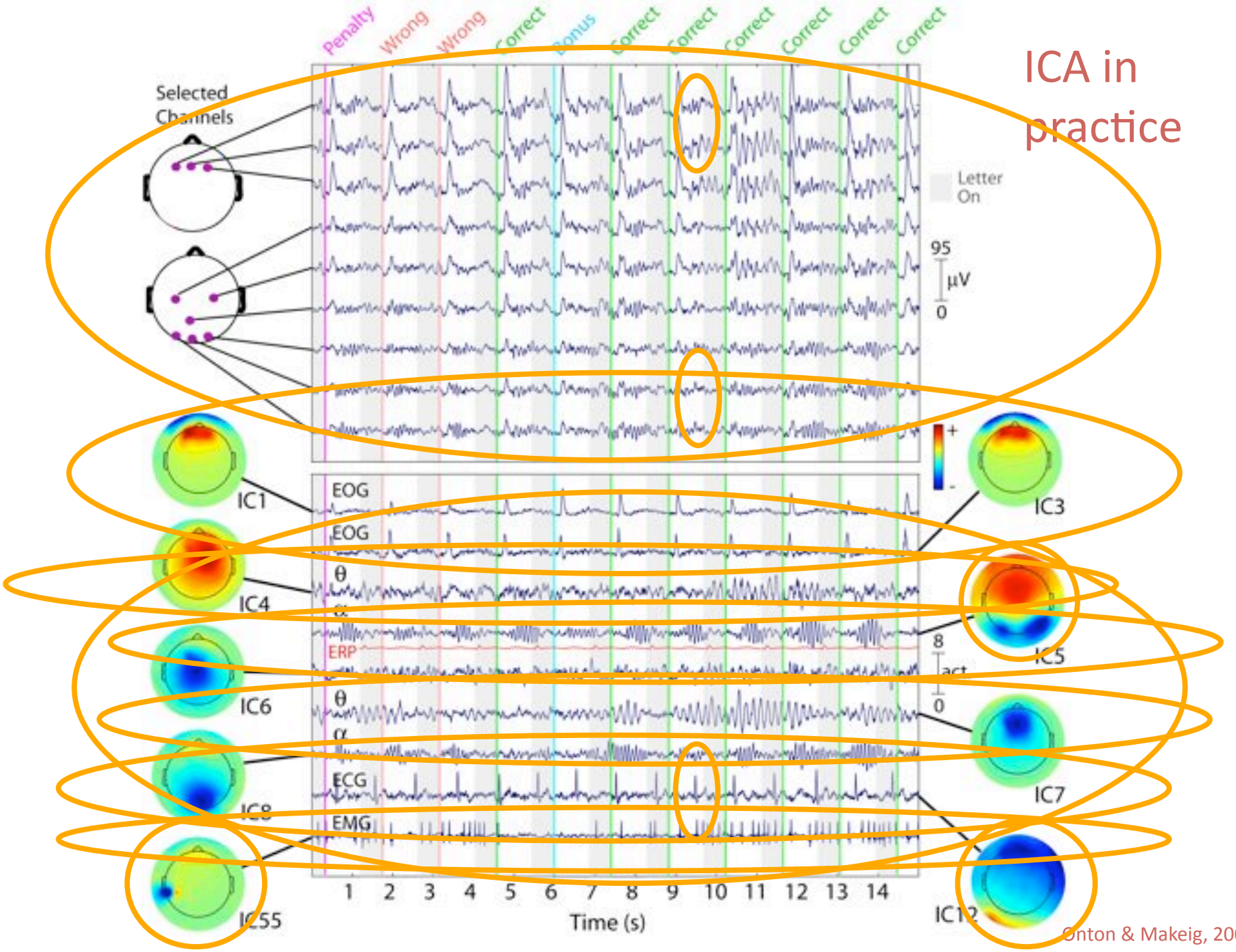
S. Makeig, 2005

2

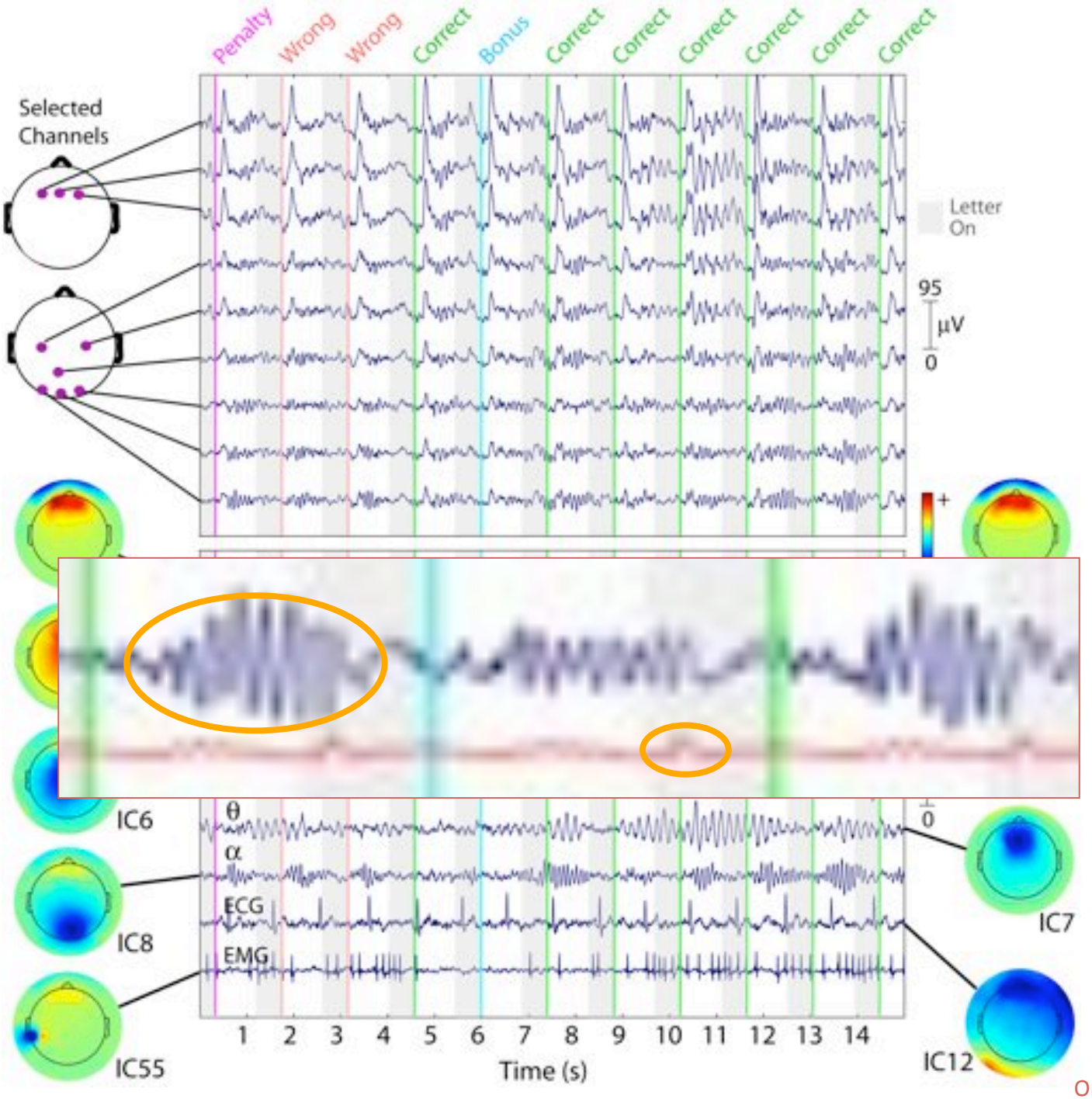
"ICA is capable of isolating overlapping EEG phenomena including alpha and theta bursts and spatially separable ERP components, to separate [ICs]."

- Makeig et al., 1996

ICA in practice



Onton & Makeig, 2006



Onton, Makeig (2006)

3

"ICA training is insensitive to different random seeds,"

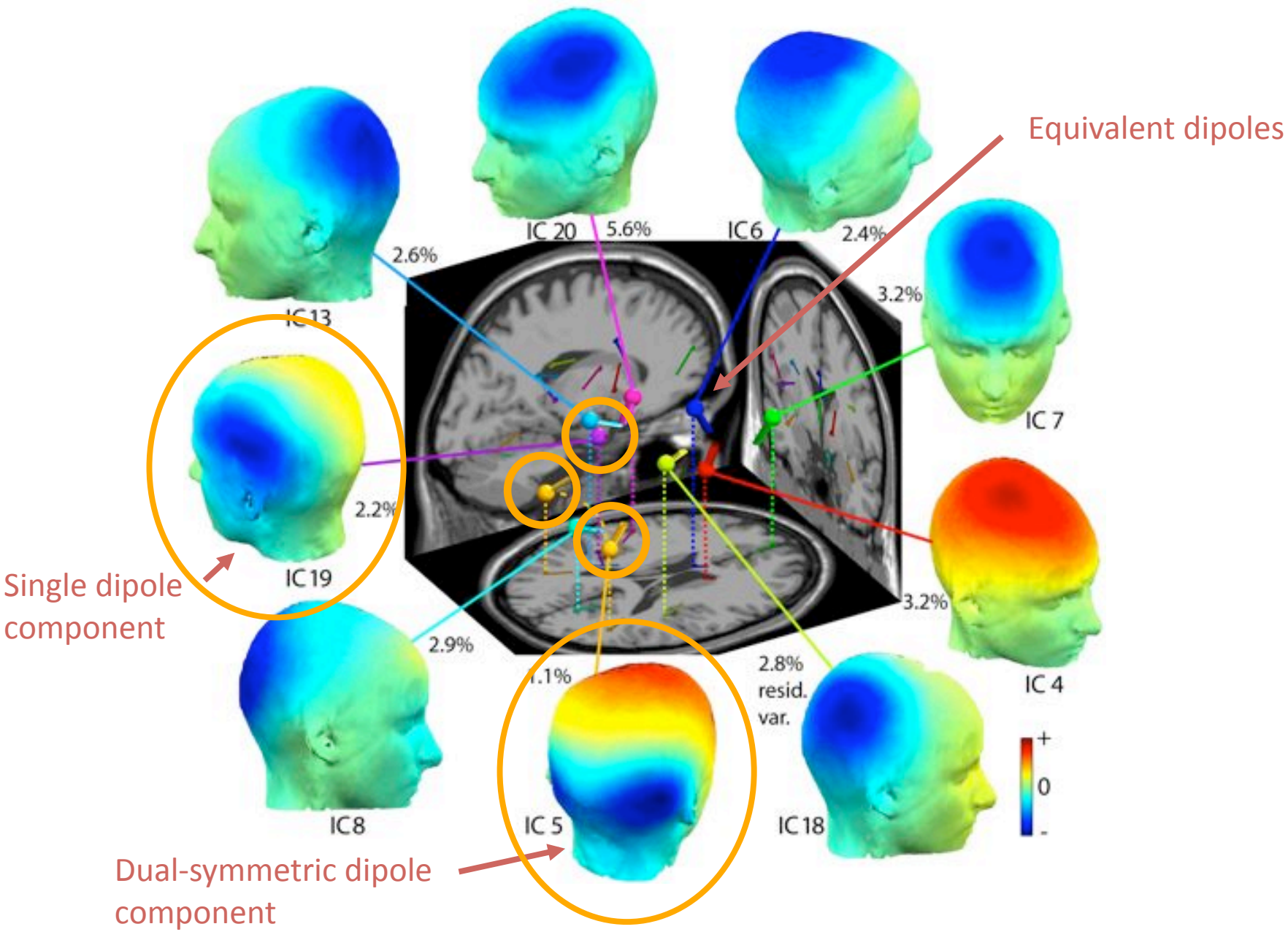
… and can separate out independent components of data with hundreds of channels.

- Makeig et al., 1996

4

Brain-based, ‘dipolar’ independent components of EEG data are projections of single (dual) cortical patches.

Independent cortical components

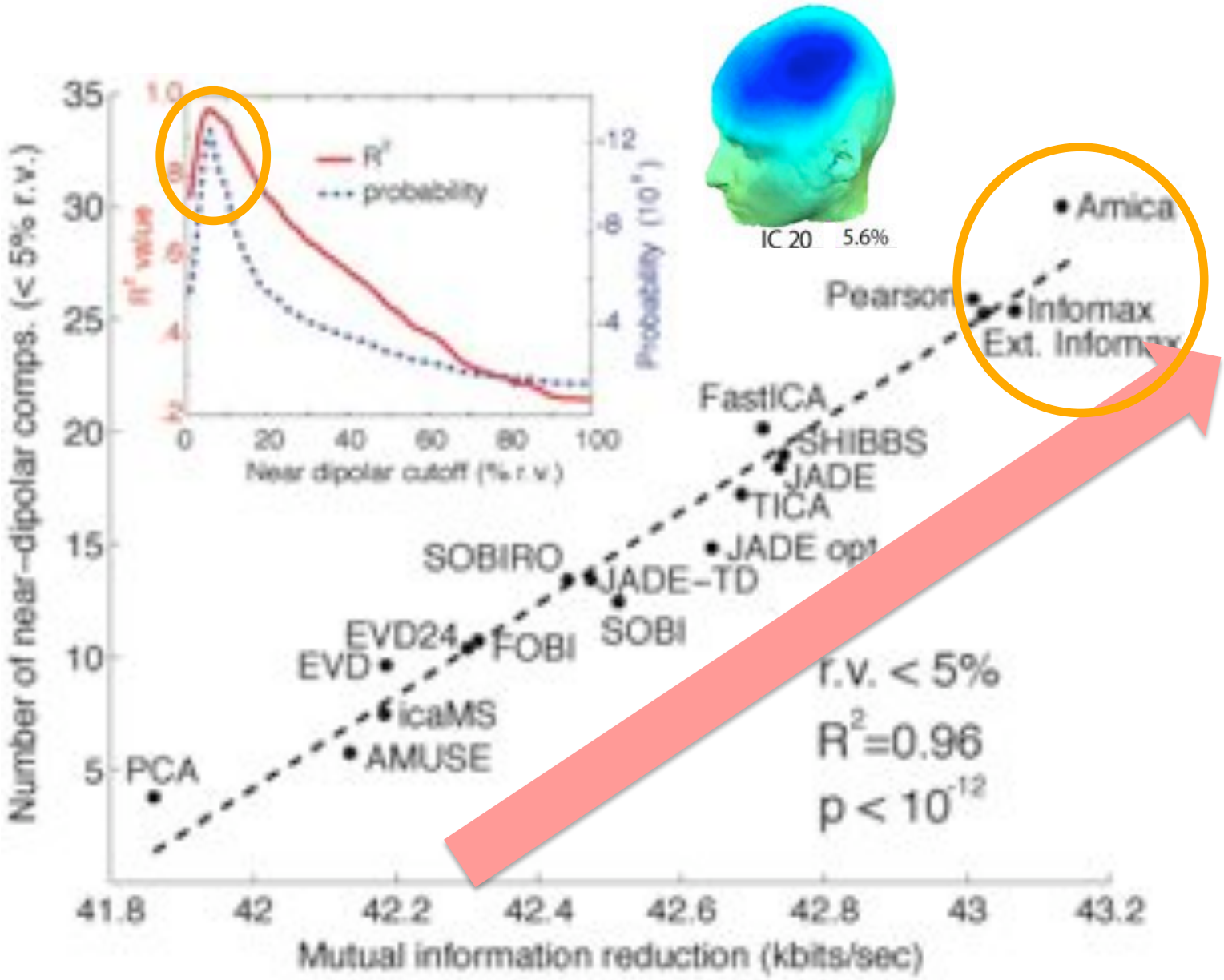


Equivalent dipoles

Single dipole component

Dual-symmetric dipole component

Julie Onton & S. Makeig (2006)



A. Delorme, J. Palmer, S. Makeig, 2009

THUS → ICA (BSS) decompositions that

find components whose time courses are **more independent**

→ also find **more** components whose scalp maps are **'dipolar'**!

Thus, the two approaches to

constraining the EEG inverse problem,

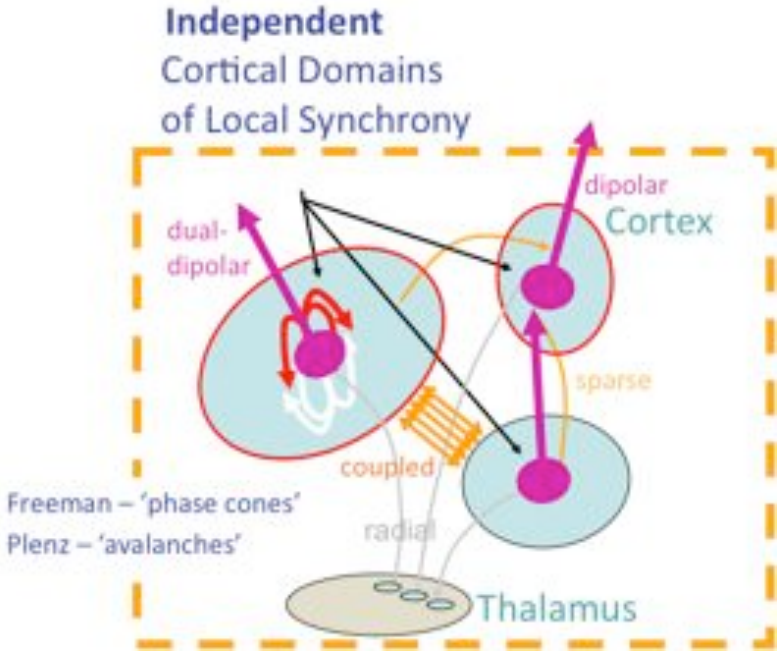
biophysical and ***statistical***,

are directly interlinked.

