Functional High-Definition Imaging of EEG Brain Dynamics

Scott Makeig

Institute for Neural Computation

University of California San Diego

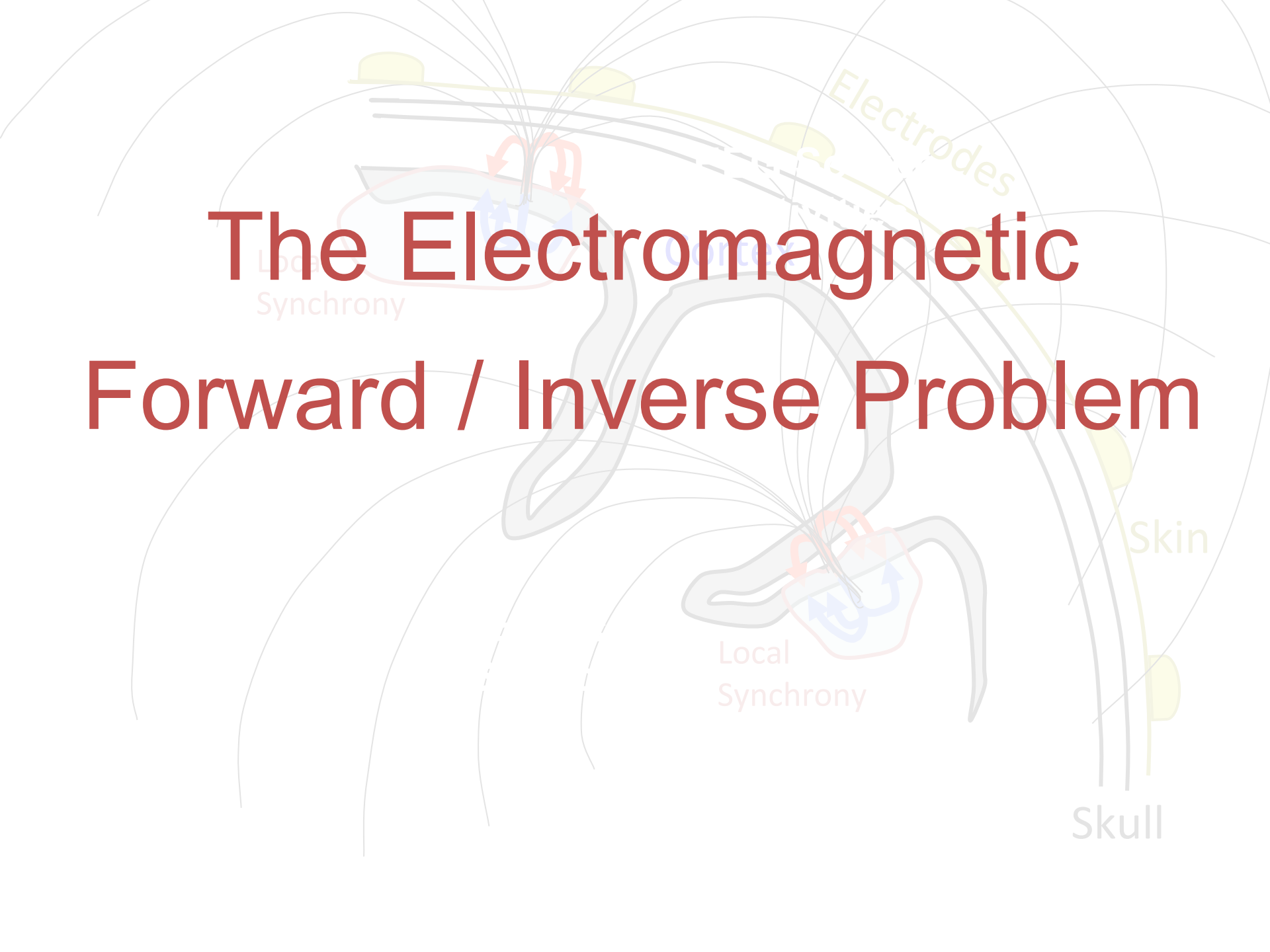
16th EEGLAB Workshop

Aspet, France

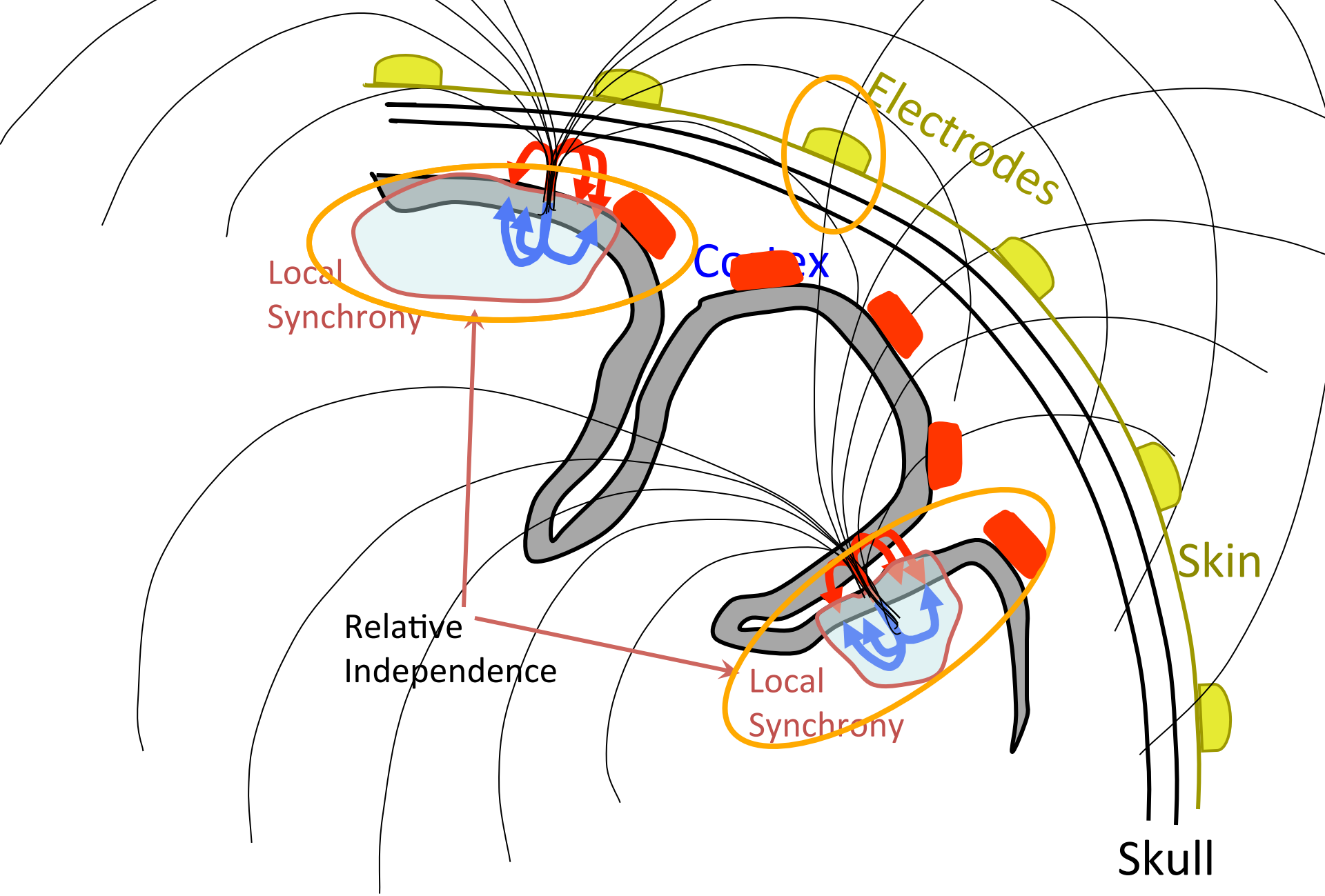
June 2013

Phase cones (Freeman)

Avalanches (Plenz)