S. Makeig, 2010

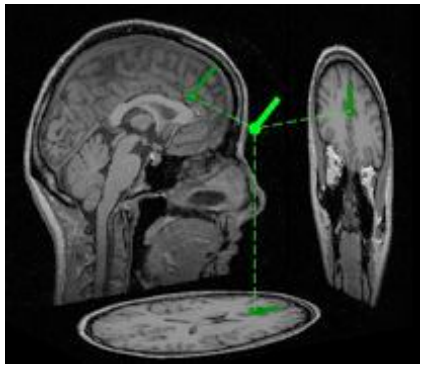
Why?

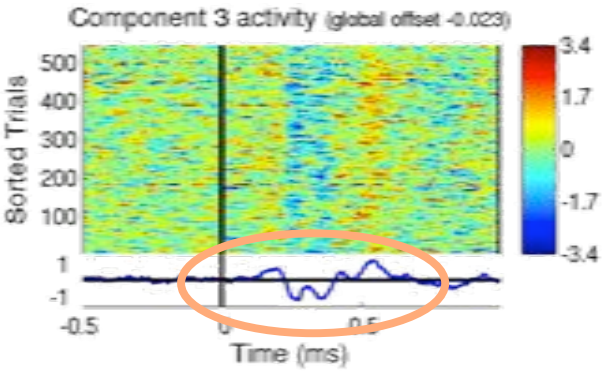
Very likely because the physiological assumptions motivating the use of ICA for EEG data are *substantially* correct…

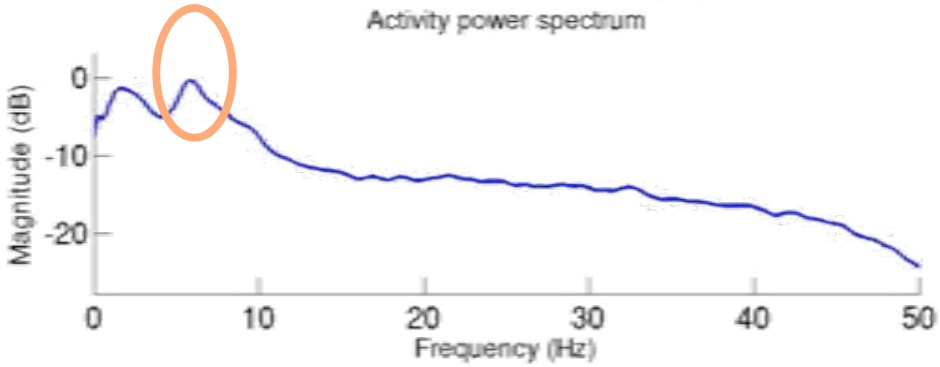


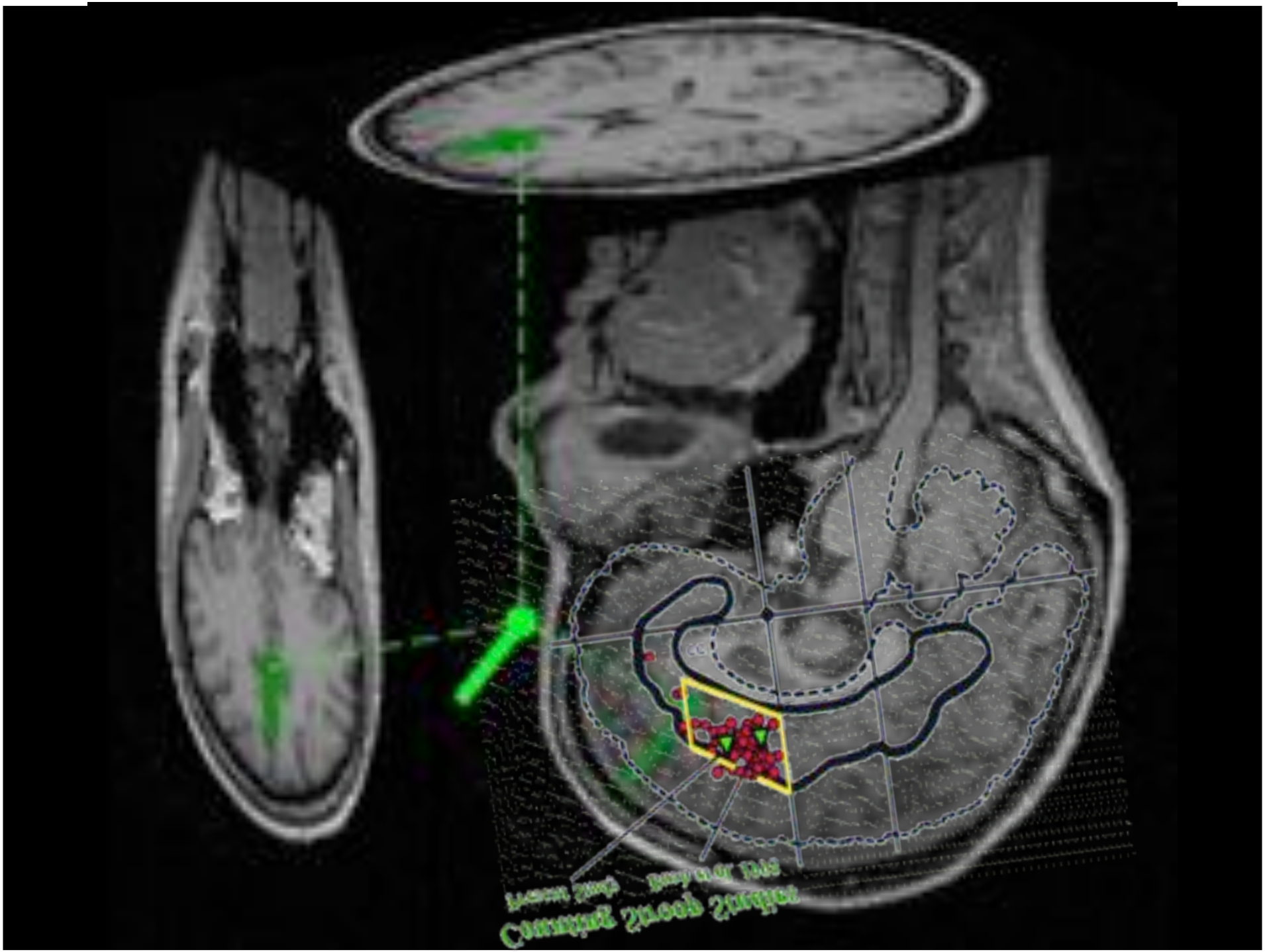
S. Makeig (2007)

Frontal Midline Theta Process

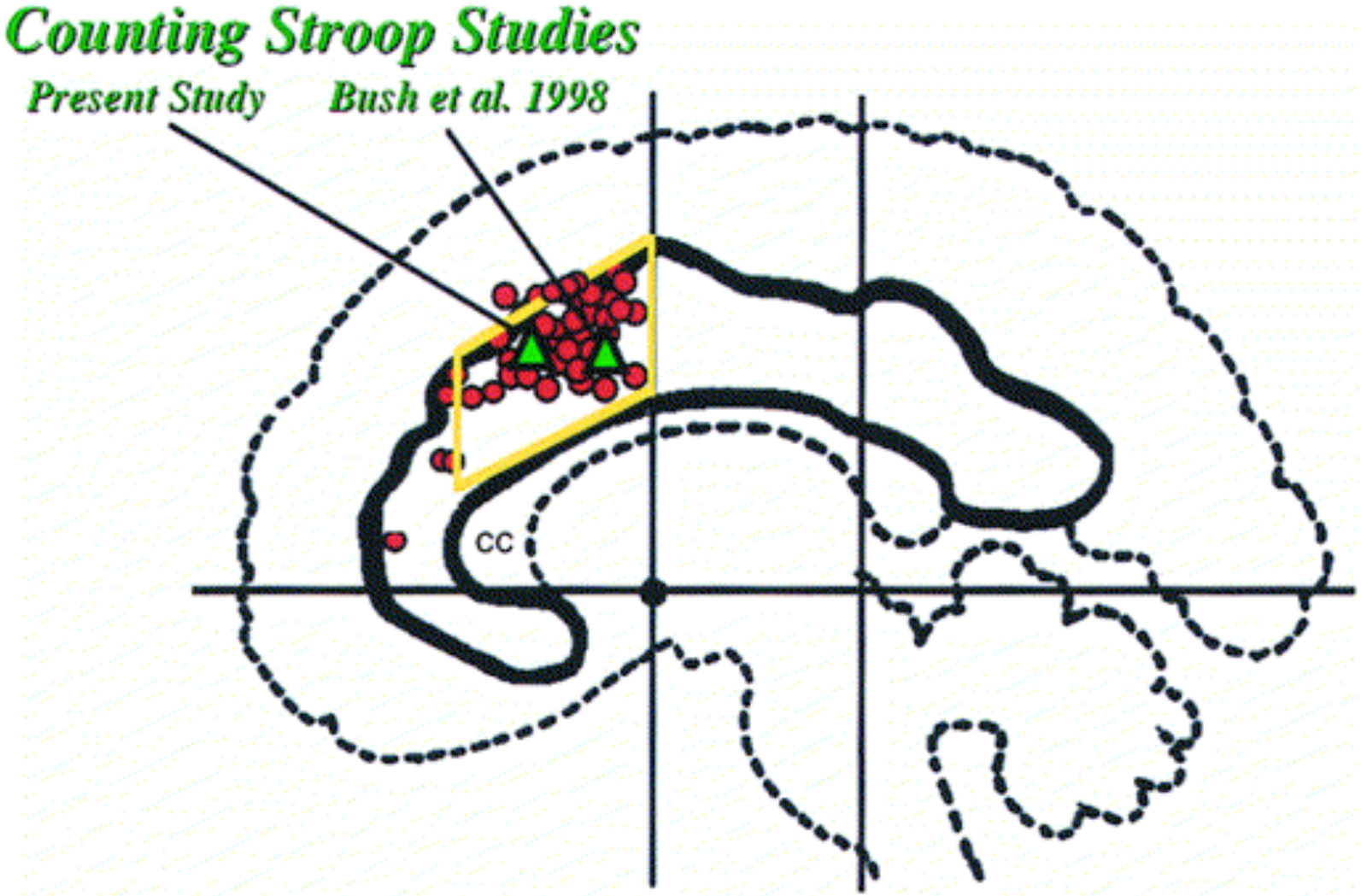








Anterior Cingulate Cognitive Division



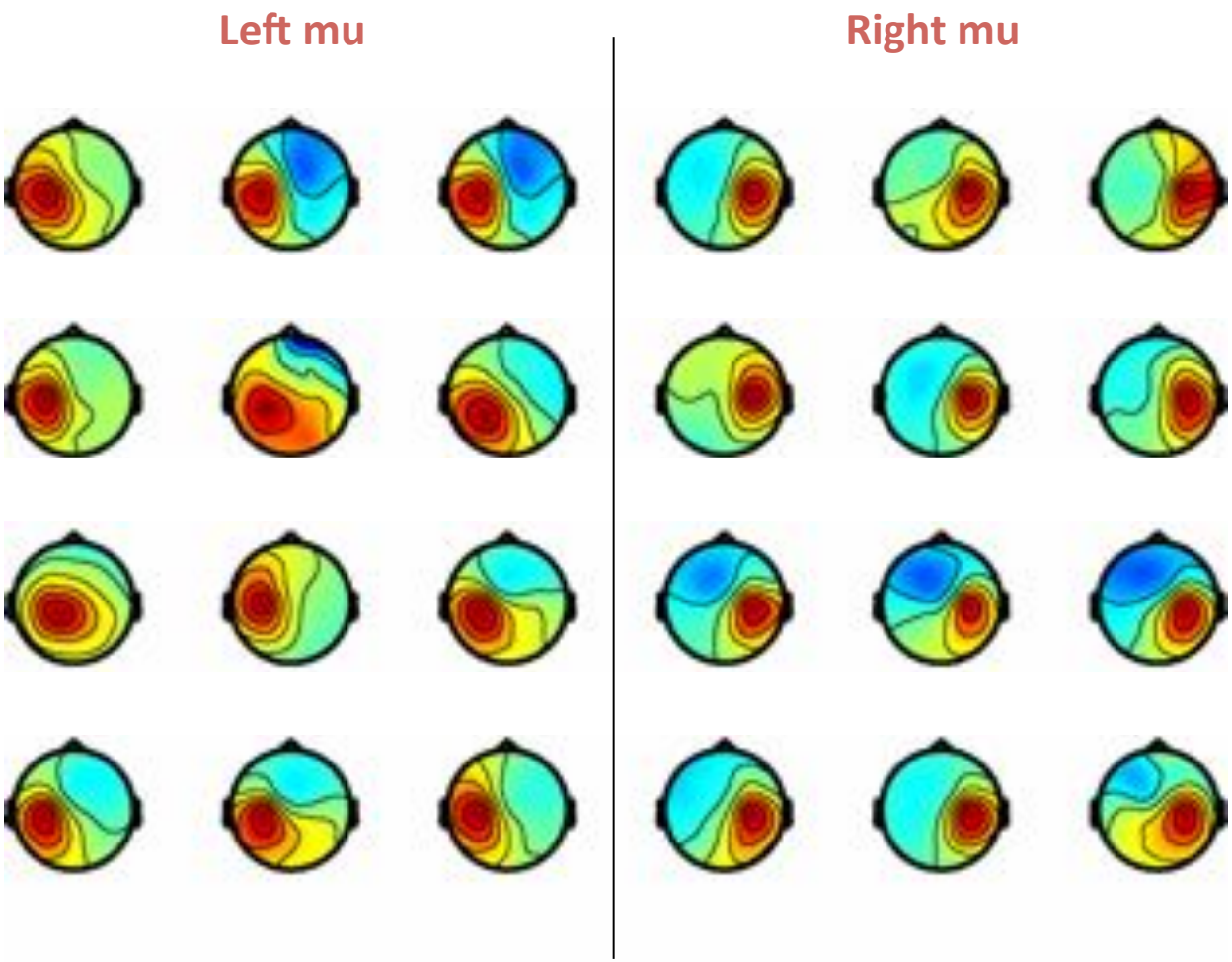
Bush et al., 1999

5

Similar independent components tend to reappear in different subjects performing the same task.

S. Makeig, 2007

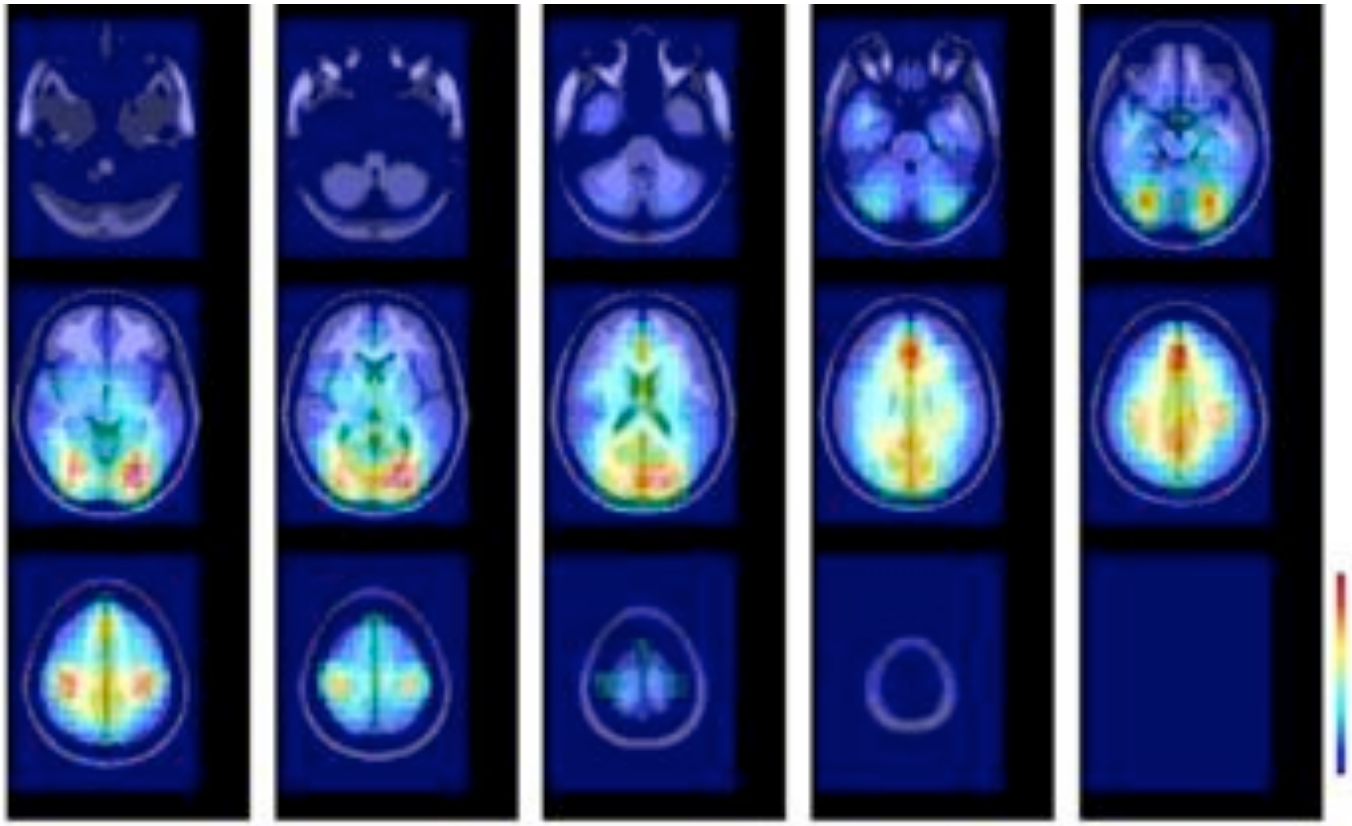
Clustering ICA components



Makeig et al., *2003*

Equivalent dipole density

Visual Working Memory



Sternberg letter memory task

Onton et al., 2005

Onton et al., ‘05

6

Independent components of EEG data tend to be **functionally** independent **–**

changes in their activity patterns tend to reflect **'top-down' changes** in **cognitive state** and/or **cognitive appraisal.**

S. Makeig, 2007

Embodied Cognition & Agency

Brain processes

have evolved and function

*to optimize the **outcome***

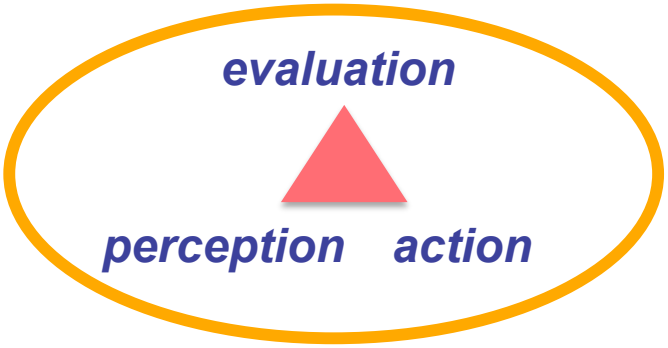
*of the **behavior***

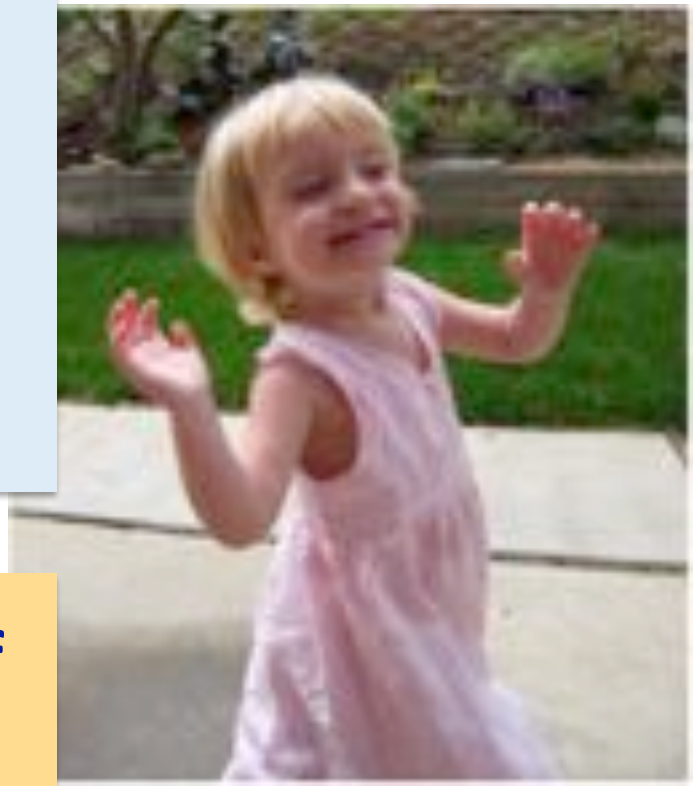
the brain organizes

in response to

perceived challenges

and opportunities.



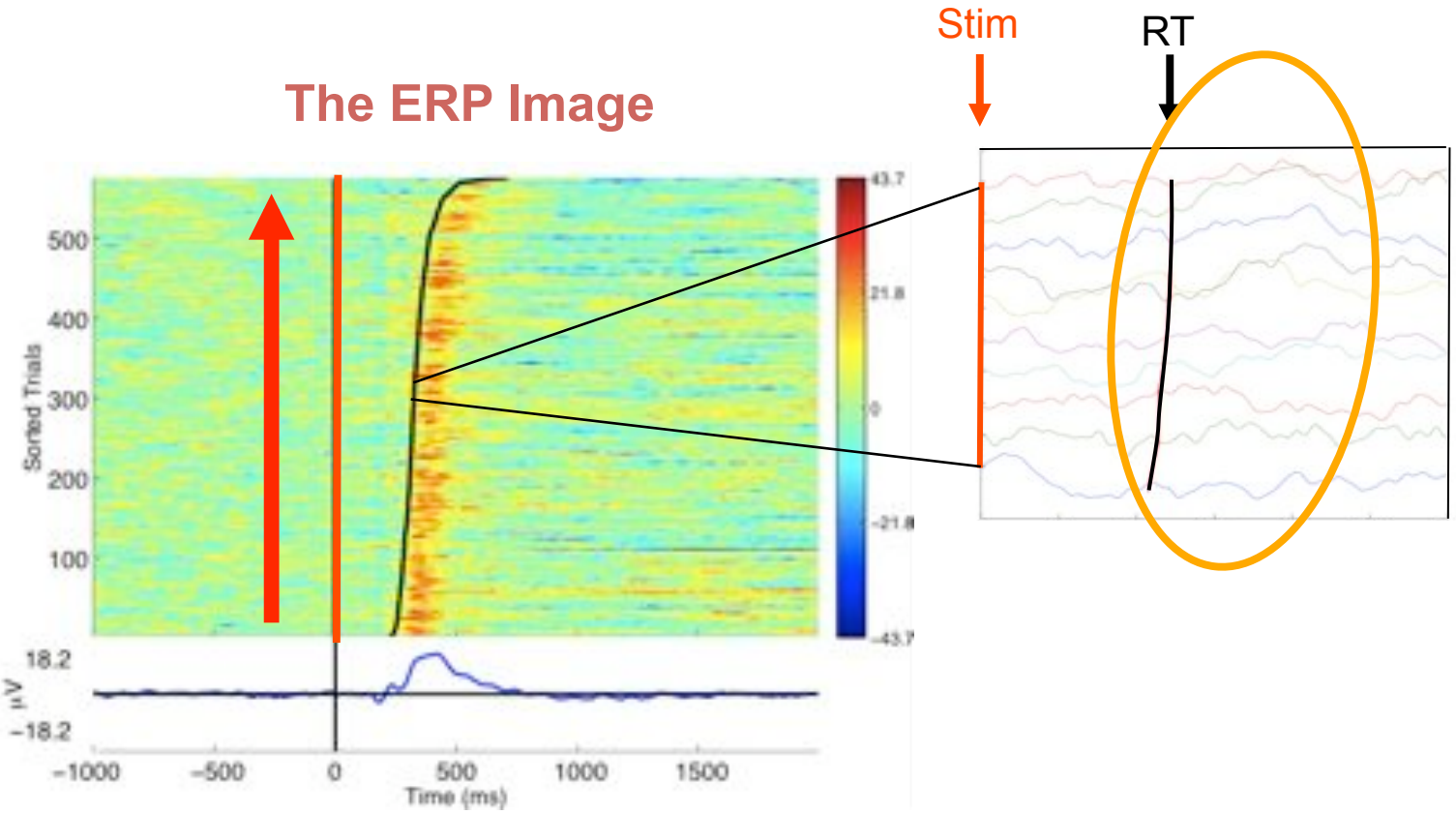


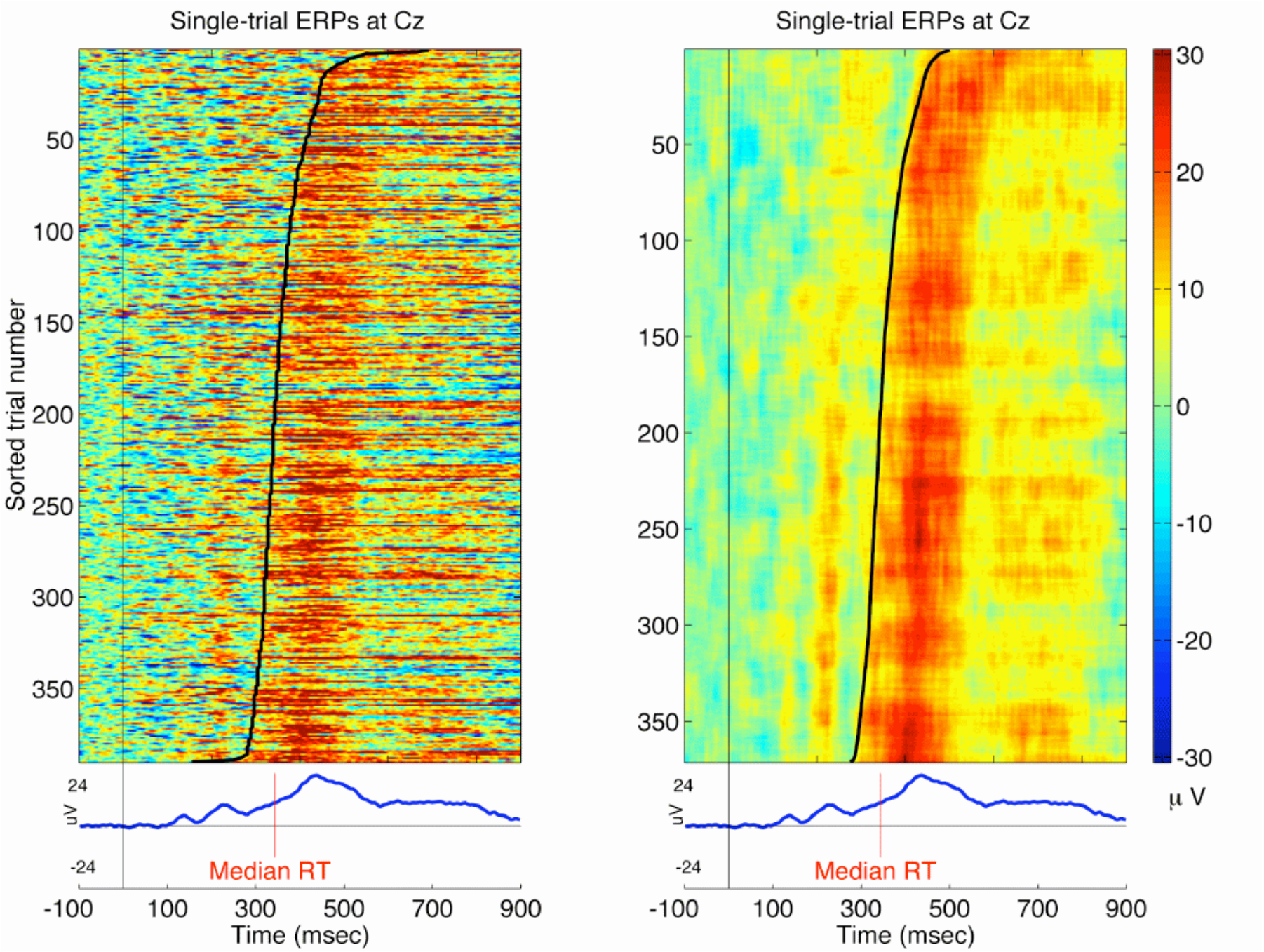
Brains meet the challenge of the moment!

S Makeig 2010

Collections of single trials, even at the source level, are regular, **but in multiple ways** – so they *appear* noisy!

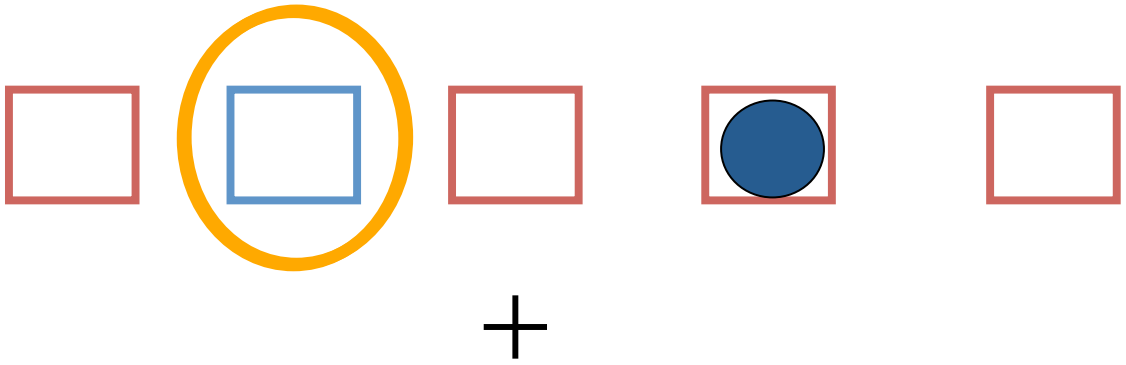
The ERP Image





Jung et al., *Human Brain Mapping*, 2001.

Visual Selective Attention Task

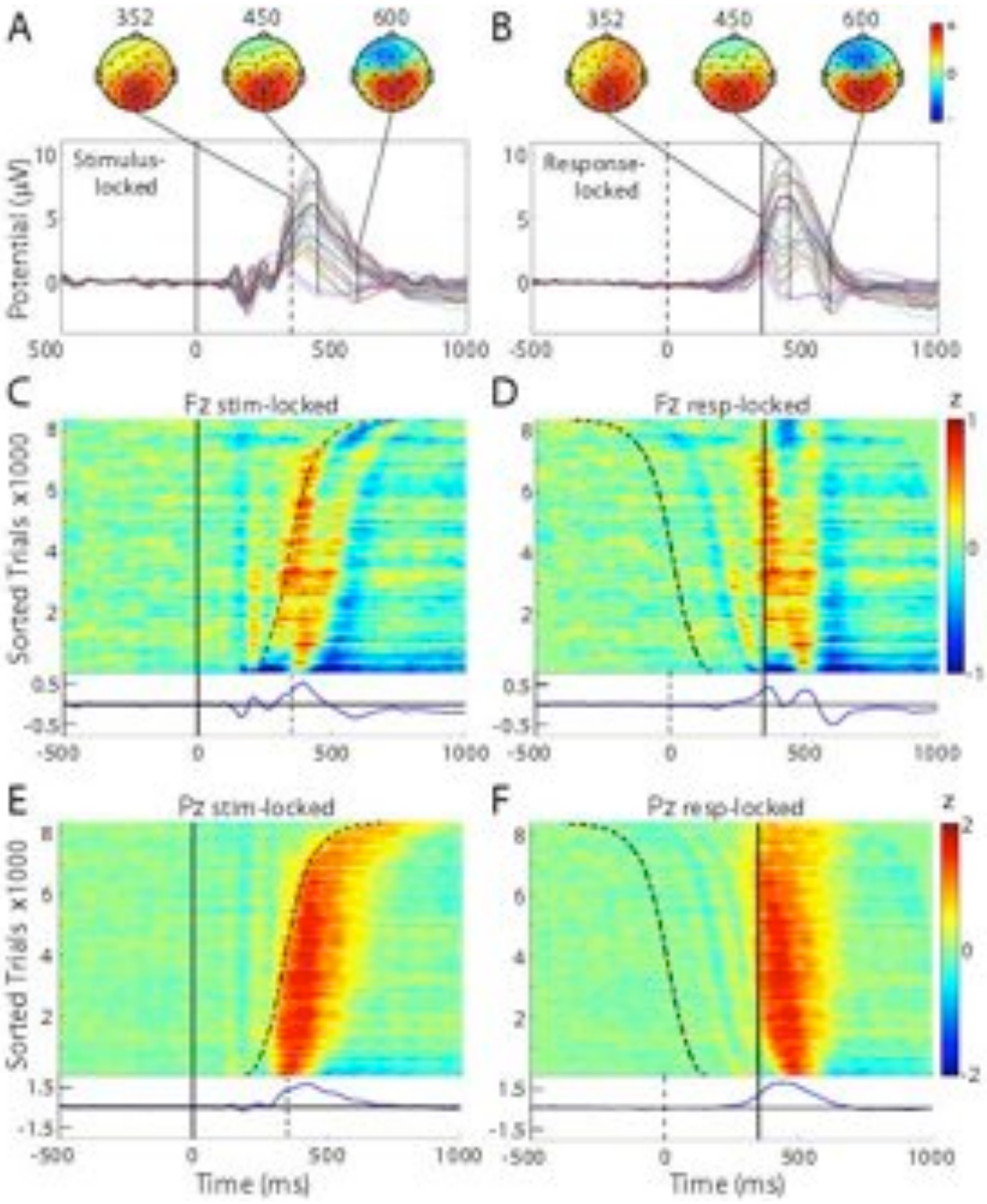


15 subjects

S. Makeig (2001)

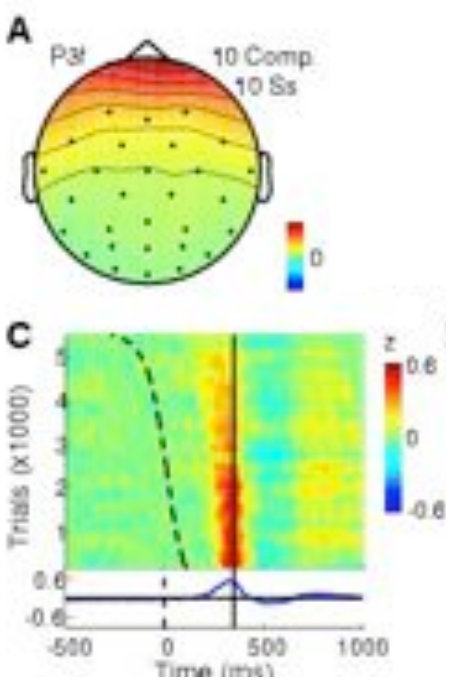
timtopo()

erpimage()