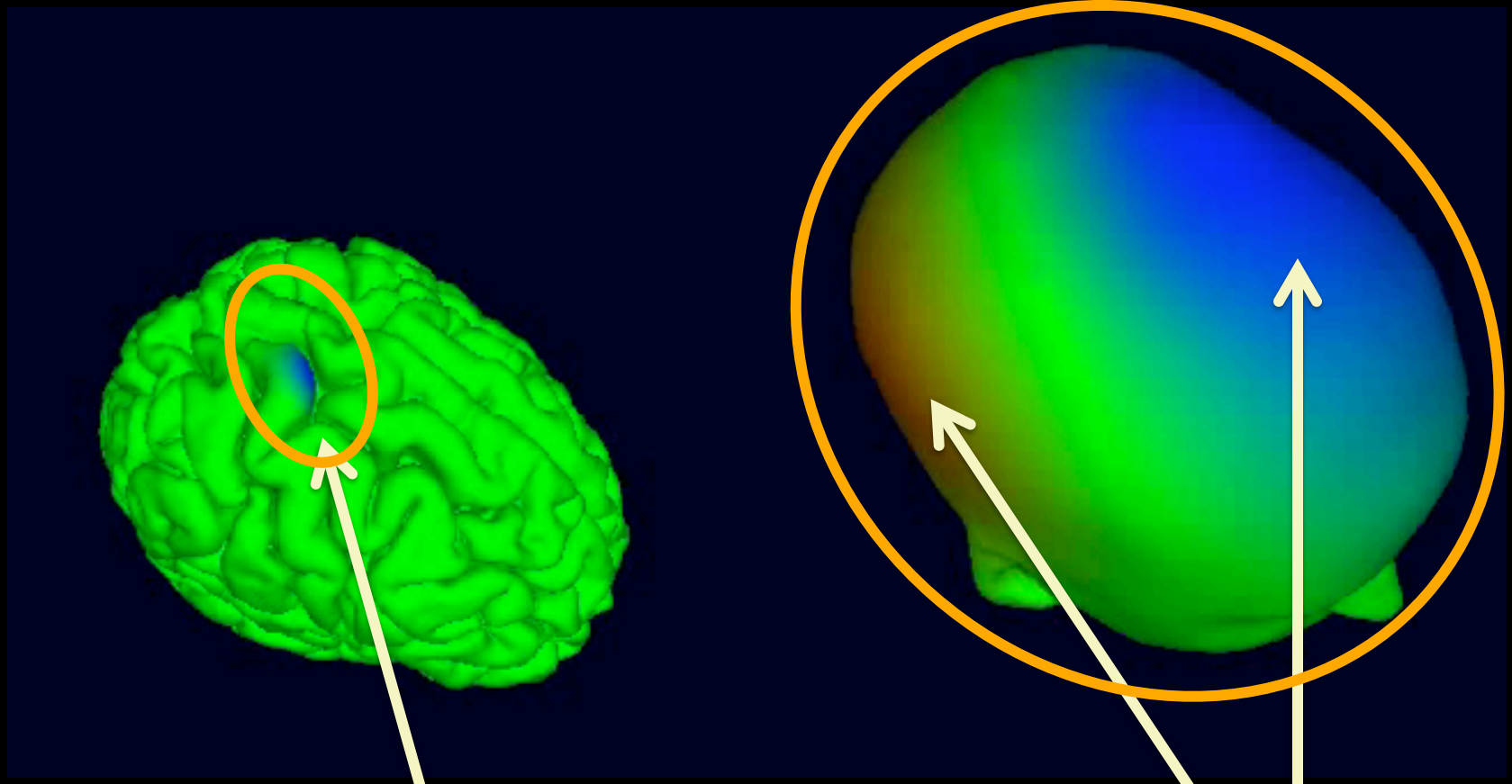


The Electromagnetic Forward / Inverse Problem



S. Makeig 2007

The very broad EEG point-spread function

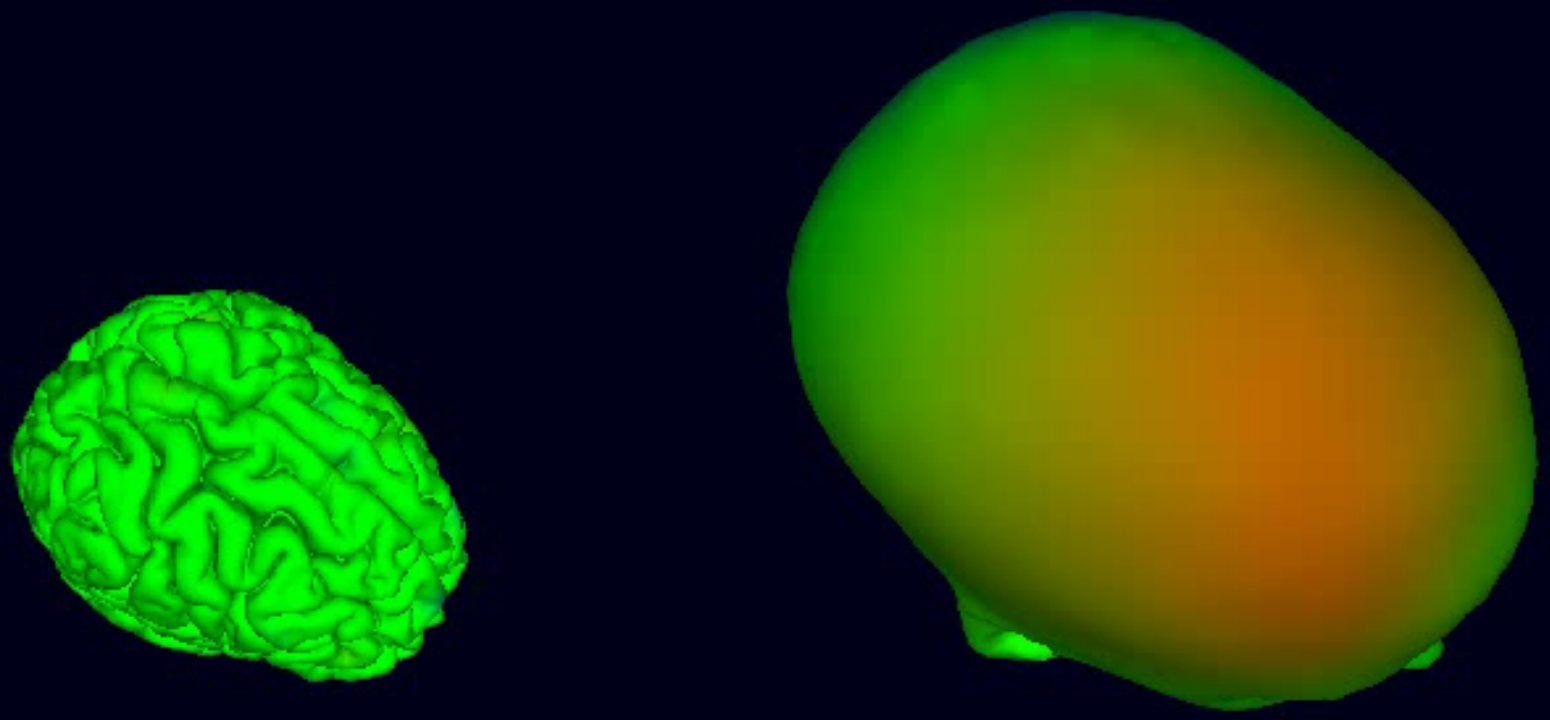


Simulated parietal source

Very broad projected scalp potentials

Akalin Acar & Makeig 2010

The very broad EEG point-spread function

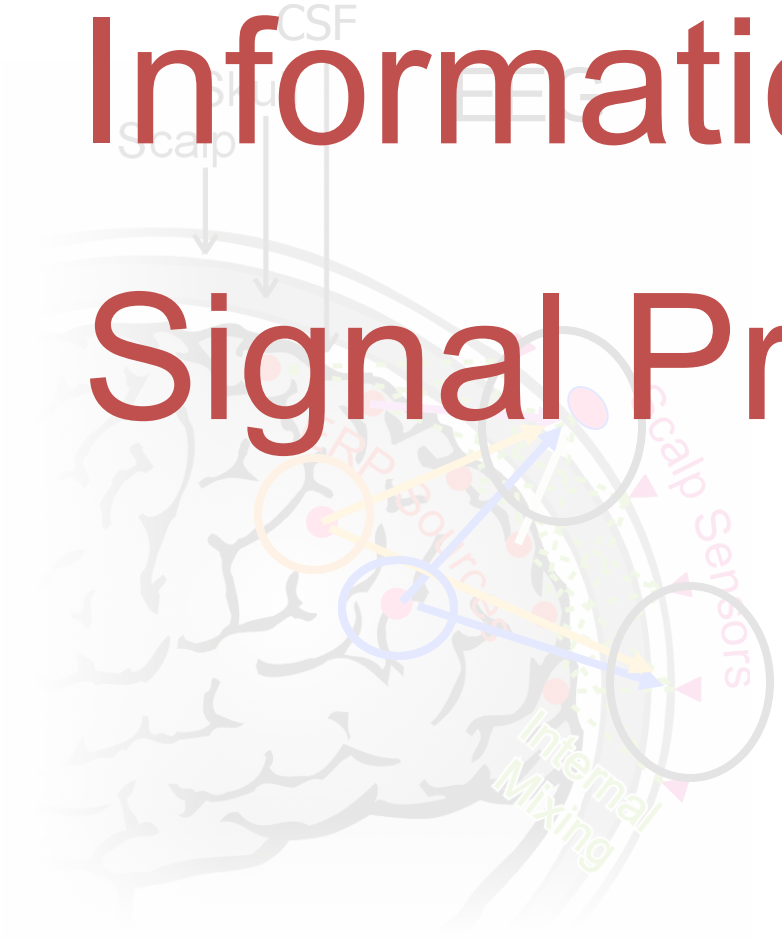


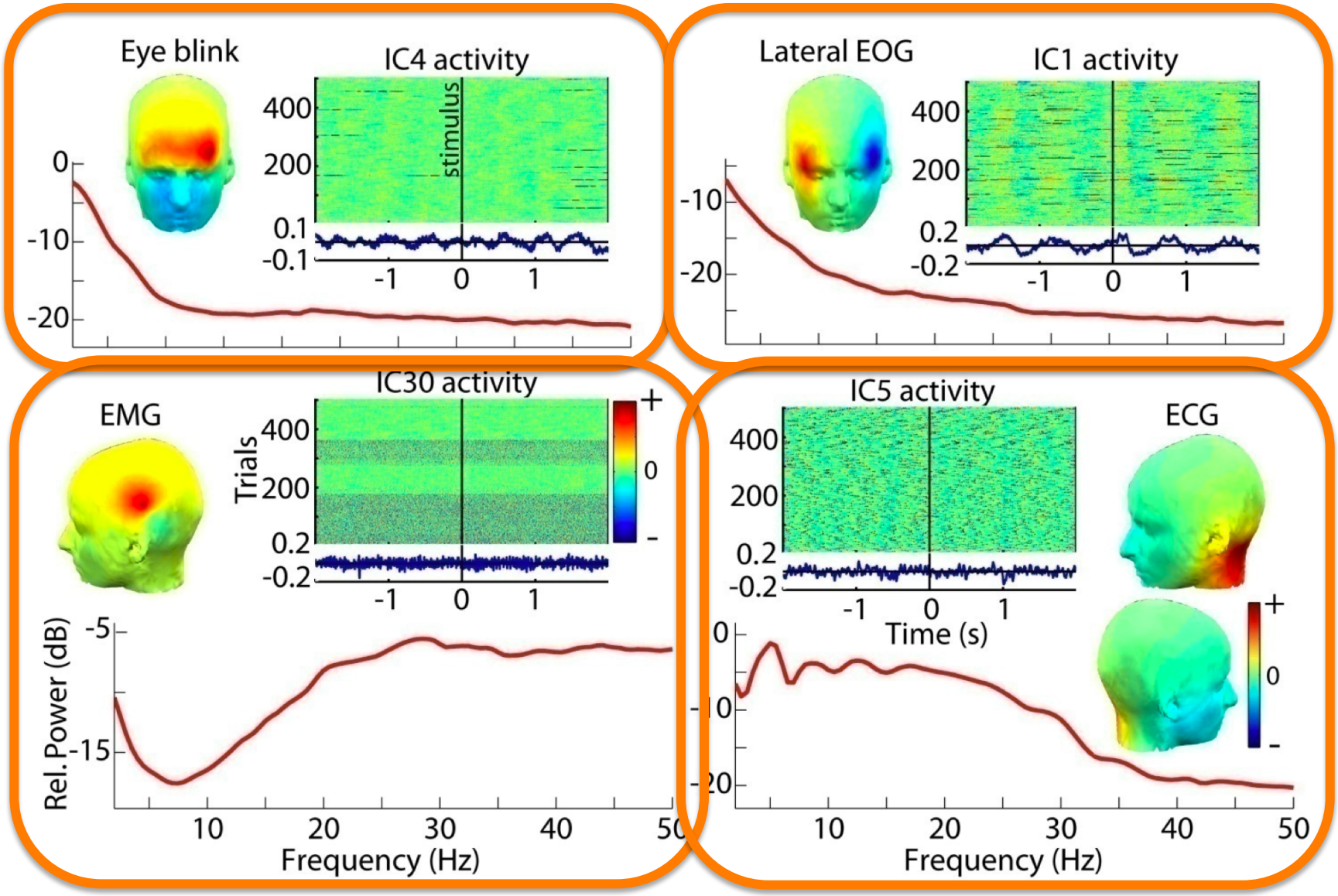
Simulated EEG summing 30 cortical sources
(animation at 1/5th real time)