S Makeig et al., *PLOS Biology* 2004

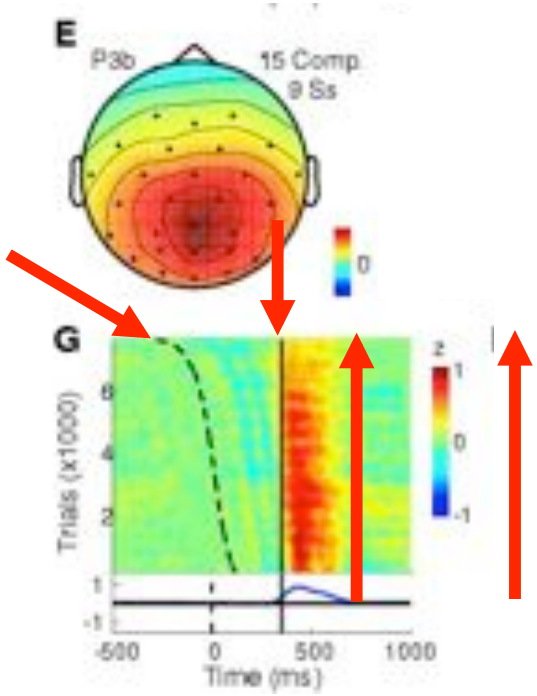
Two of nine IC Clusters of Target-Stimulus Response-Locked Data Epochs



P3f

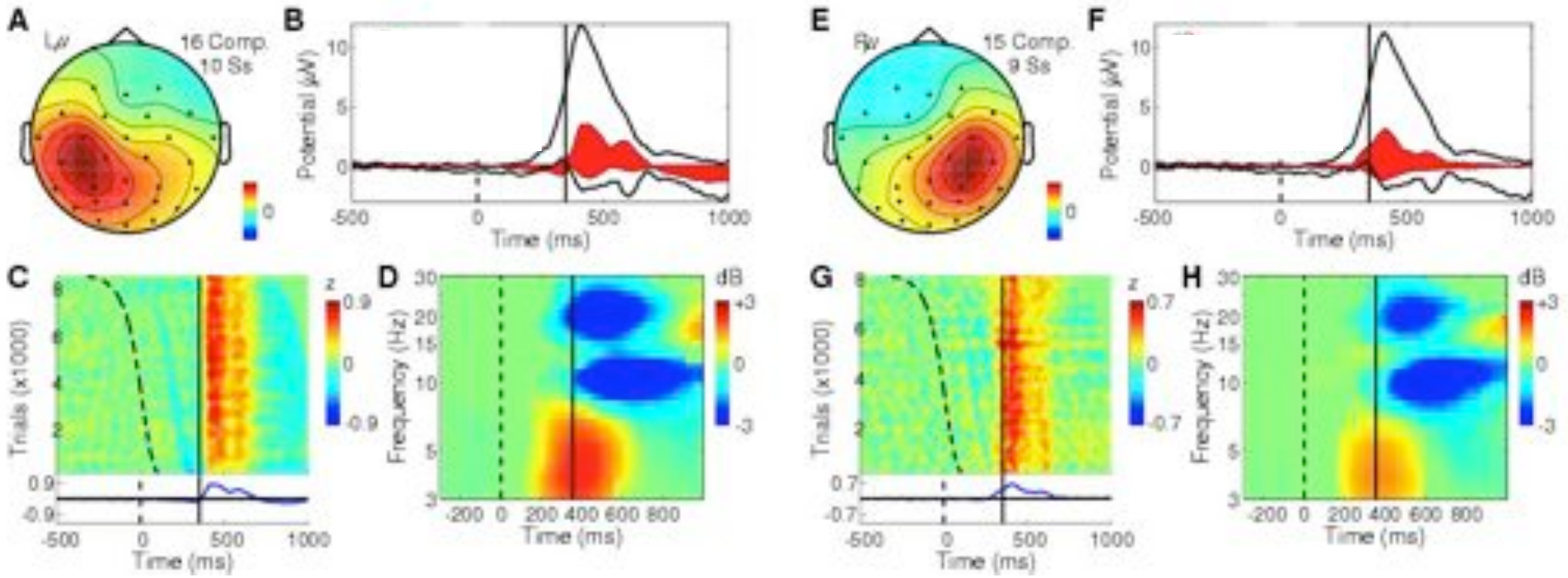
topoplot()

erpimage()



P300
(P3b)

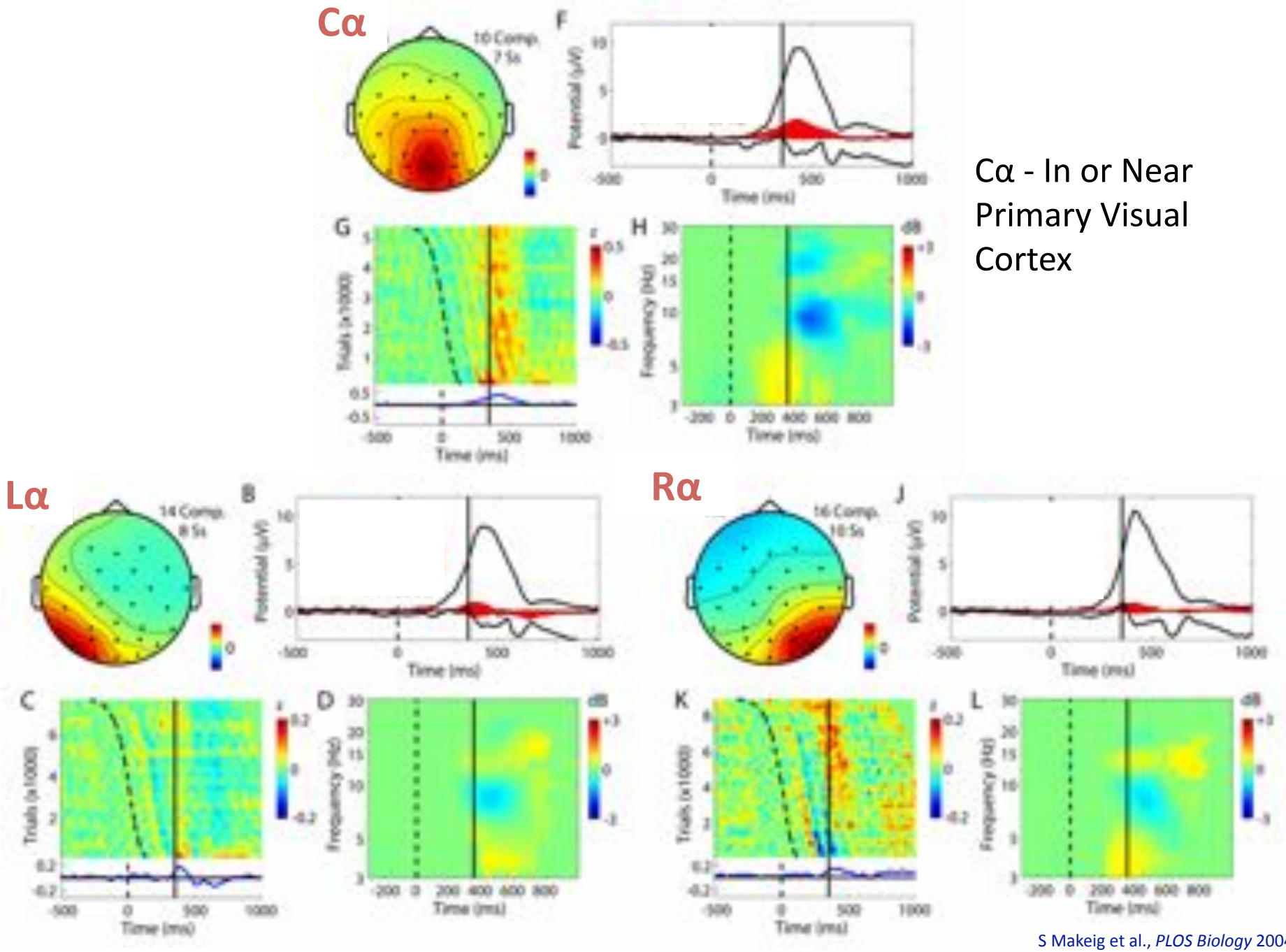
S Makeig et al., *PLOS Biology* 2004



Lμ - In or Near
Right Hand
Somatomotor
Cortex

Rμ - In or Near
Left Hand
Somatomotor
Cortex

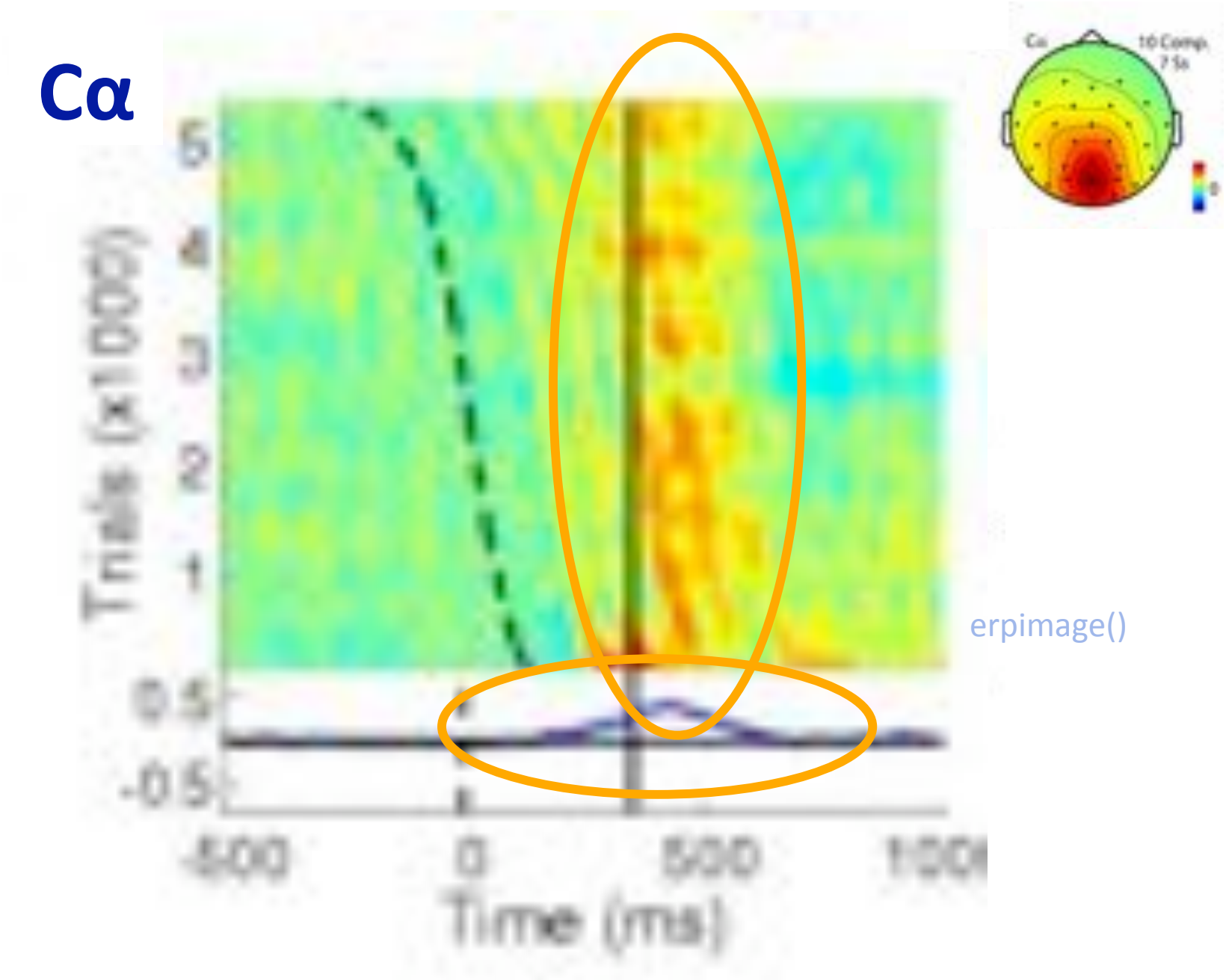
S Makeig et al., *PLOS Biology* 2004



Cα - In or Near Primary Visual Cortex

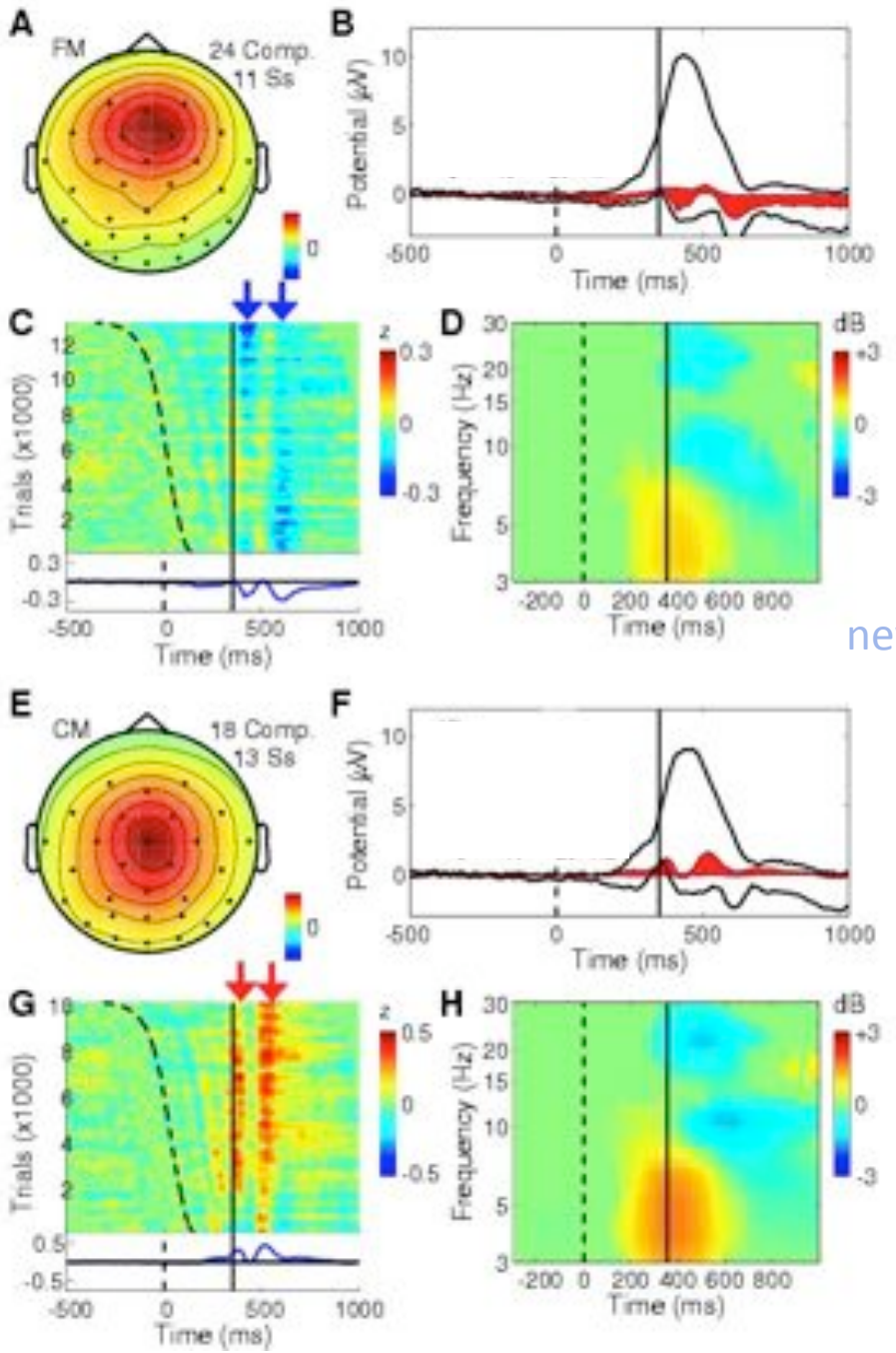
S Makeig et al., *PLOS Biology* 2004

Cα



erpimage()

S Makeig et al., *PLOS Biology* 2004



envtopo()
std_envtopo()

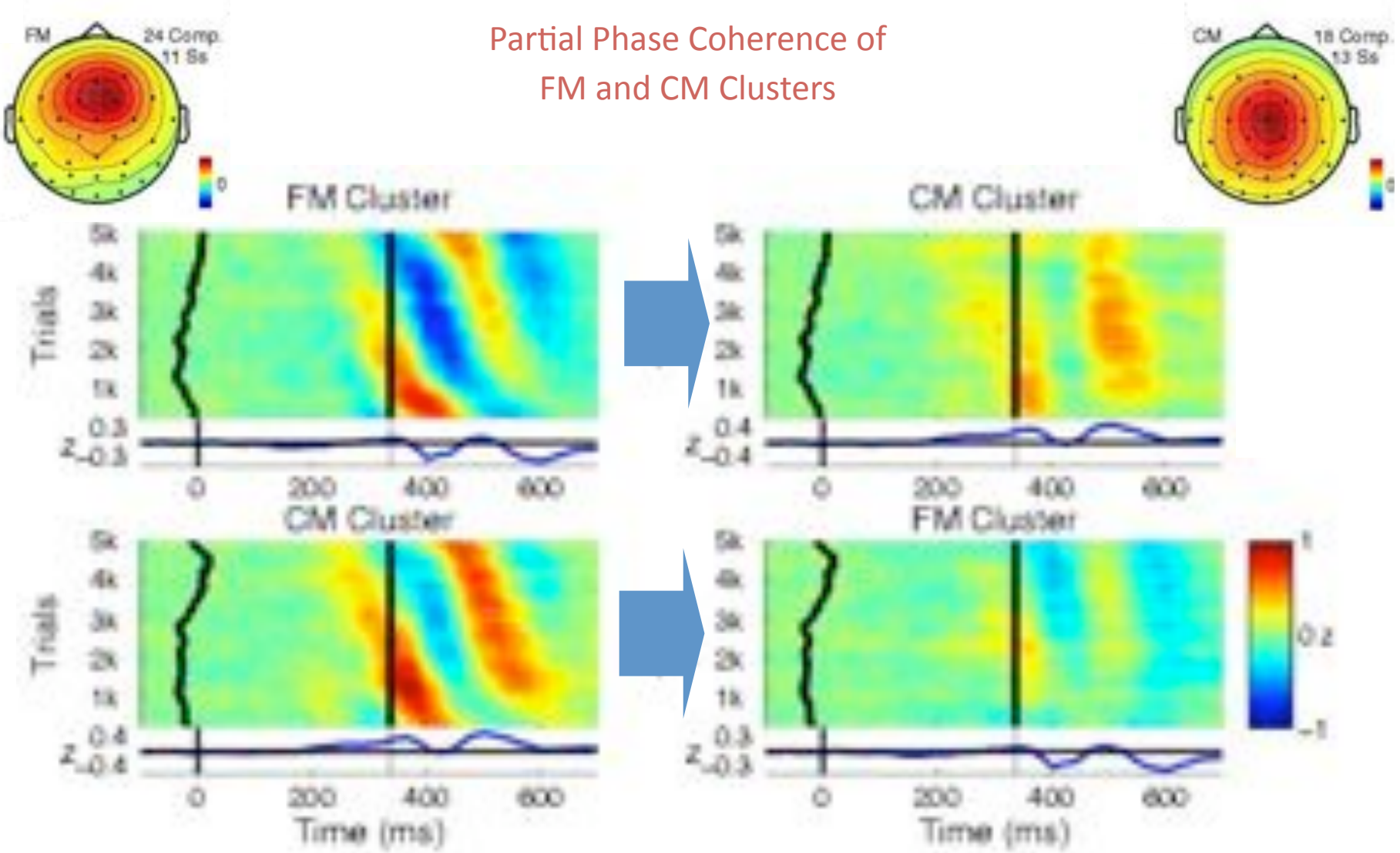
FM - In or Near Rostral Cingulate Zone (dACC)

newtimef()

CM - In or Near Motor Cingulate / Supplementary Motor Cortex

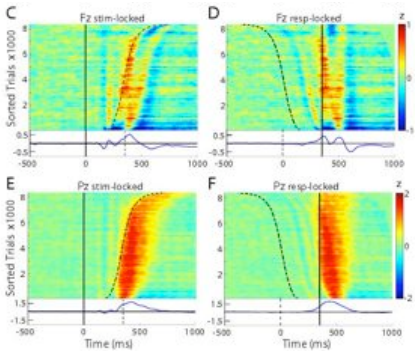
S Makeig et al., *PLOS Biology* 2004

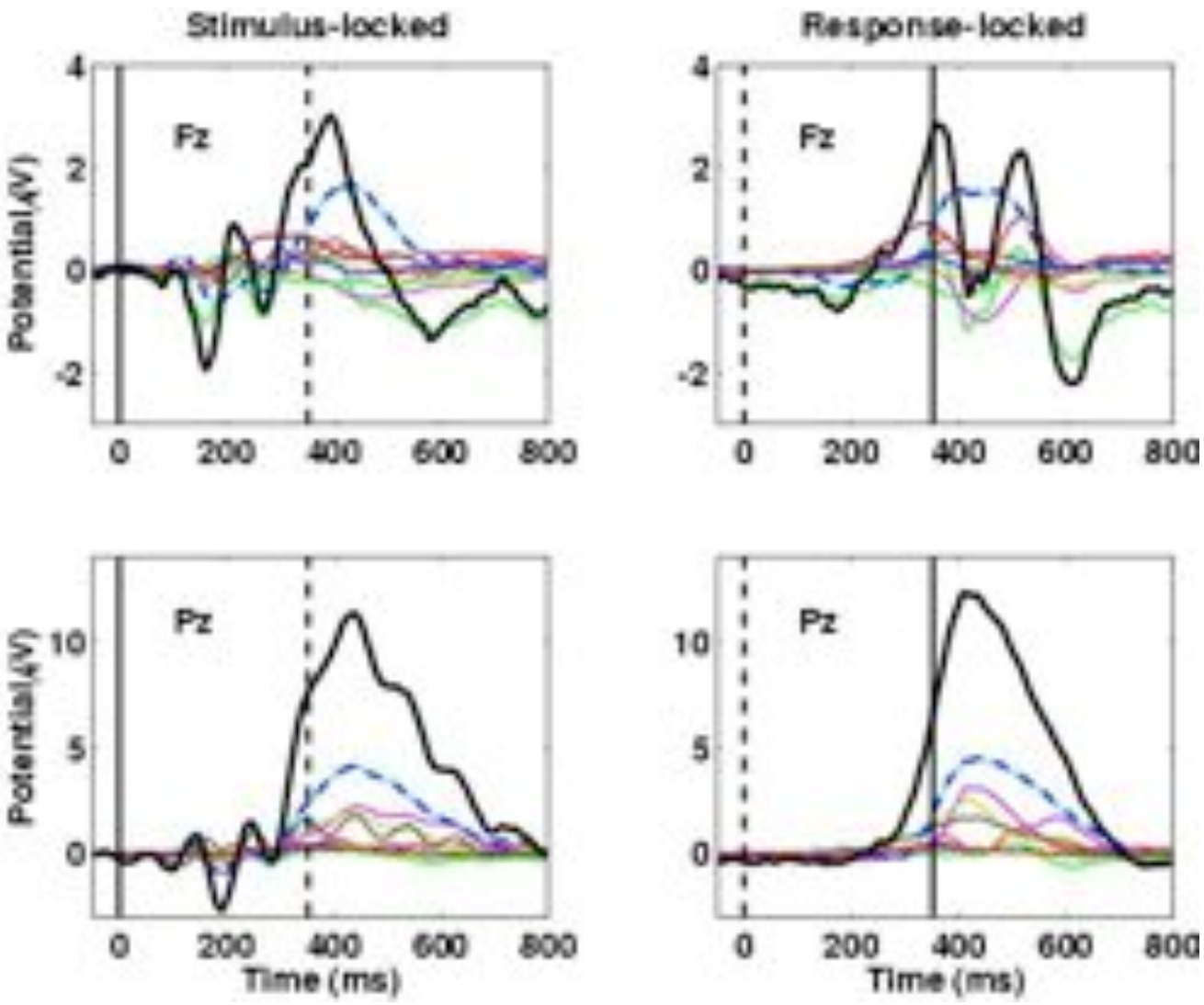
Partial Phase Coherence of FM and CM Clusters



S Makeig et al., *PLOS Biology* 2004

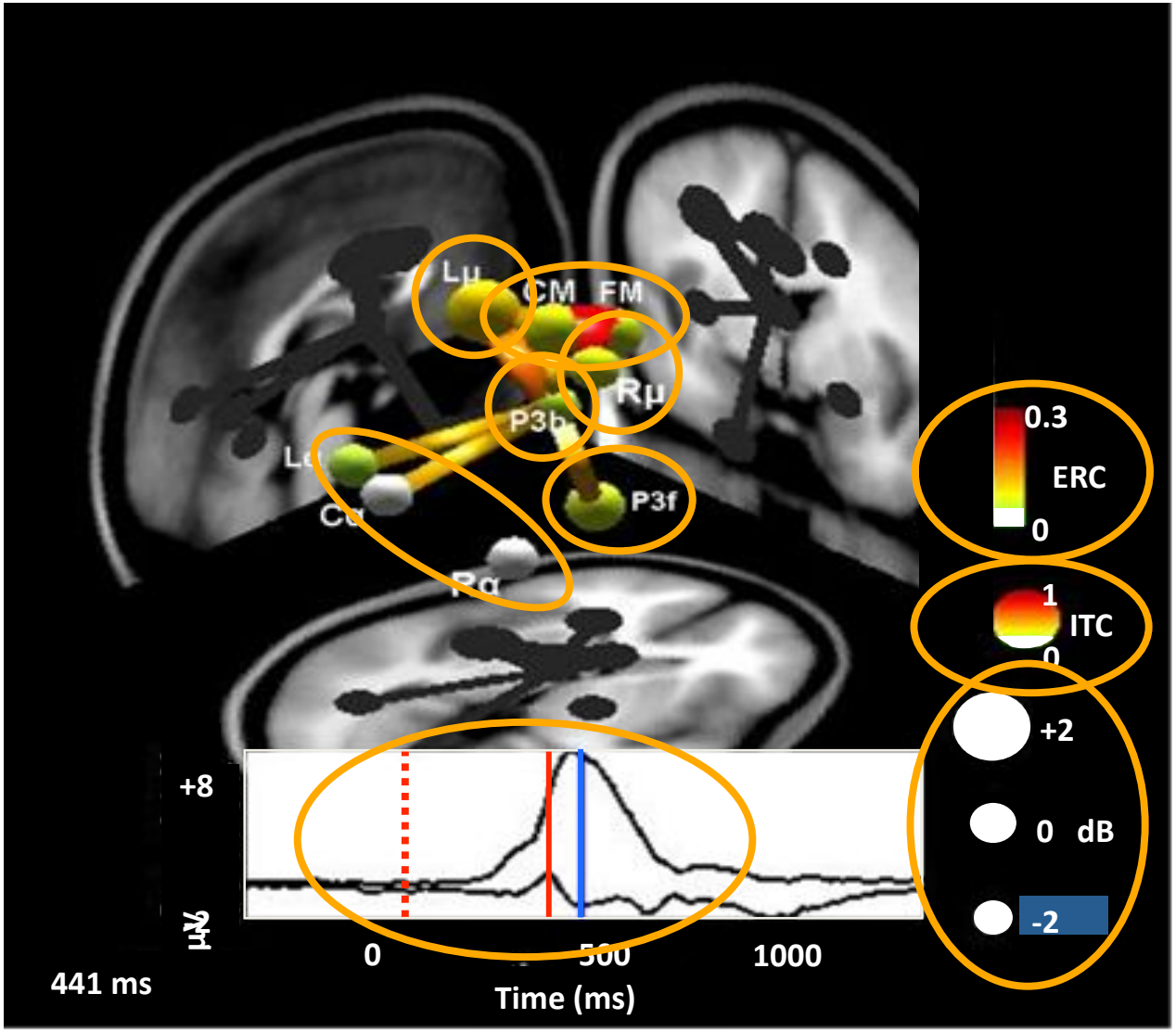
Complex event-related dynamics *sum to* 'the' P300





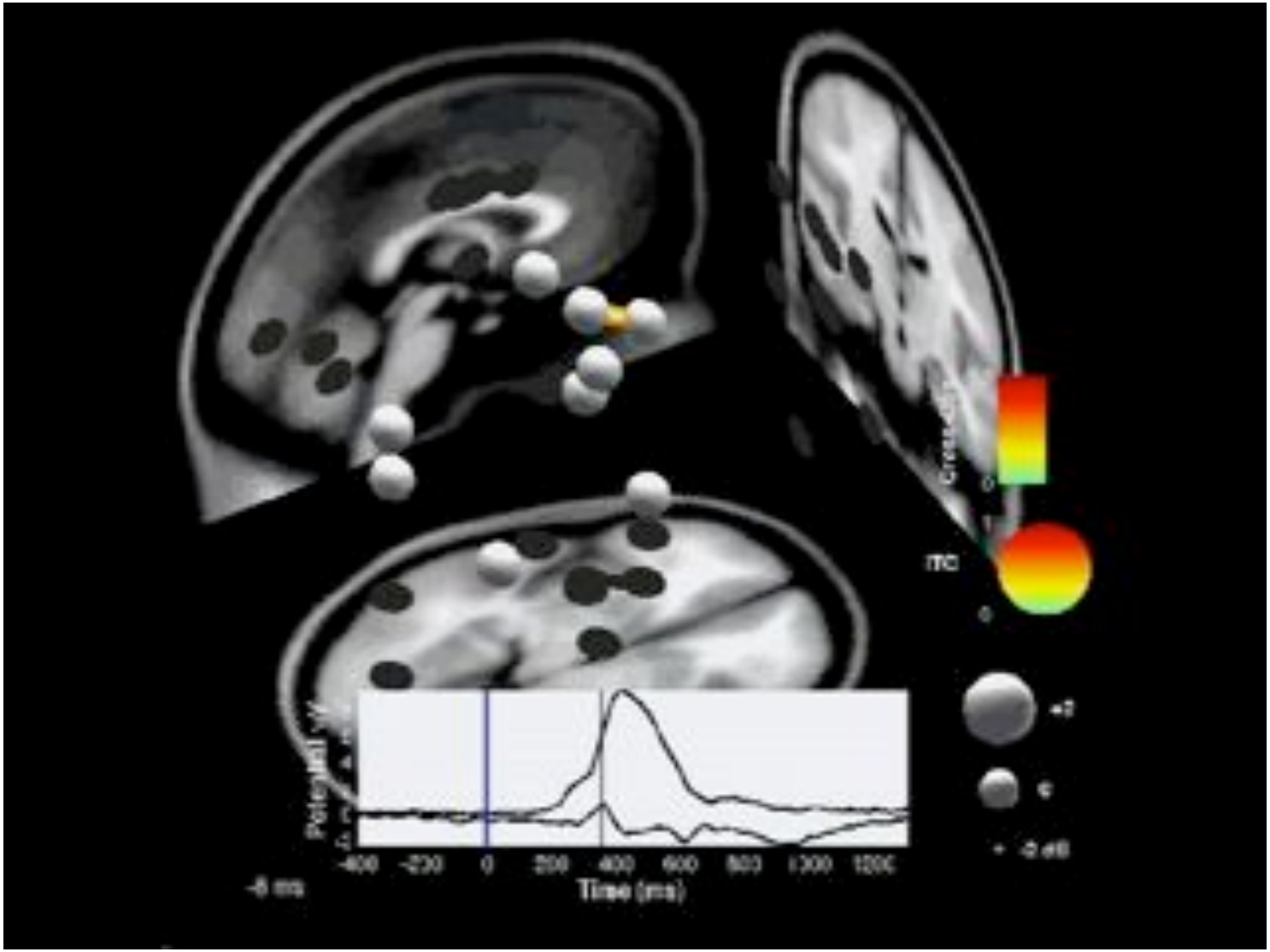
S Makeig et al., *PLOS Biology* 2004

ICA-modeled theta-band event-related dynamics accompanying the speeded manual target responses



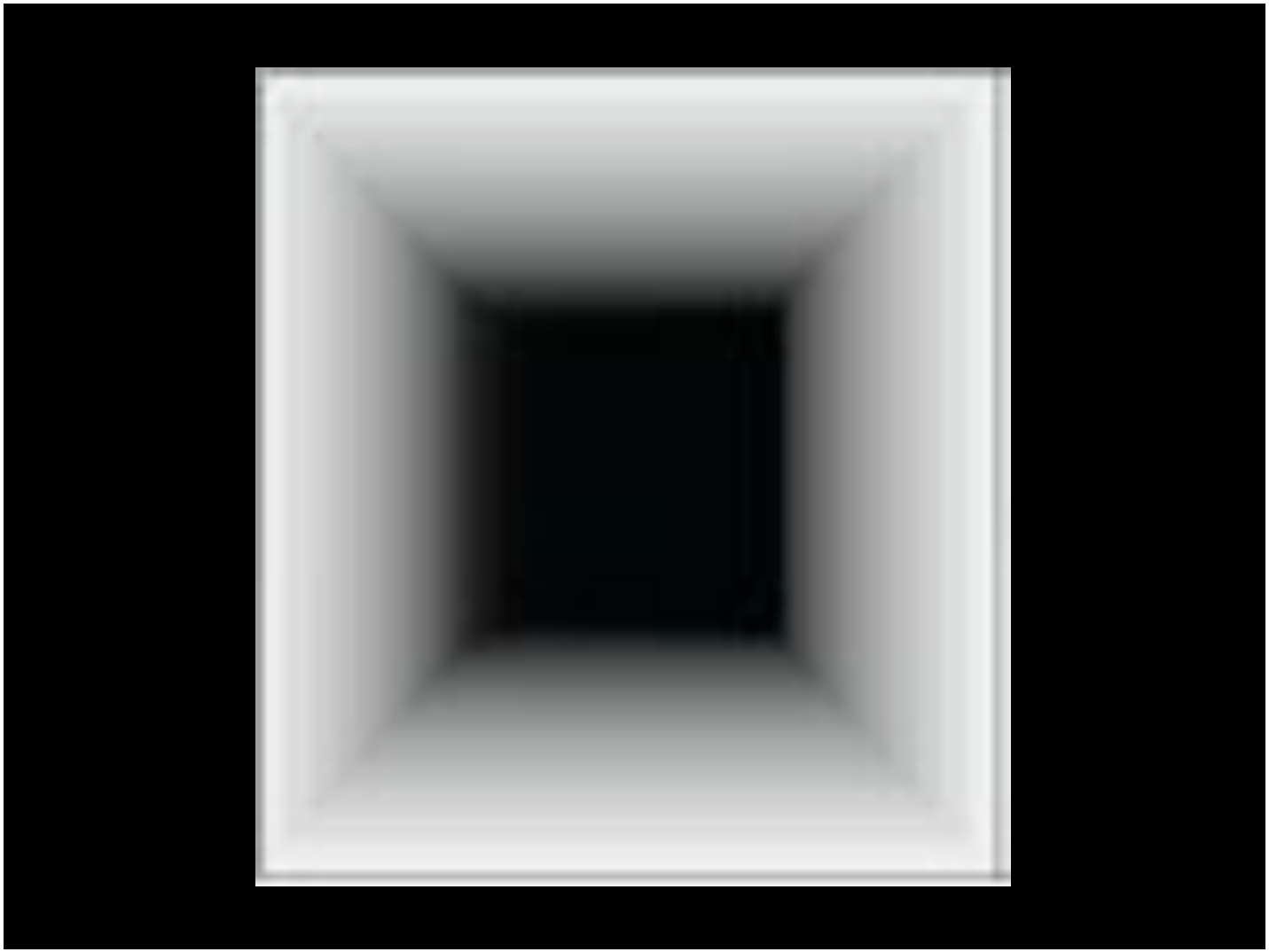
brainmovie3d()