Akalin Acar & Makeig 2010

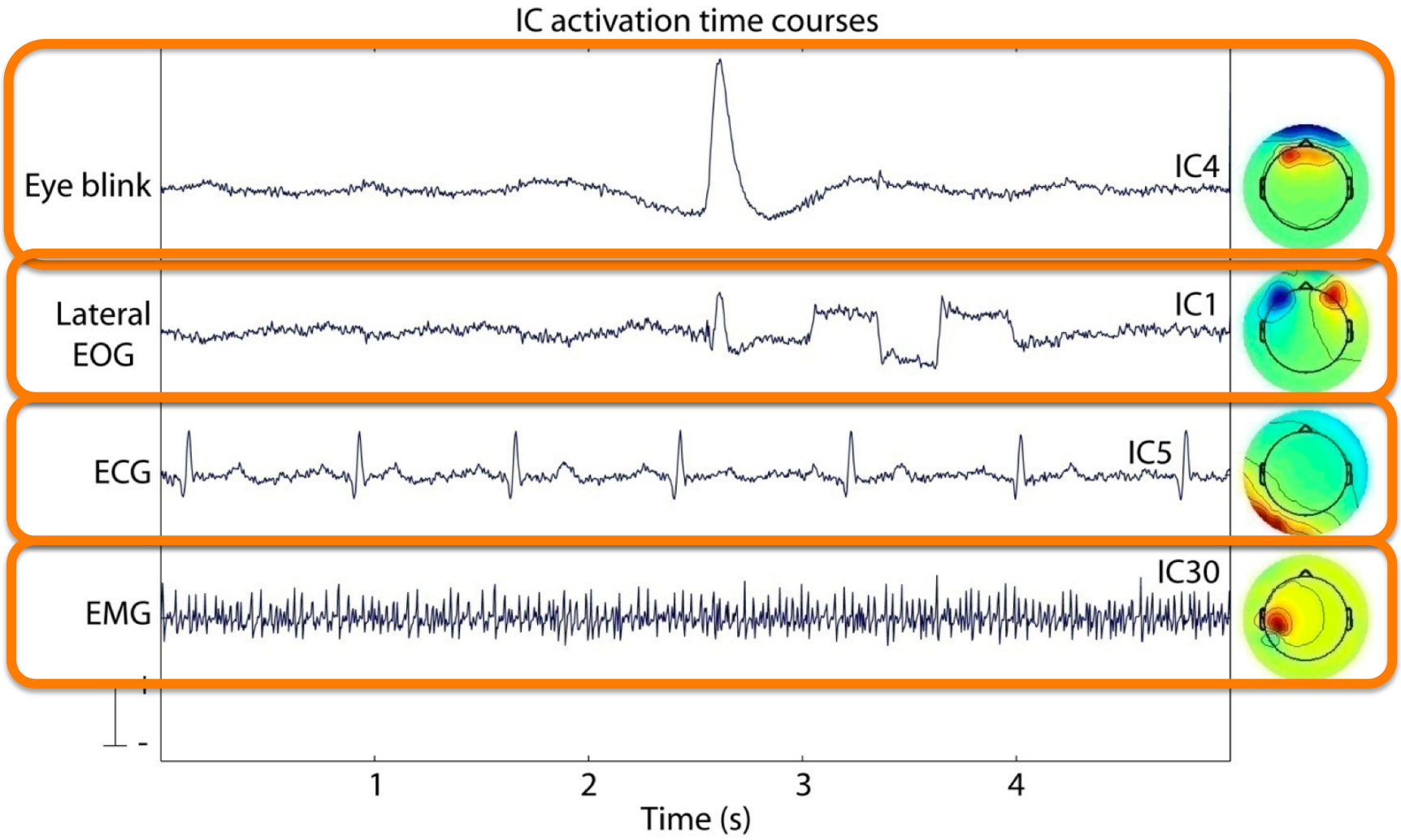
Blind EEG Source Separation by ICA

Information-based Signal Processing

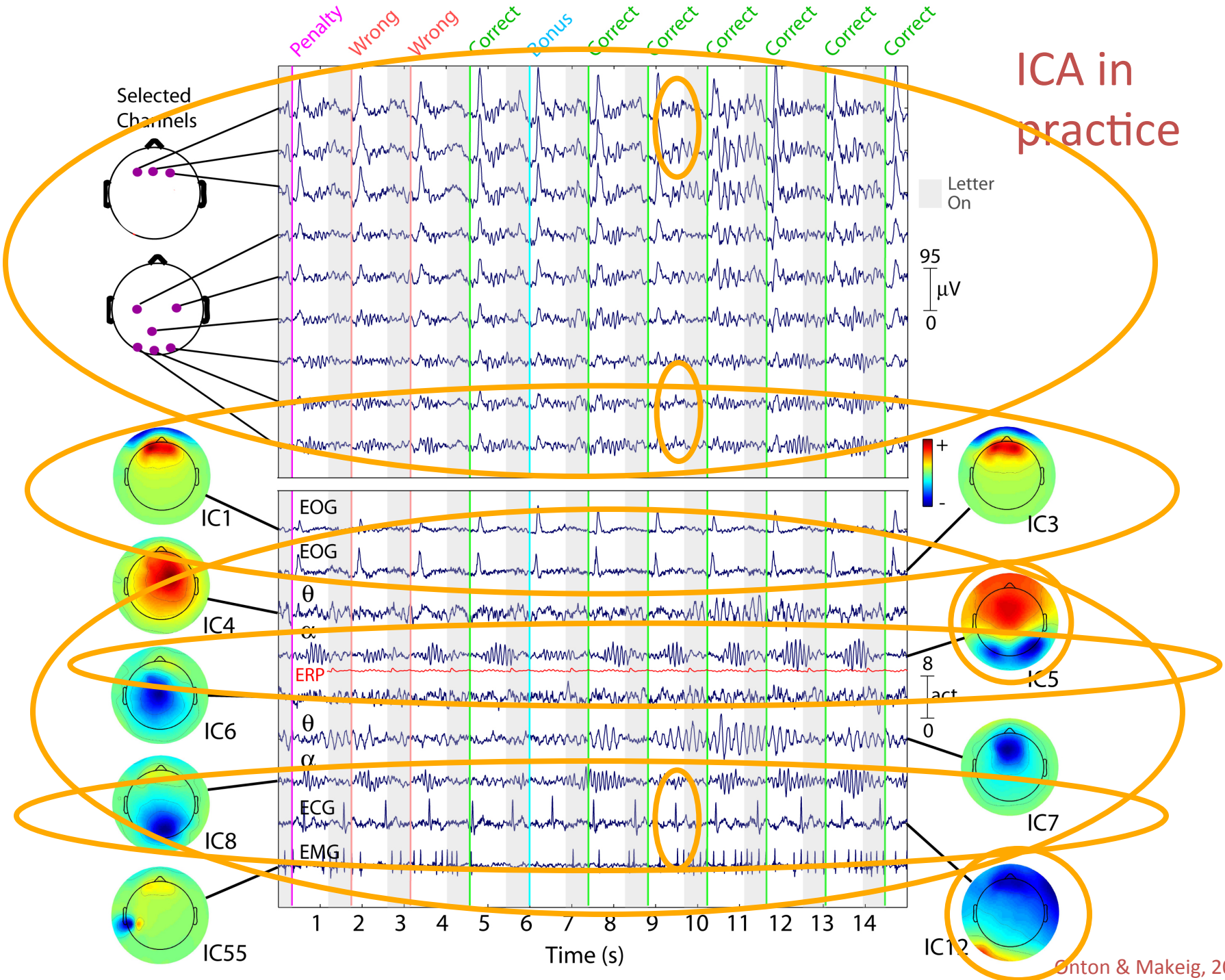




J. Onton & S. Makeig 2006



J. Onton & S. Makeig 2006


ICA in practice
Penalty
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Wrong
Correct
Bonus
Correct
Correct
Correct
Correct
Correct
Correct
Selected Channels