S Makeig et al., *PLOS Biology* 2004



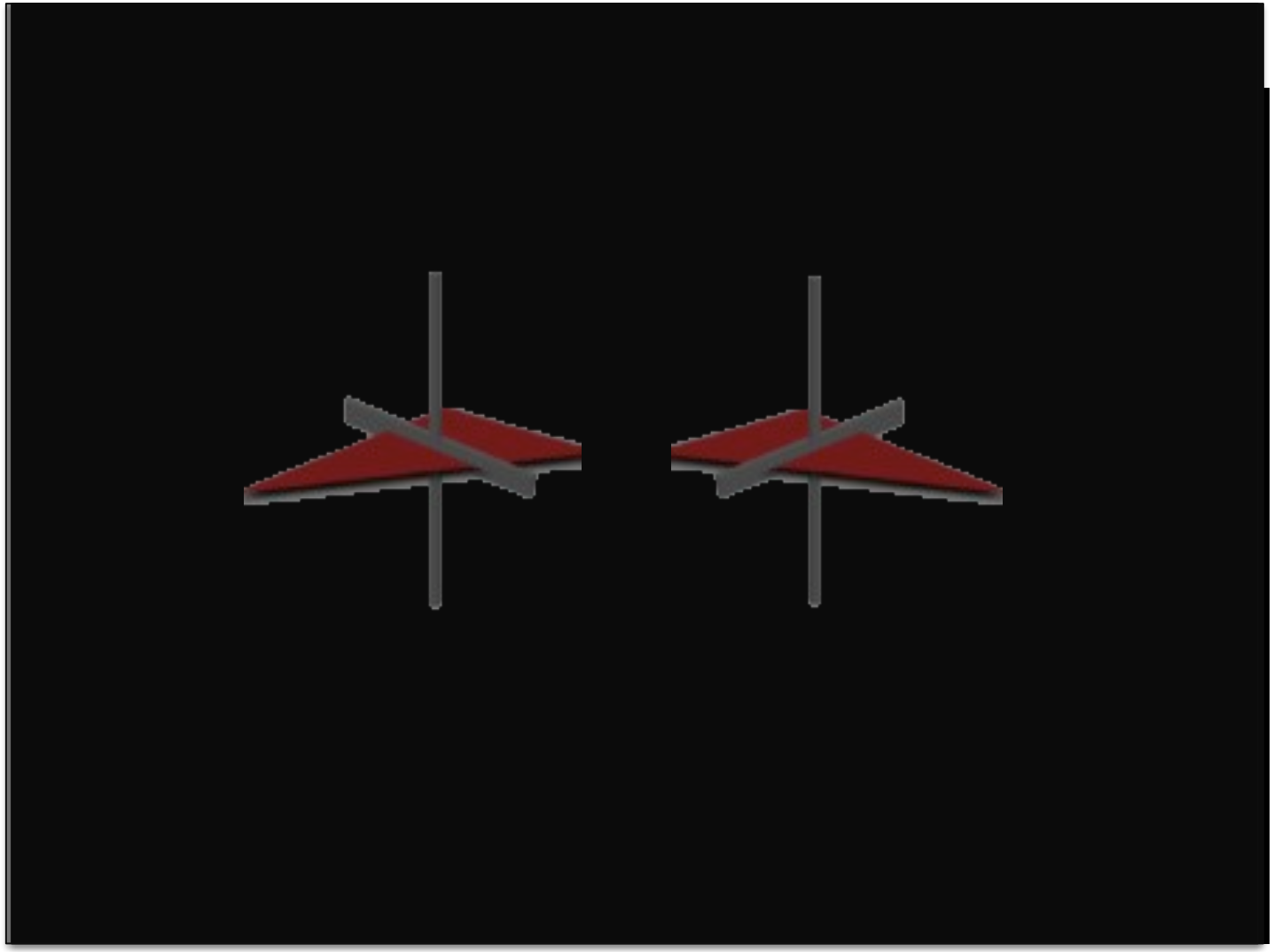
S Makeig et al., *PLOS Biology* 2004

A Passive Spatial Navigation Paradigm



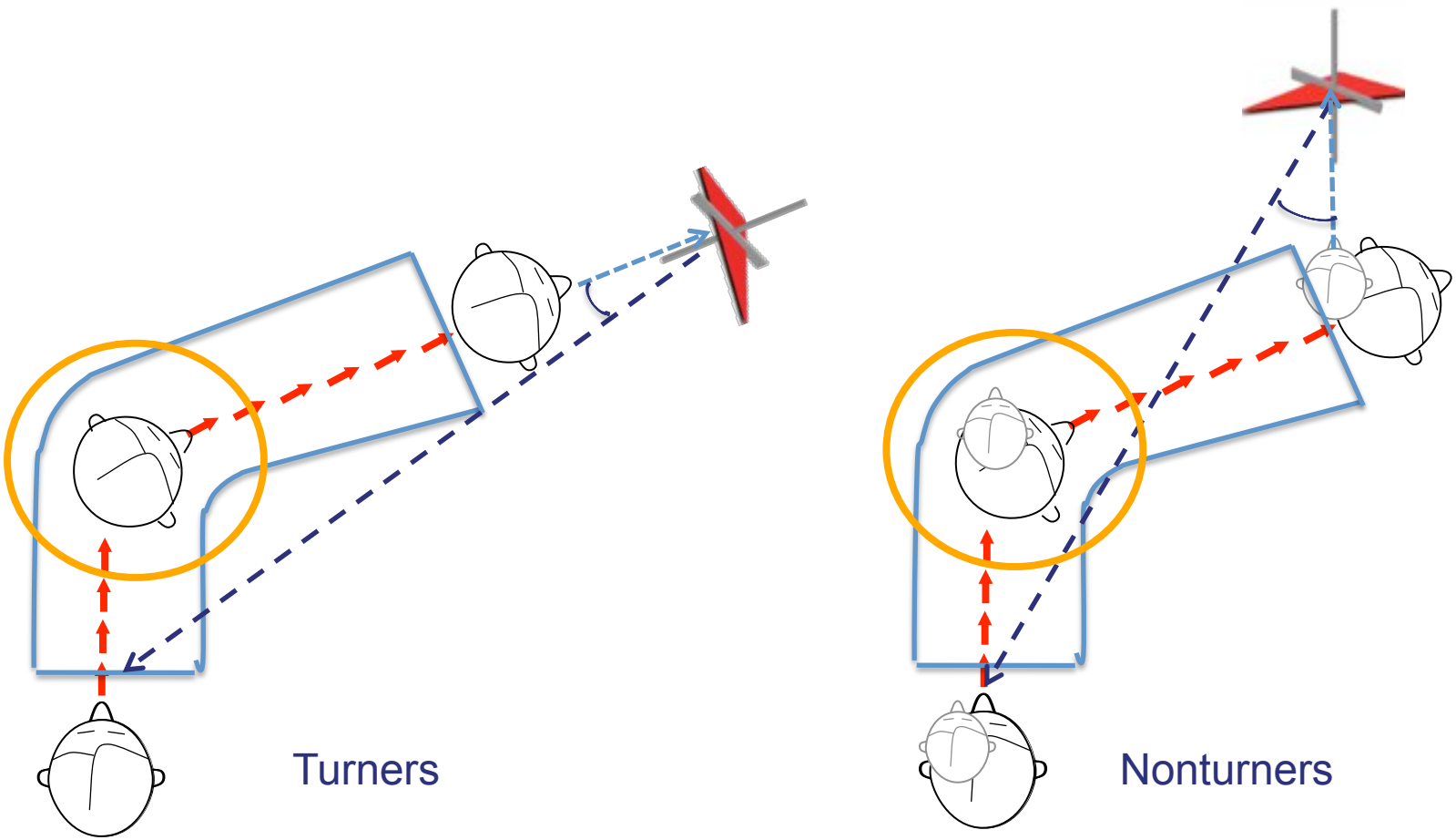
Klaus Gramann et al., 2010

A Passive Spatial Navigation Paradigm



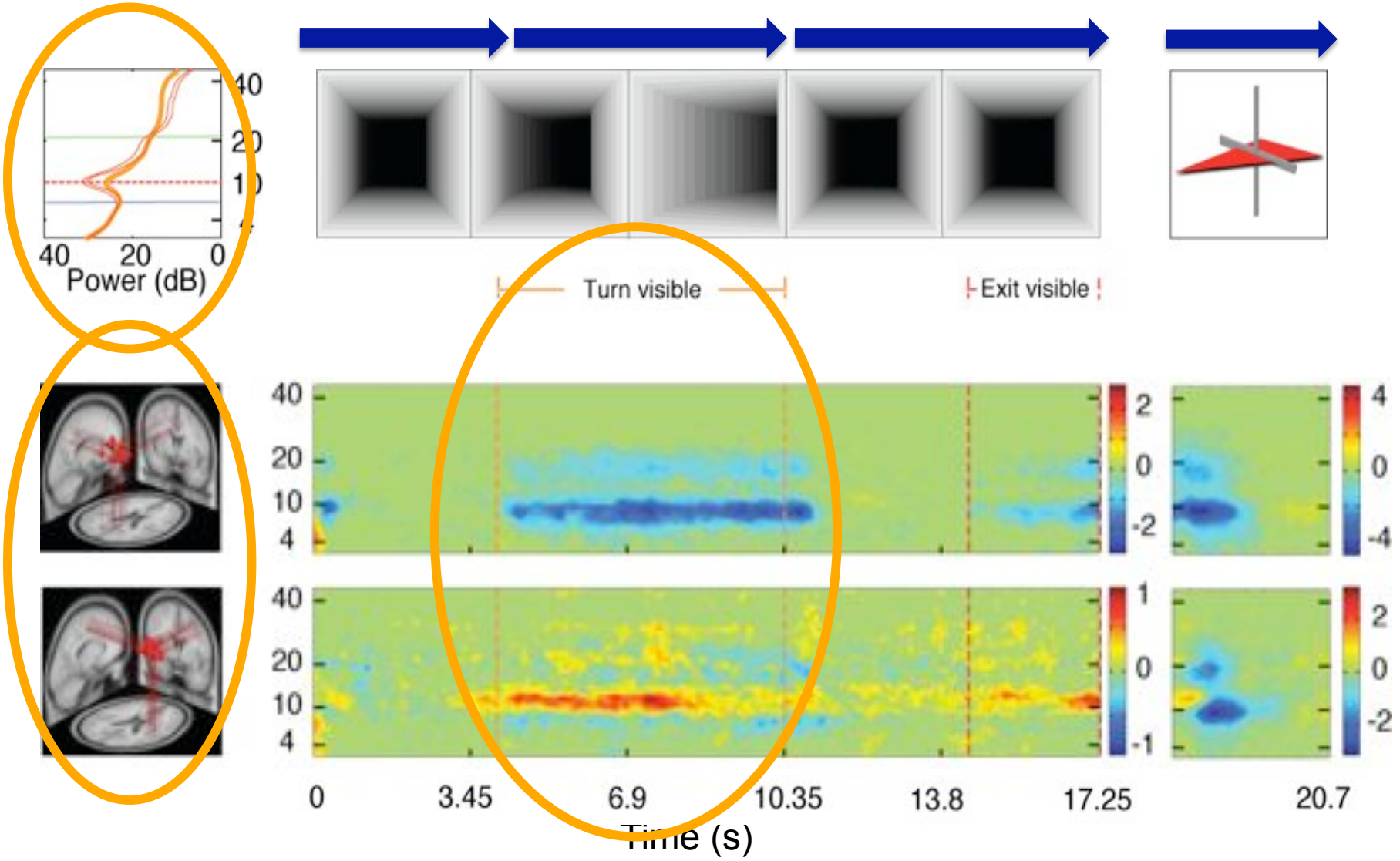
Klaus Gramann et al., 2010

‘Turner’ and ‘Nonturner’ subjects use different spatial orienting styles



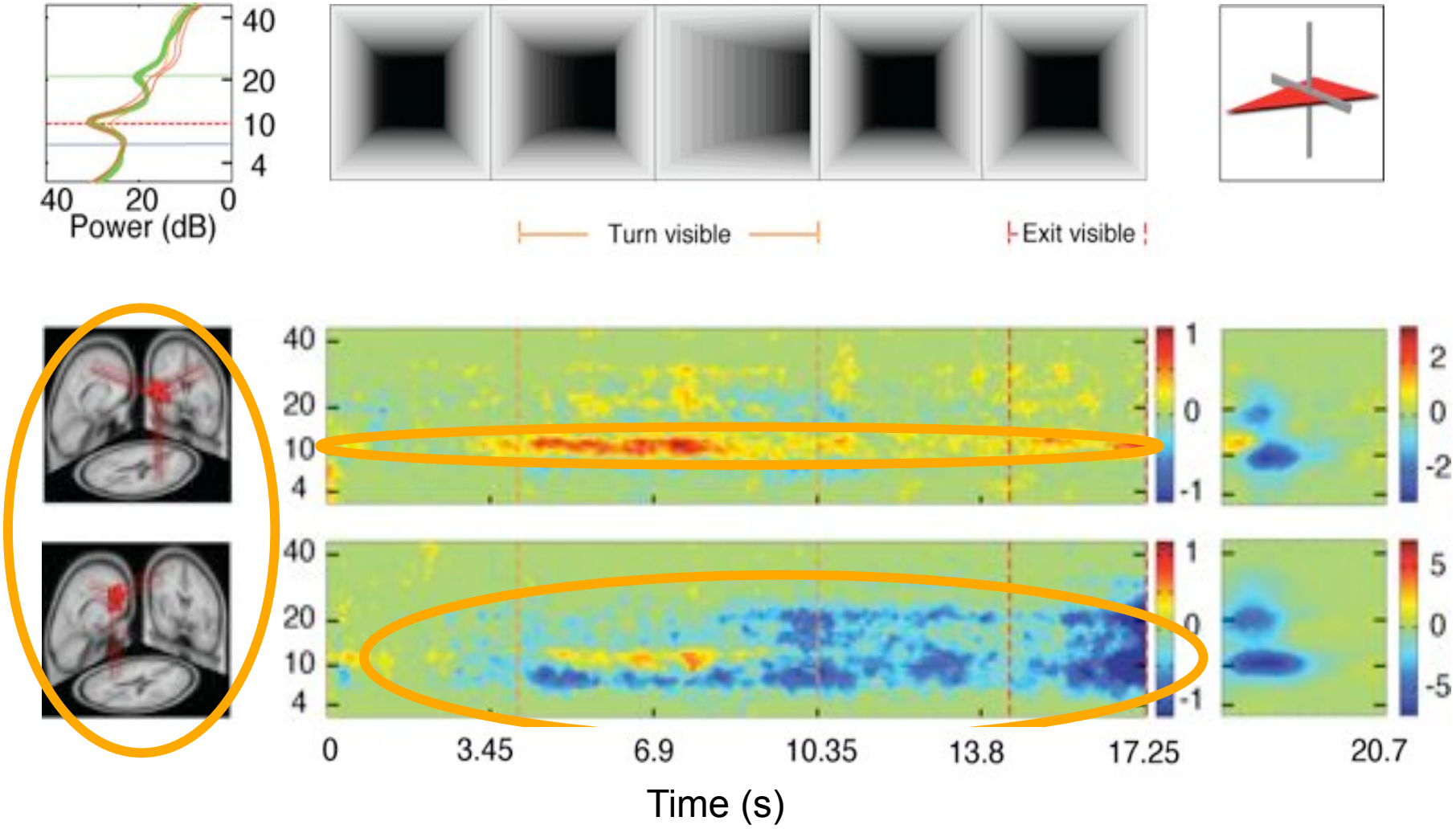
Klaus Gramann et al., 2010

Parietal component clusters



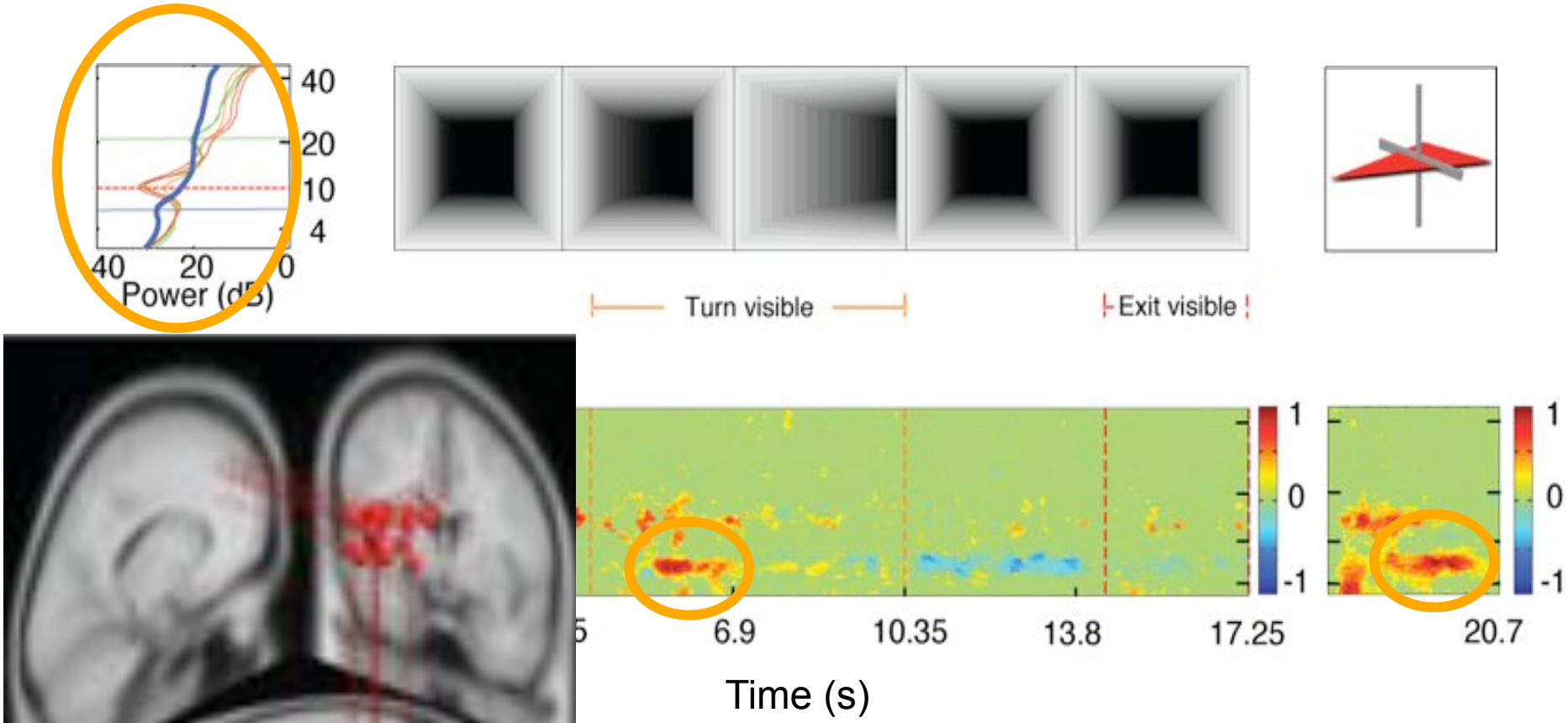
Klaus Gramann et al., 2010

Pre-motor component clusters



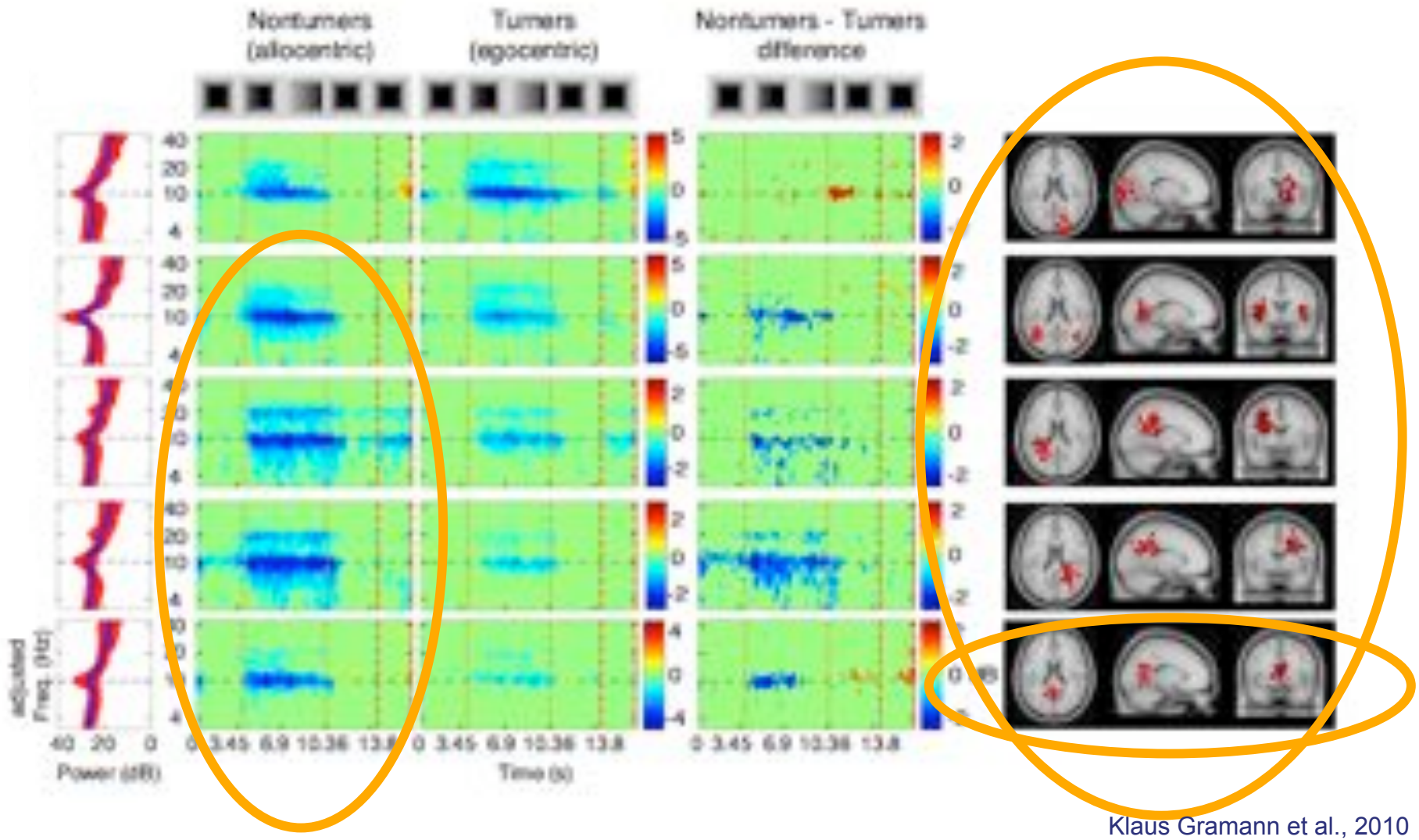
Klaus Gramann et al., 2010

Medial prefrontal component clusters



Klaus Gramann et al., 2010

Clusters distinguishing Turners & Nonturners



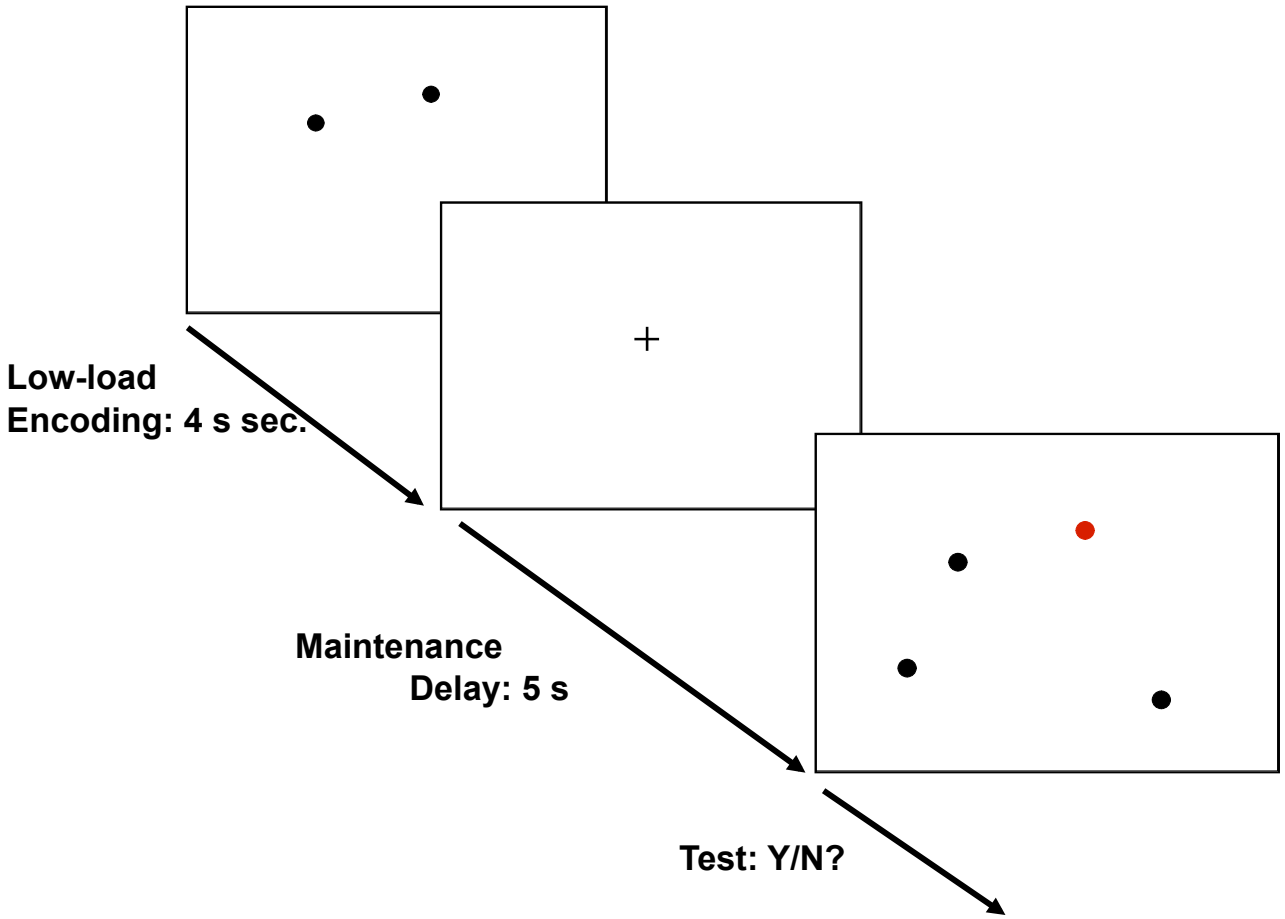
Klaus Gramann et al., 2010

EEG & Aging

Visual spatial working memory in young and older adults

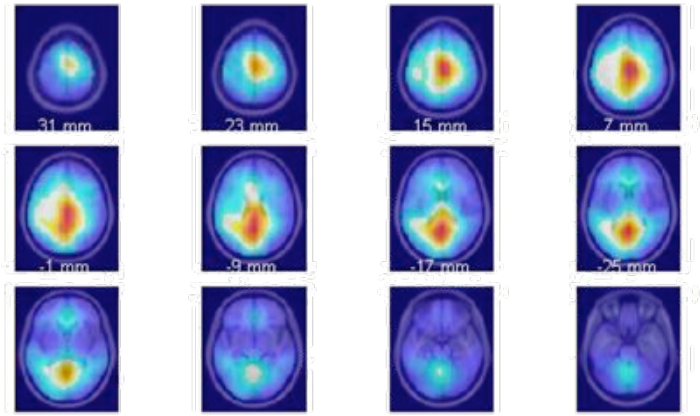
V. Bjerre J. Onton, & S. Makeig, 2006

Visual spatial working memory in young and older adults

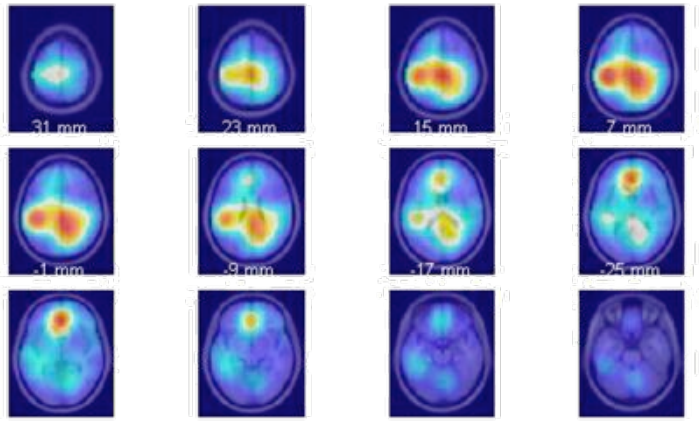


V. Bjerre J. Onton, & S. Makeig, 2006

Visual spatial working memory in young and older adults



Young adults

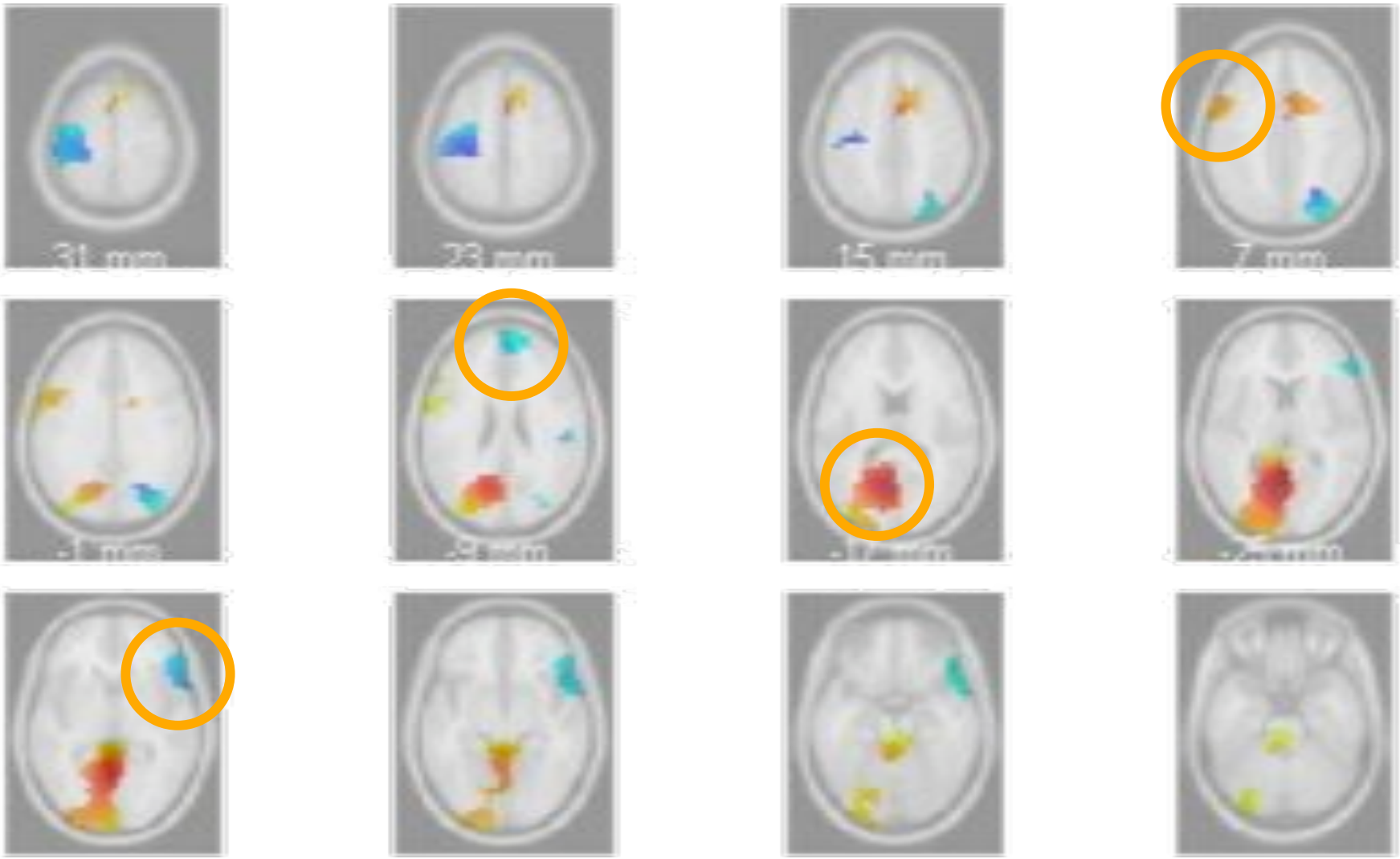


Older adults

V. Bjerre J. Onton, & S. Makeig, 2006

V. Bjerre J. Onton, & S. Makeig, 2006

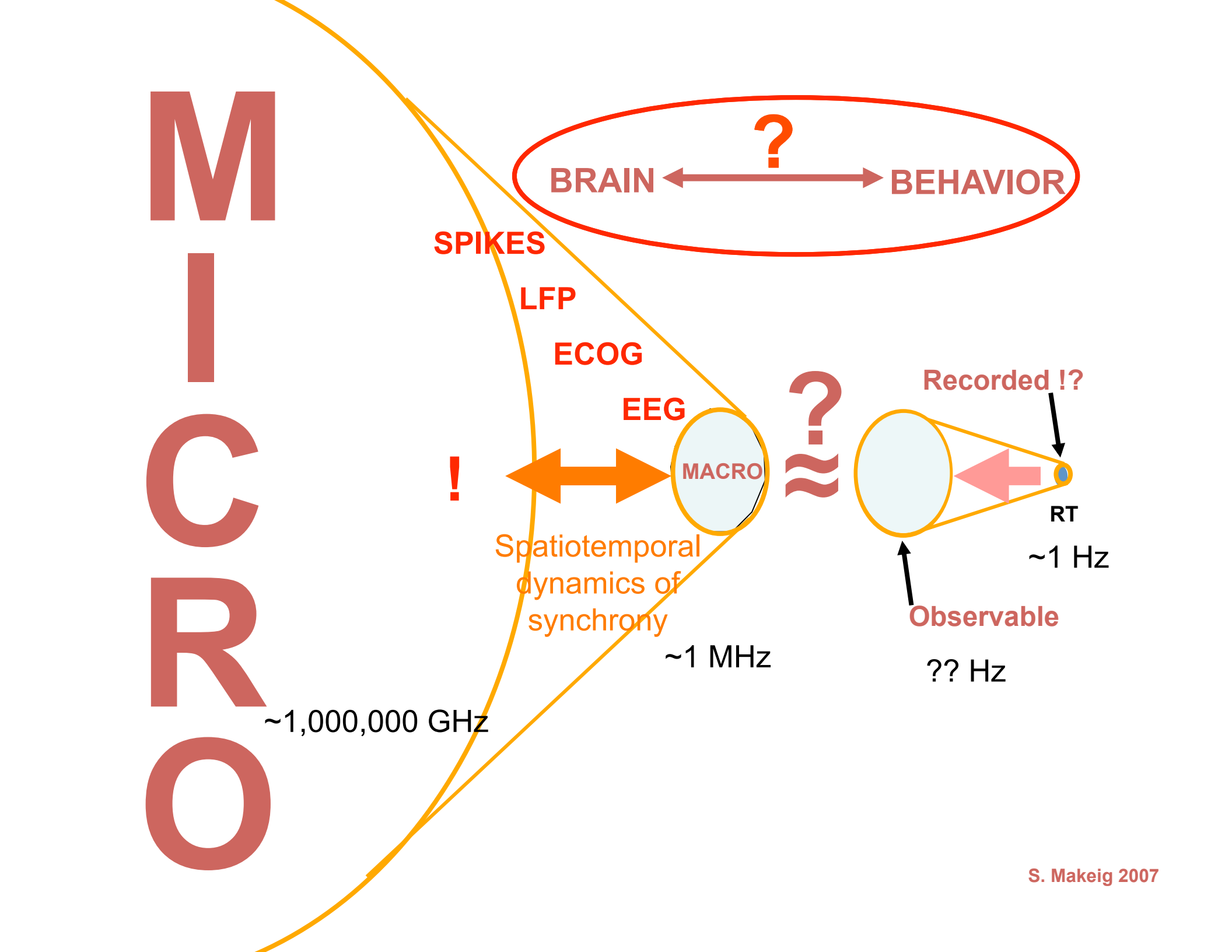
Young adults – Older adults



V. Bjerre J. Onton, & S. Makeig, 2006

Active Cognition

Increasing the behavioral bandwidth …


MICRO
?
BRAIN
BEHAVIOR
SPIKES
LFP
ECOG
EEG
!
MACRO
≈?
Recorded !?
RT
~1 Hz
Observable
?? Hz
Spatiotemporal dynamics of synchrony
~1 MHz
~1,000,000 GHz
S. Makeig 2007