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95
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EOG
EOG
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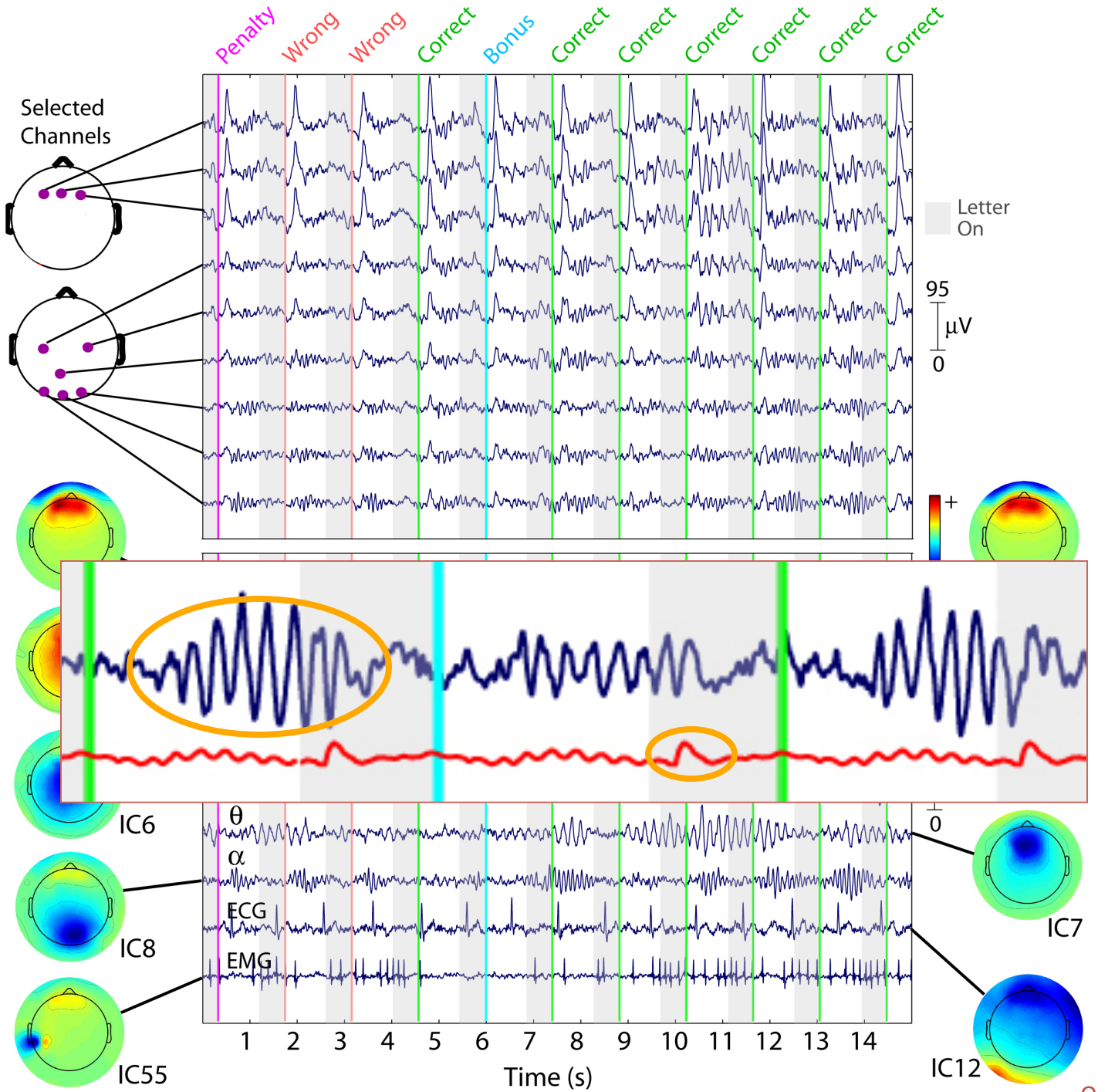
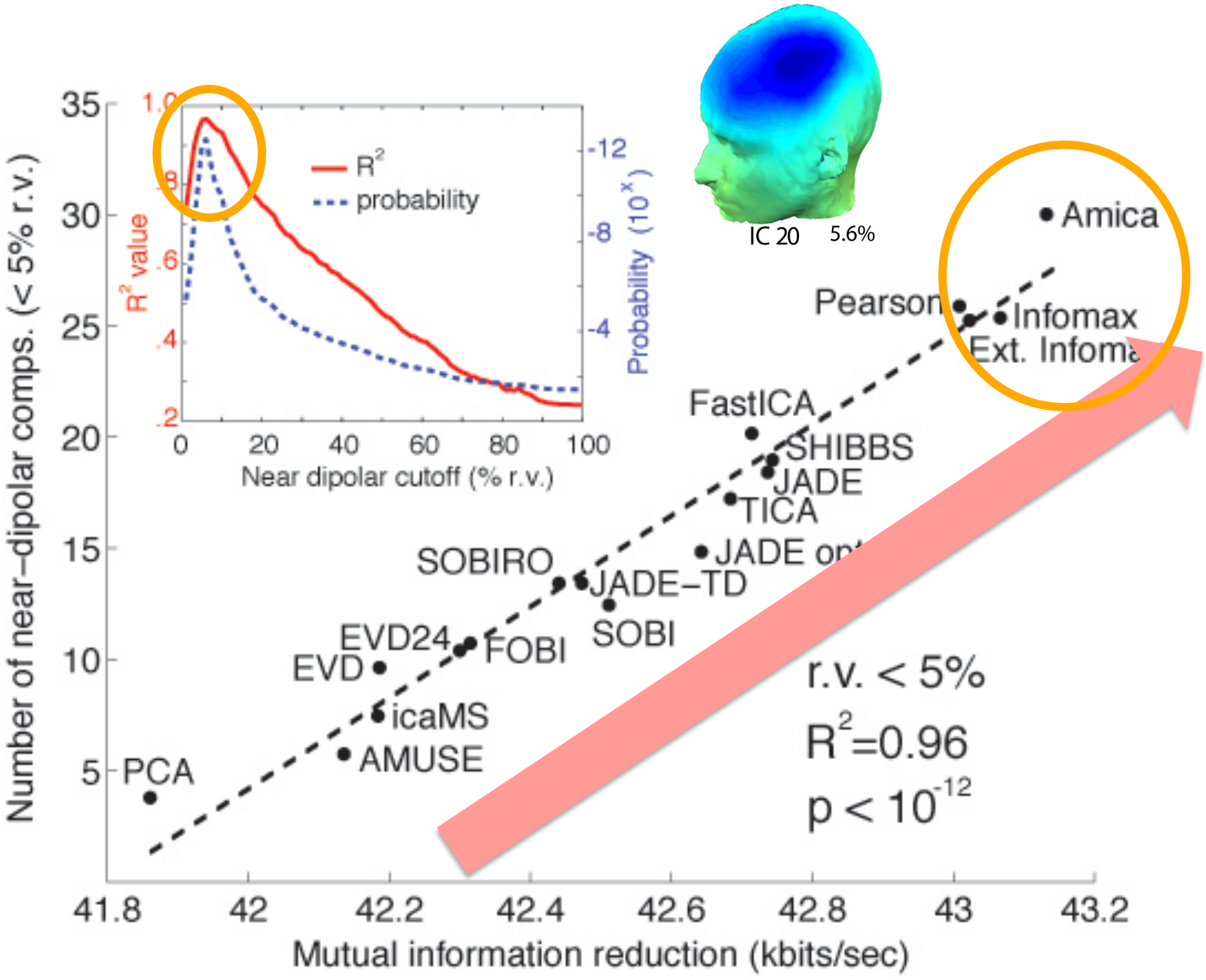
α
ERP
θ
α
ECG
EMG
8
act
0
IC1
IC3
IC4
IC5
IC6
IC7
IC8
IC55
IC12
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (s)
Onton & Makeig, 2006



Onton, Makeig (2006)



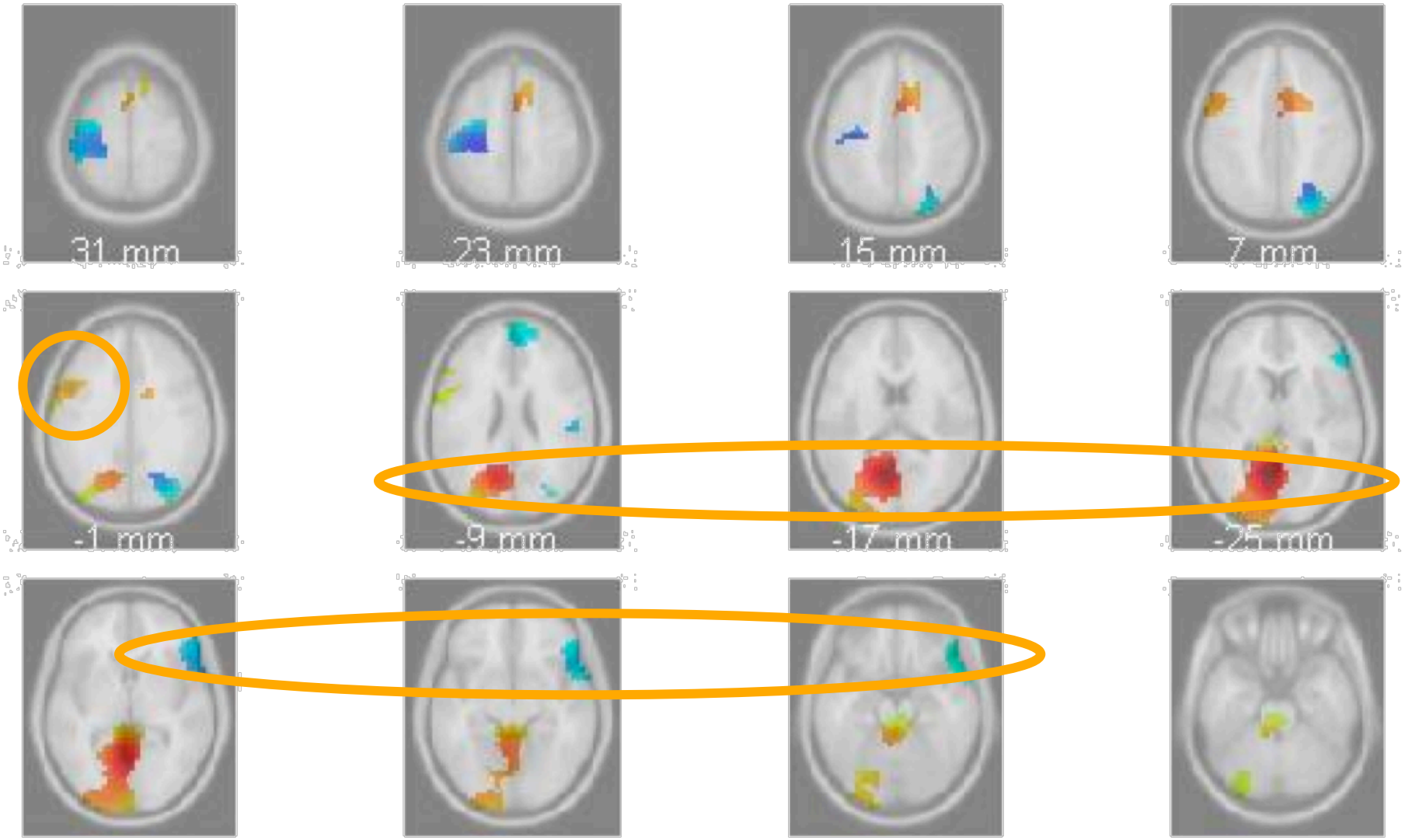
A. Delorme, J. Palmer, S. Makeig, 2009

Visual spatial working memory in young and older adults

EEG & Aging

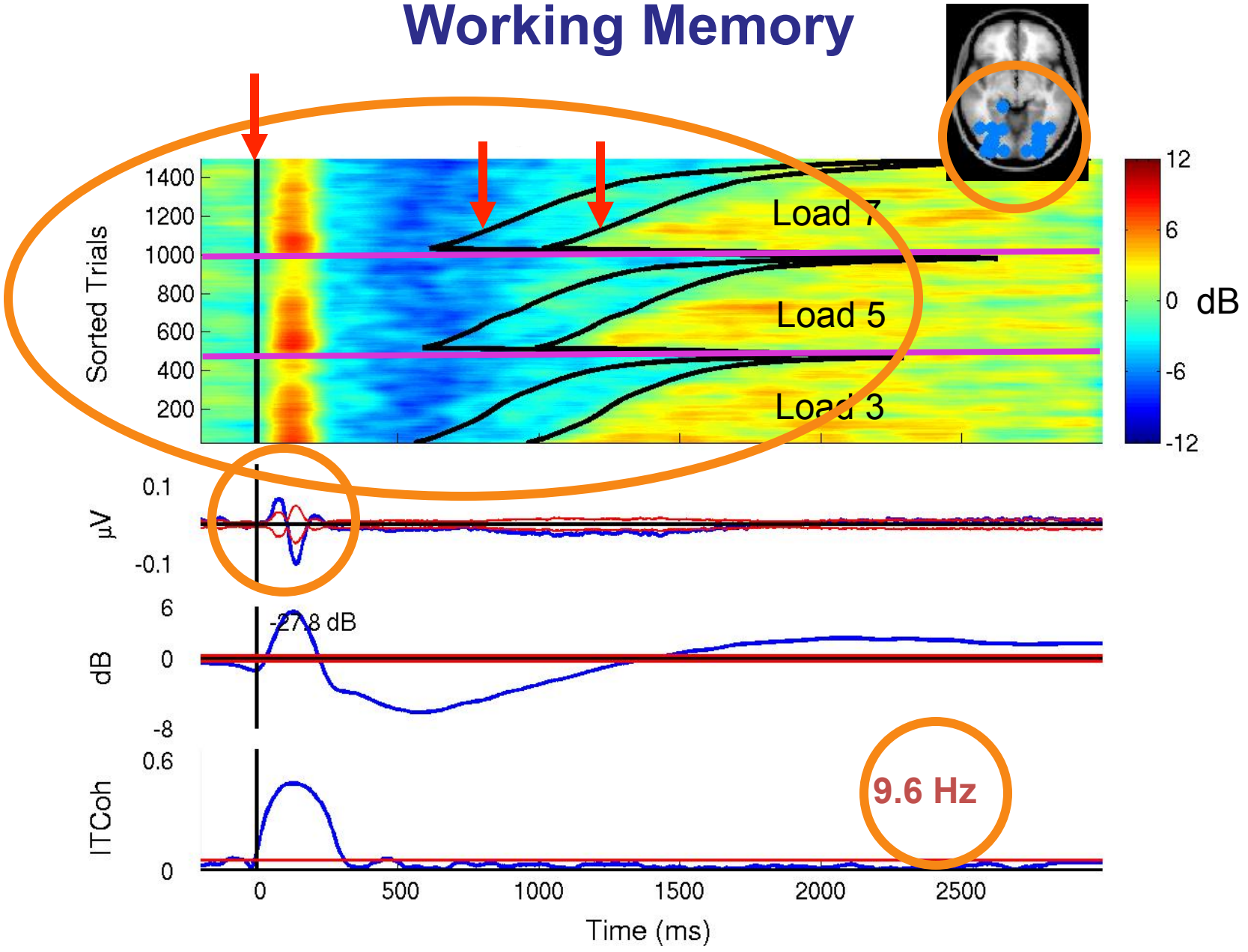
V. Bjerre J. Onton, & S. Makeig, 2006

Young adults – Older adults



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

Working Memory

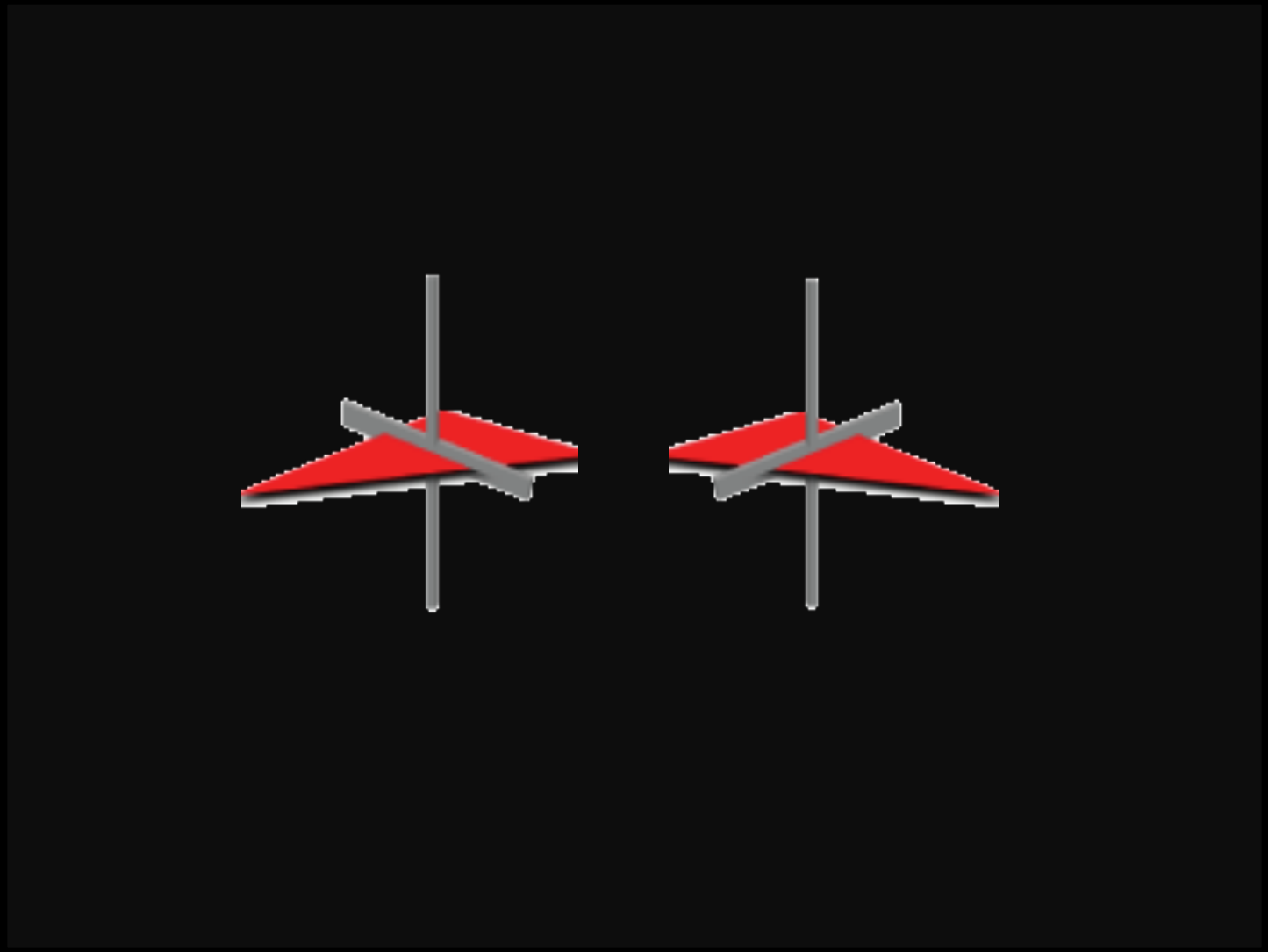


Onton & Makeig, in prep.