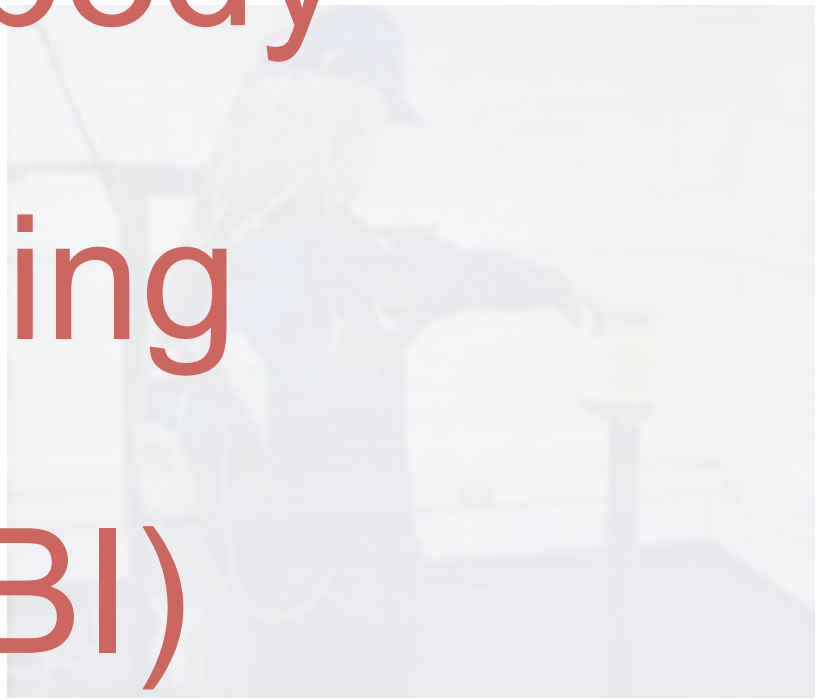
Brain imaging during movement – How?

- Current advances in miniaturization, computer power, and information-based signal processing make possible a new imaging modality:

→ **Mobile Brain/Body Imaging** (MoBI)

Concept:

Combine whole-head EEG, eye gaze tracking, and whole-body motion capture recording in a real-world 3-D environment.



Mobile Brain/body Imaging (MoBI)

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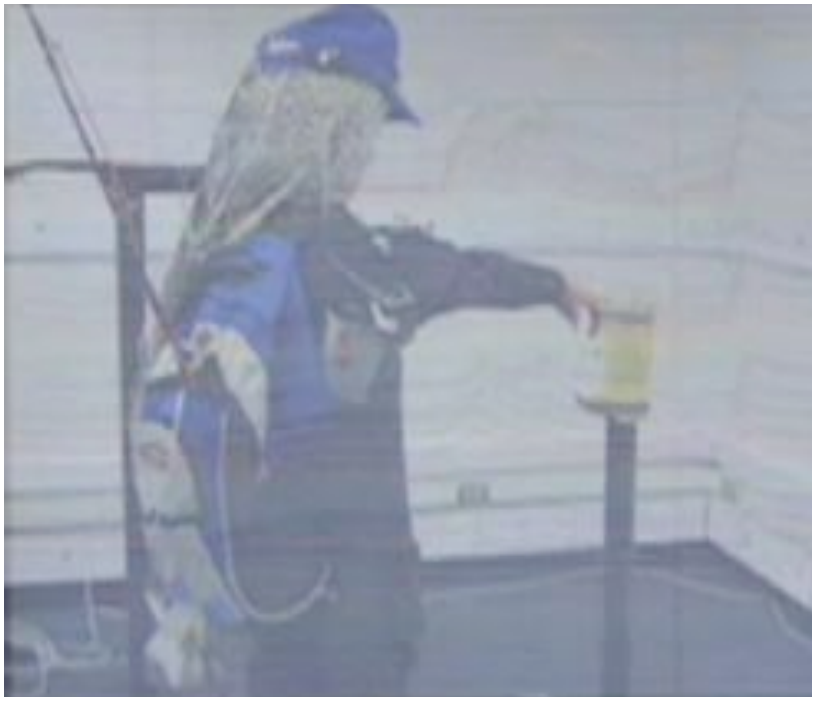
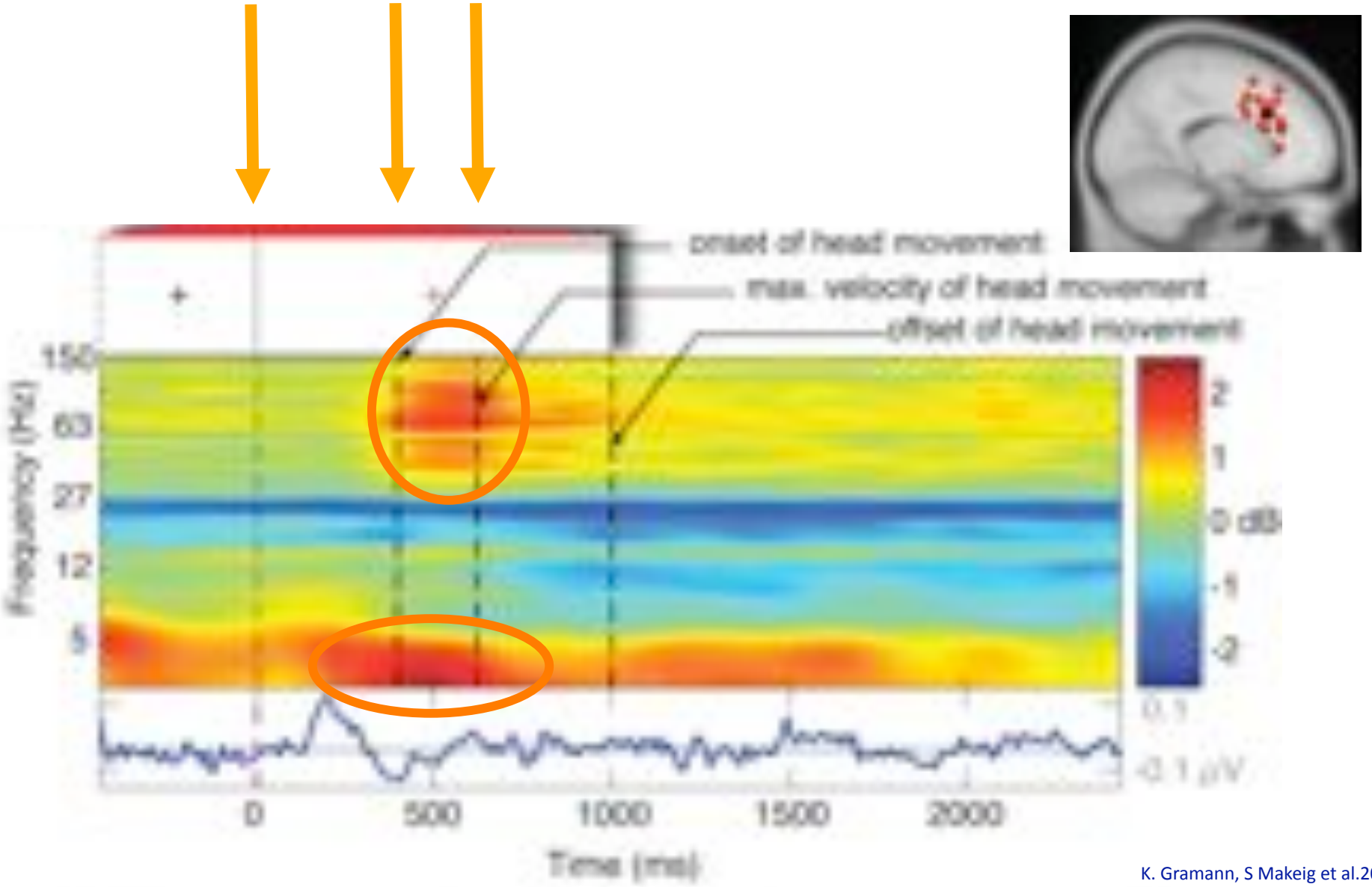
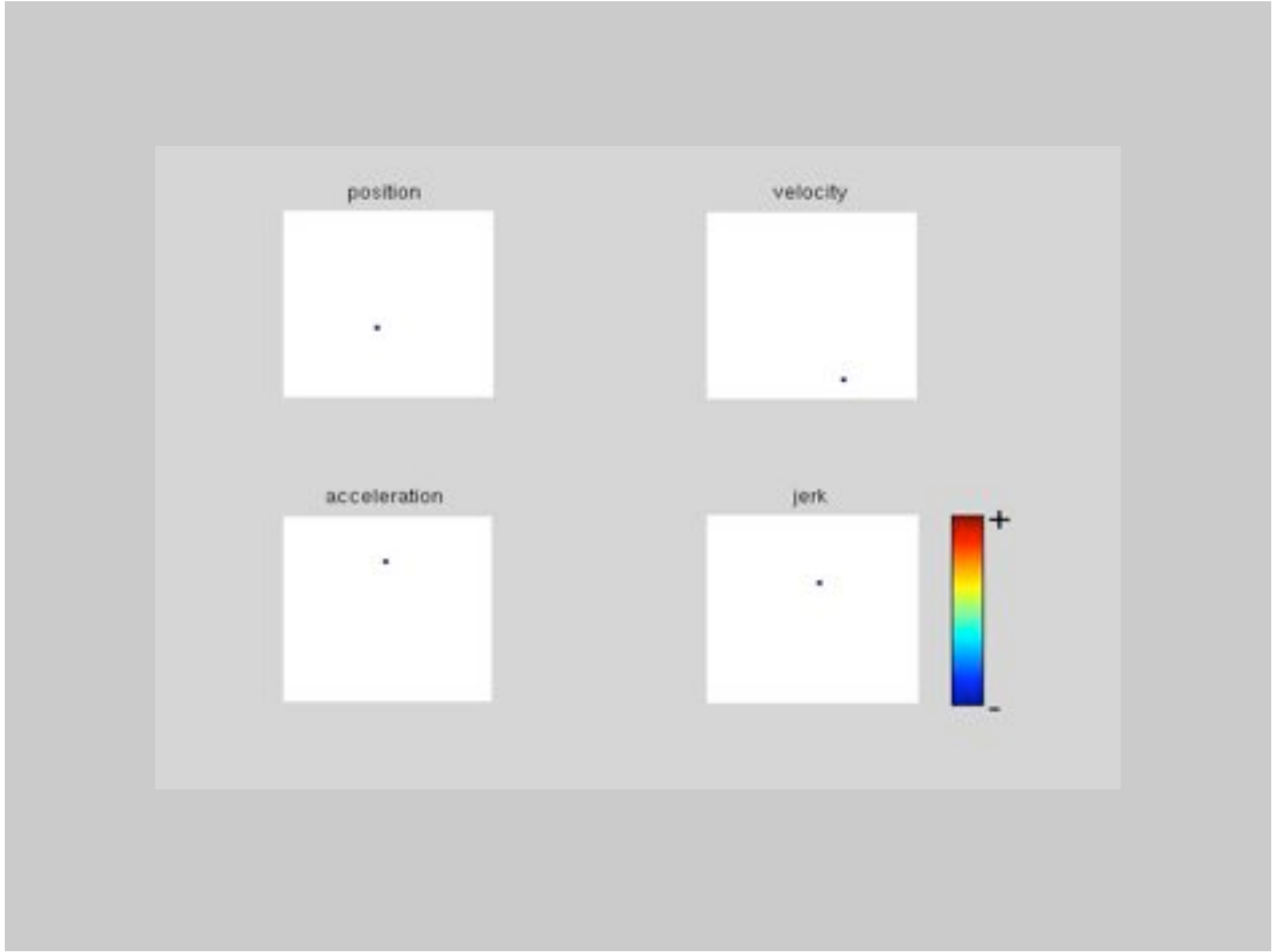


Scott Makeig, 2008

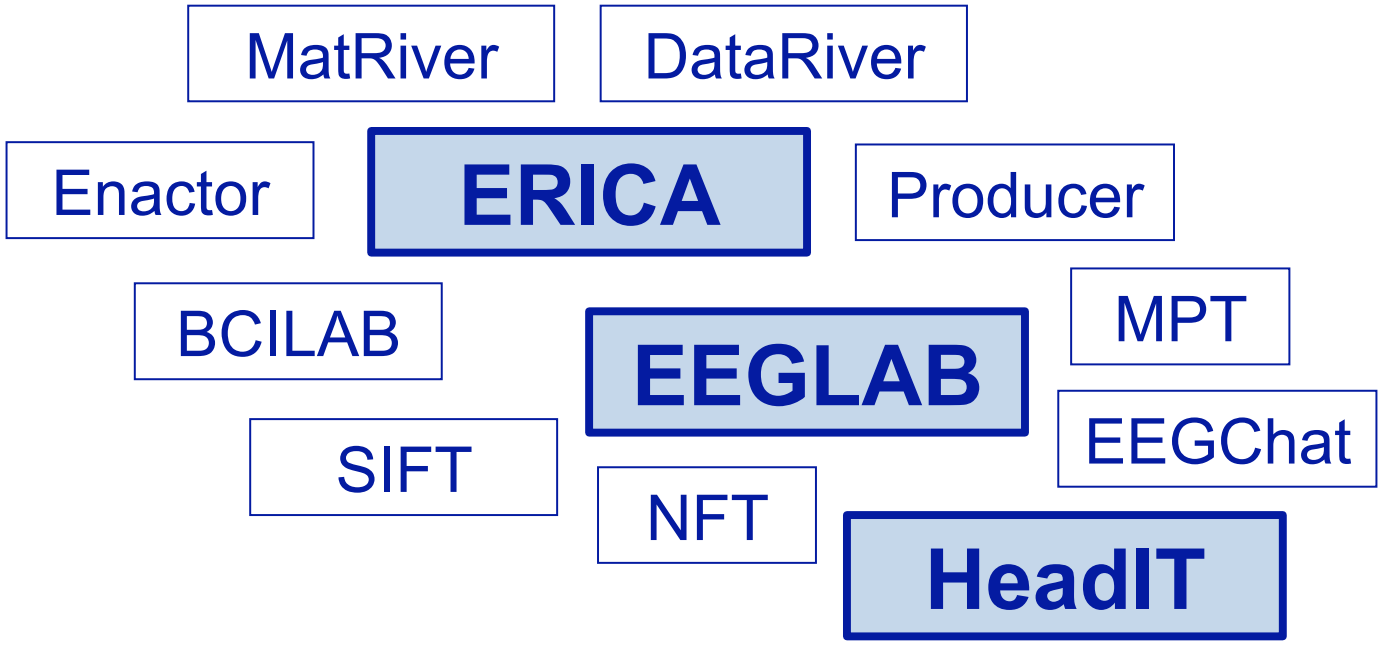
3-D Orienting Head Turns

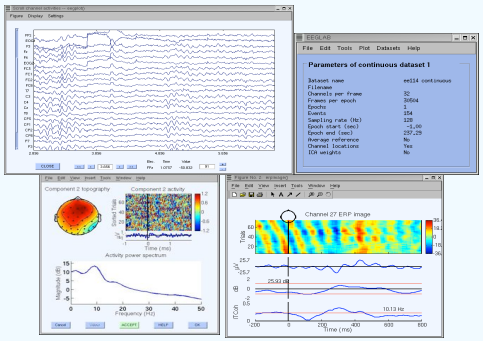


K. Gramann, S Makeig et al.2010


position
velocity
acceleration
jerk
+
-

Open-Source Electrophysiological Software





The Beginning…