A Passive Spatial Navigation Paradigm

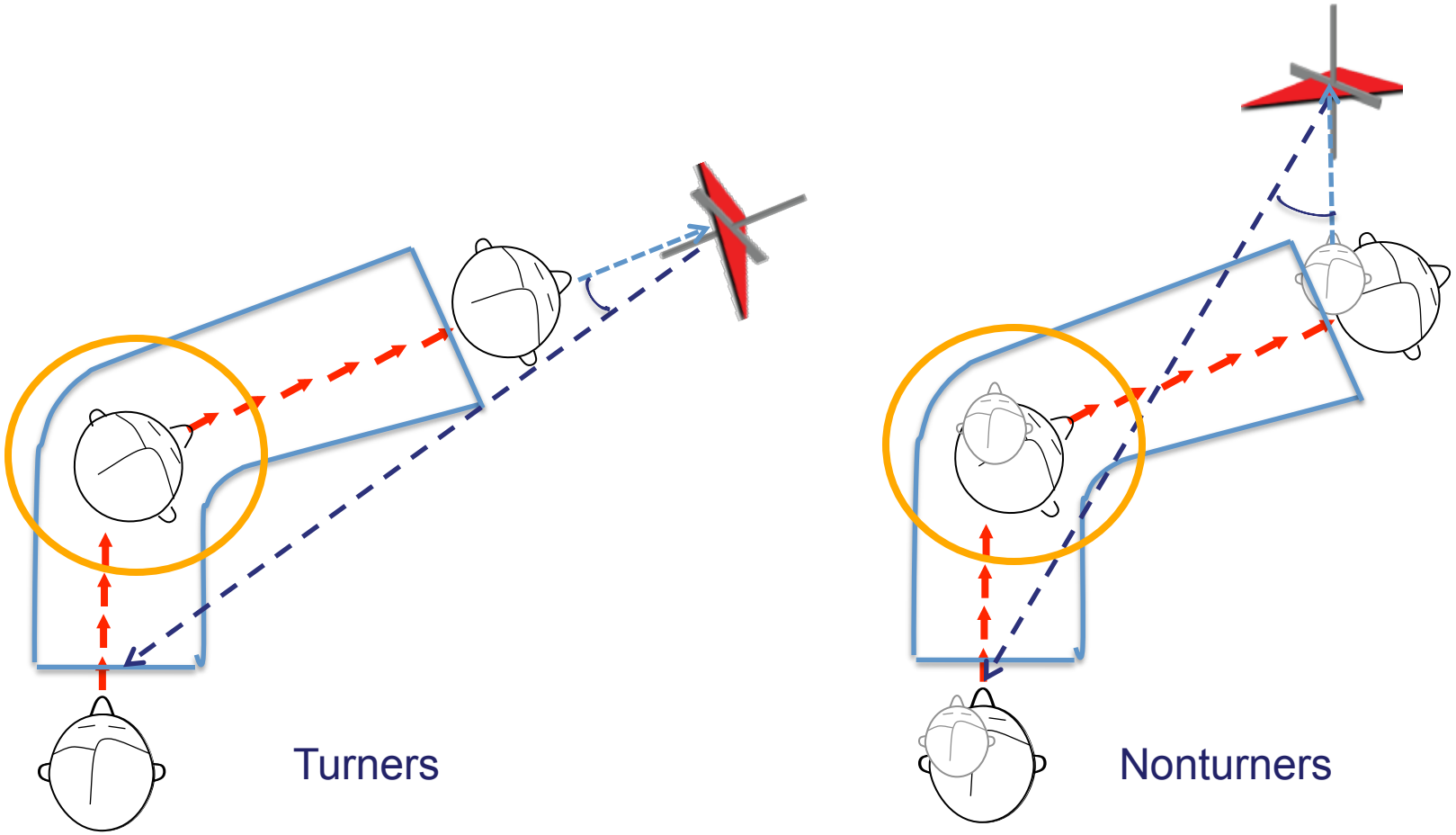
Klaus Gramann et al., 2010

A Passive Spatial Navigation Paradigm



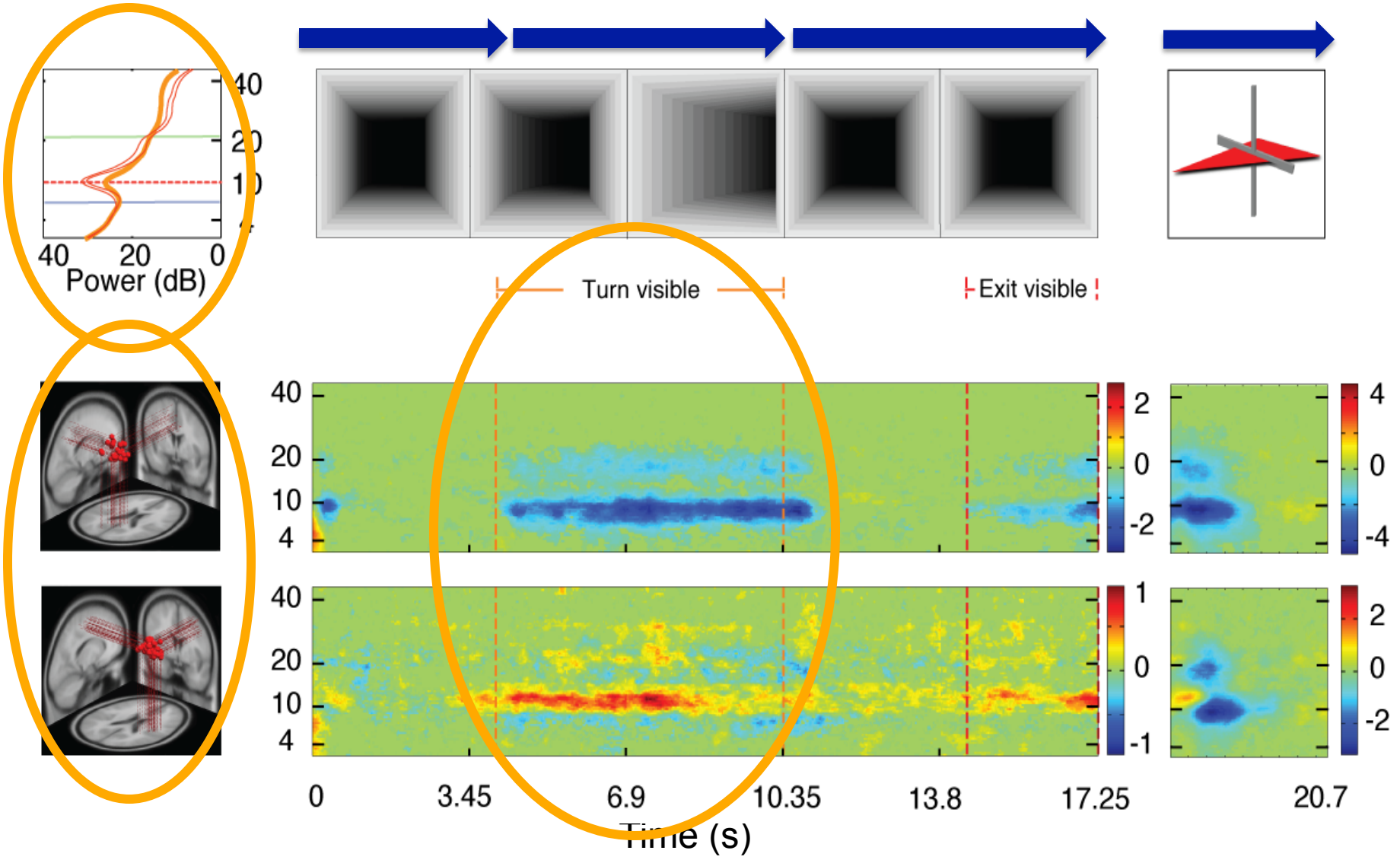
Klaus Gramann et al., 2010

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



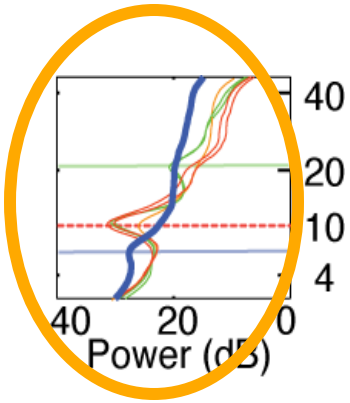
Klaus Gramann & S. Makeig, 2010

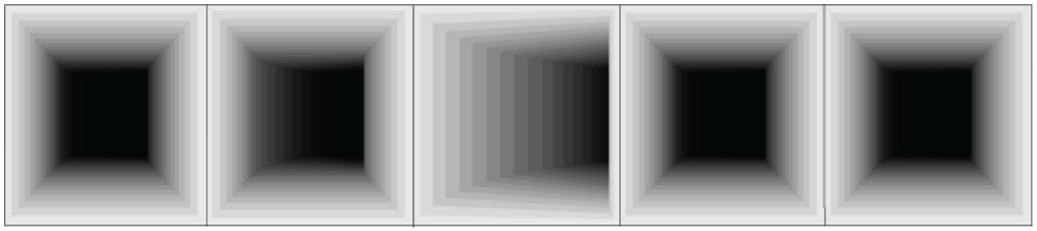
Parietal component clusters

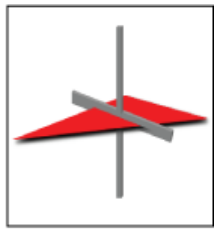


Klaus Gramann et al., 2010

Medial prefrontal component cluster

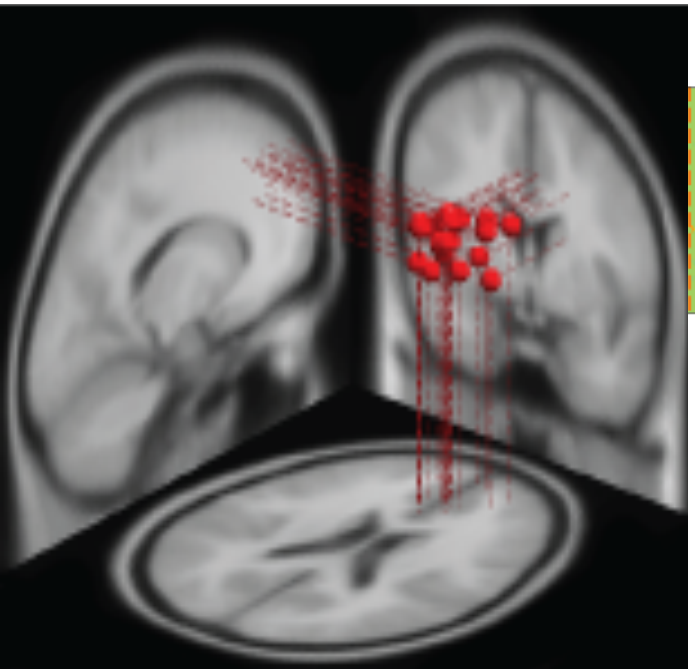


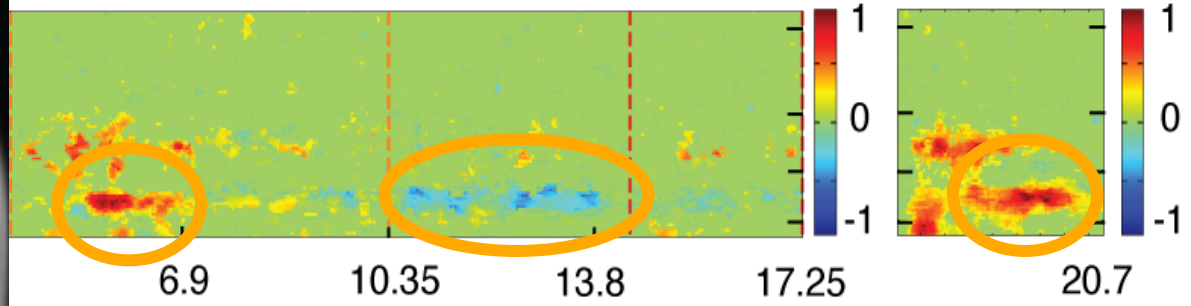




Turn visible

Exit visible

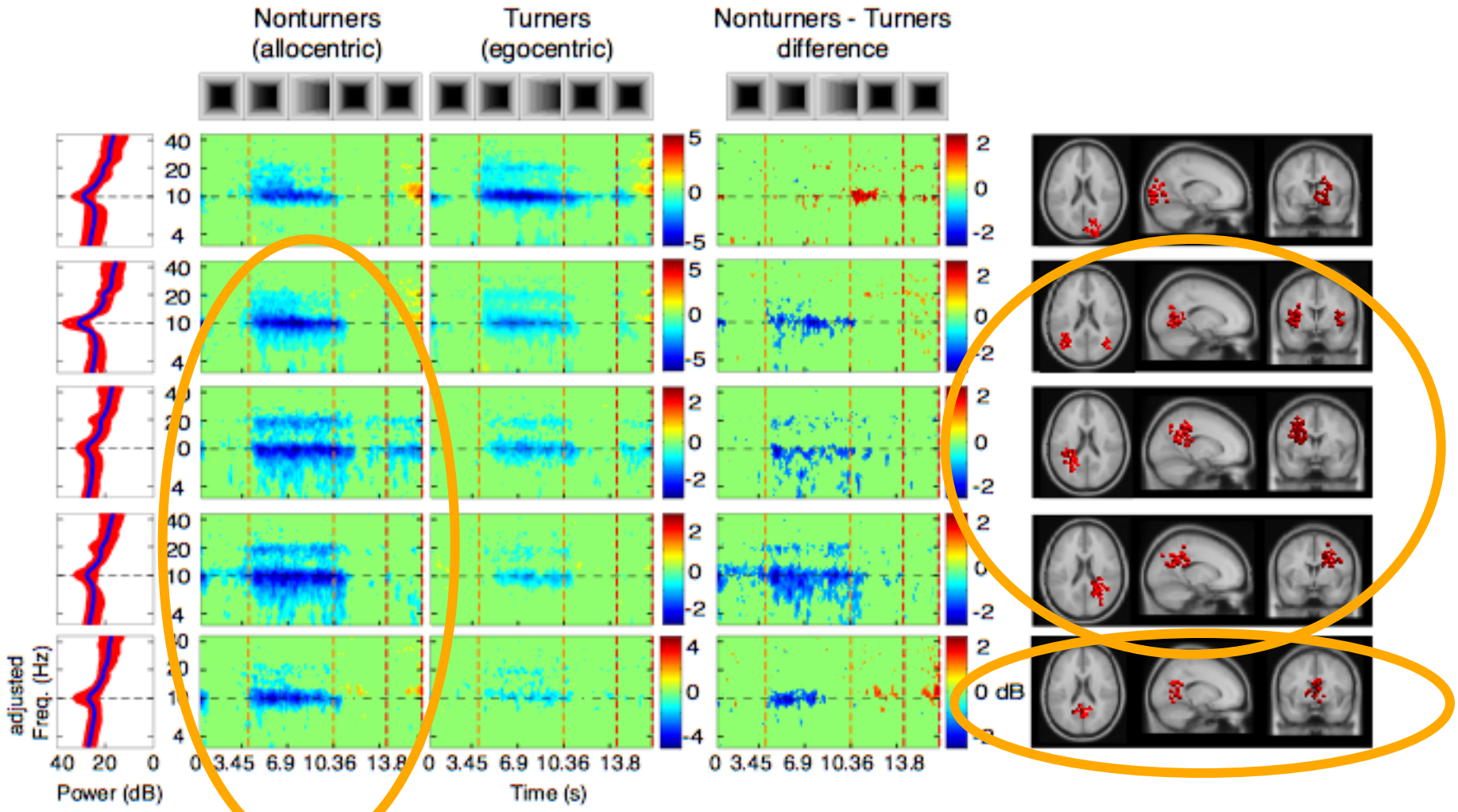




Time (s)

Klaus Gramann et al., 2010

Clusters distinguishing Turners & Nonturners

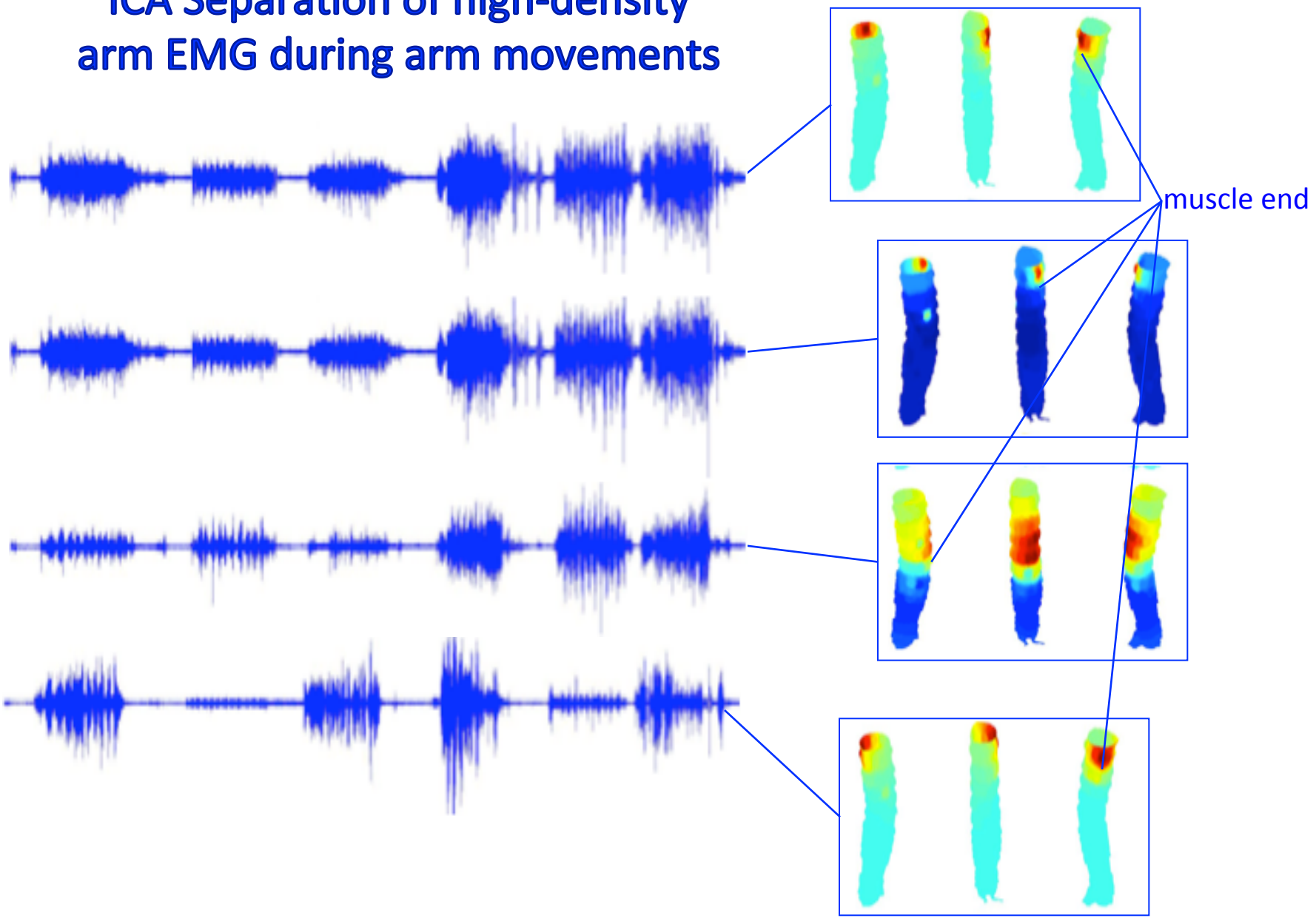


Klaus Gramann et al., 2010

High-Dimensional EMG

Cheng Cao, S Makeig 2011

ICA Separation of high-density arm EMG during arm movements



Cheng Cao, S Makeig, J Brown 2011

ICA for BCI ?

IEEE TRANSACTIONS ON REHABILITATION ENGINEERING, VOL. 8, NO. 2, JUNE 2000

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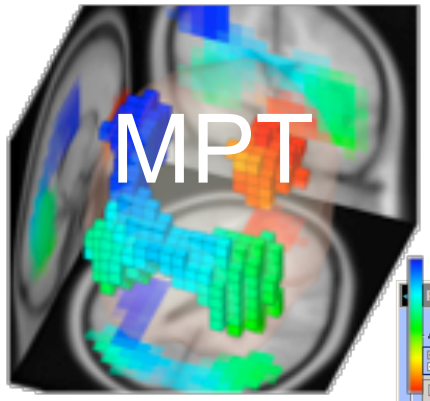
A Natural Basis for Efficient Brain-Actuated Control

Scott Makeig, Sigurd Enghoff, Tzyy-Ping Jung, and
Terrence J. Sejnowski

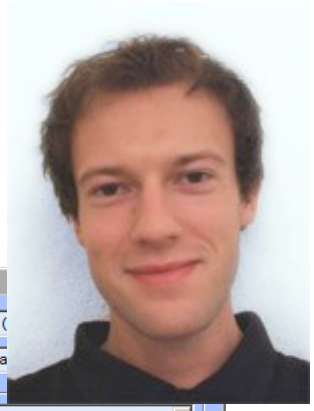
***Abstract*—The prospect of noninvasive brain-actuated control of computerized screen displays or locomotive devices is of interest to many and of crucial importance to a few 'locked-in' subjects who experience near total motor paralysis while retaining sensory and mental faculties. Currently several groups are attempting to achieve brain-actuated control of screen displays using operant conditioning of particular features of the spontaneous scalp electroencephalogram (EEG) including central μ-rhythms (9–12 Hz). A new EEG decomposition technique, independent component analysis (ICA), appears to be a foundation for new research in the design of systems for detection and operant control of endogenous EEG rhythms to achieve flexible EEG-based communication. ICA separates multichannel EEG data into spatially static and temporally independent components including separate components accounting for posterior alpha rhythms and central μ activities. We demonstrate using data from a visual selective attention task that ICA-derived μ-components can show much stronger spectral reactivity to motor events than activity measures for single scalp channels. ICA decompositions of spontaneous EEG would thus appear to form a natural basis for operant conditioning to achieve efficient and multidimensional brain-actuated control in motor-limited and locked-in subjects.**

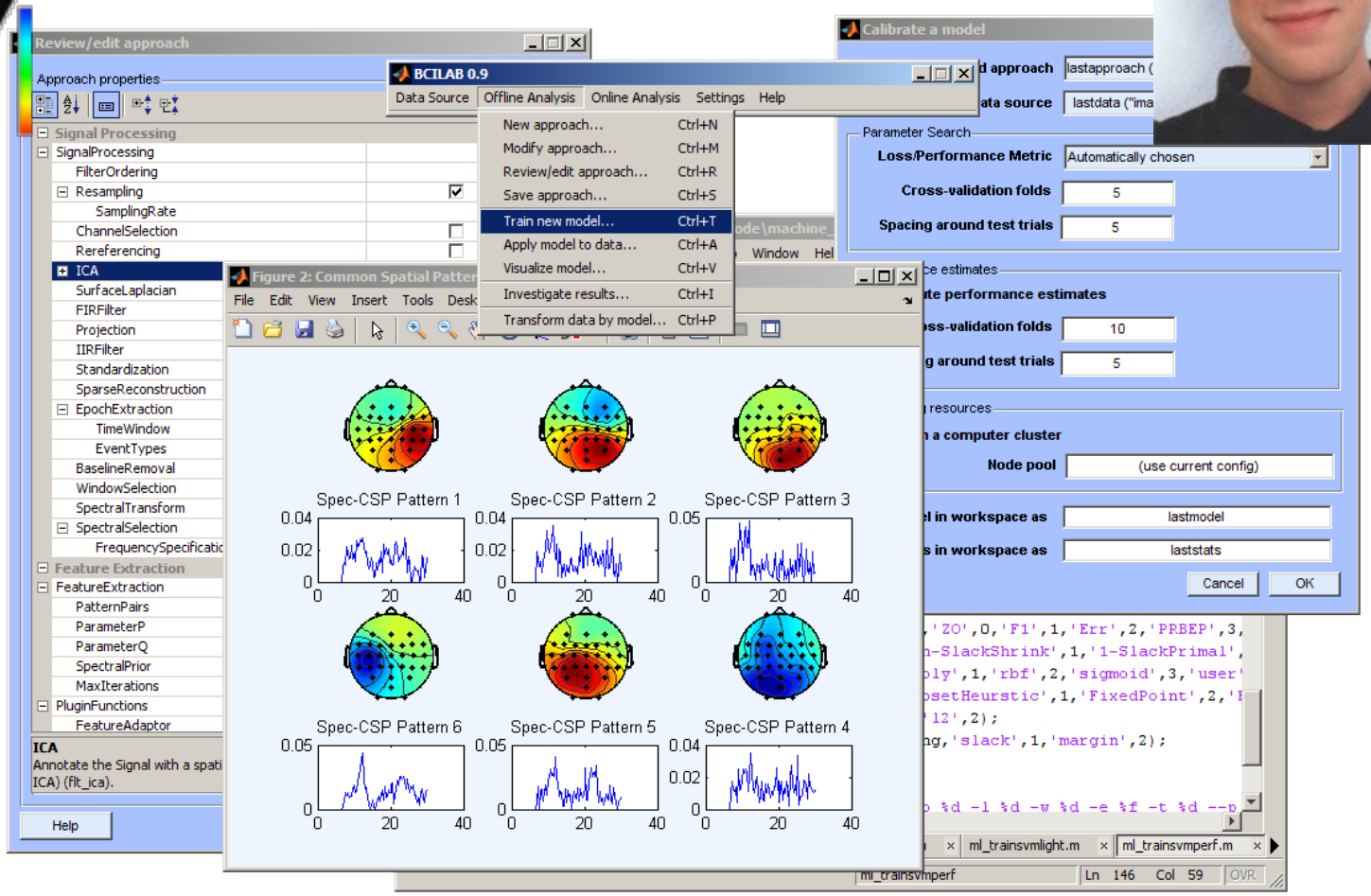
I. Introduction

Recent work in several laboratories has demonstrated that noninvasively recorded electric brain activity can be used to voluntarily control switches and communication channels, allowing a few so-called locked-in near-totally paralyzed subjects the ability to communicate, however slowly, with their families and aides ([4]; [14]; [2]). Communication rates achieved to date are in the range of several bits a



BCILAB



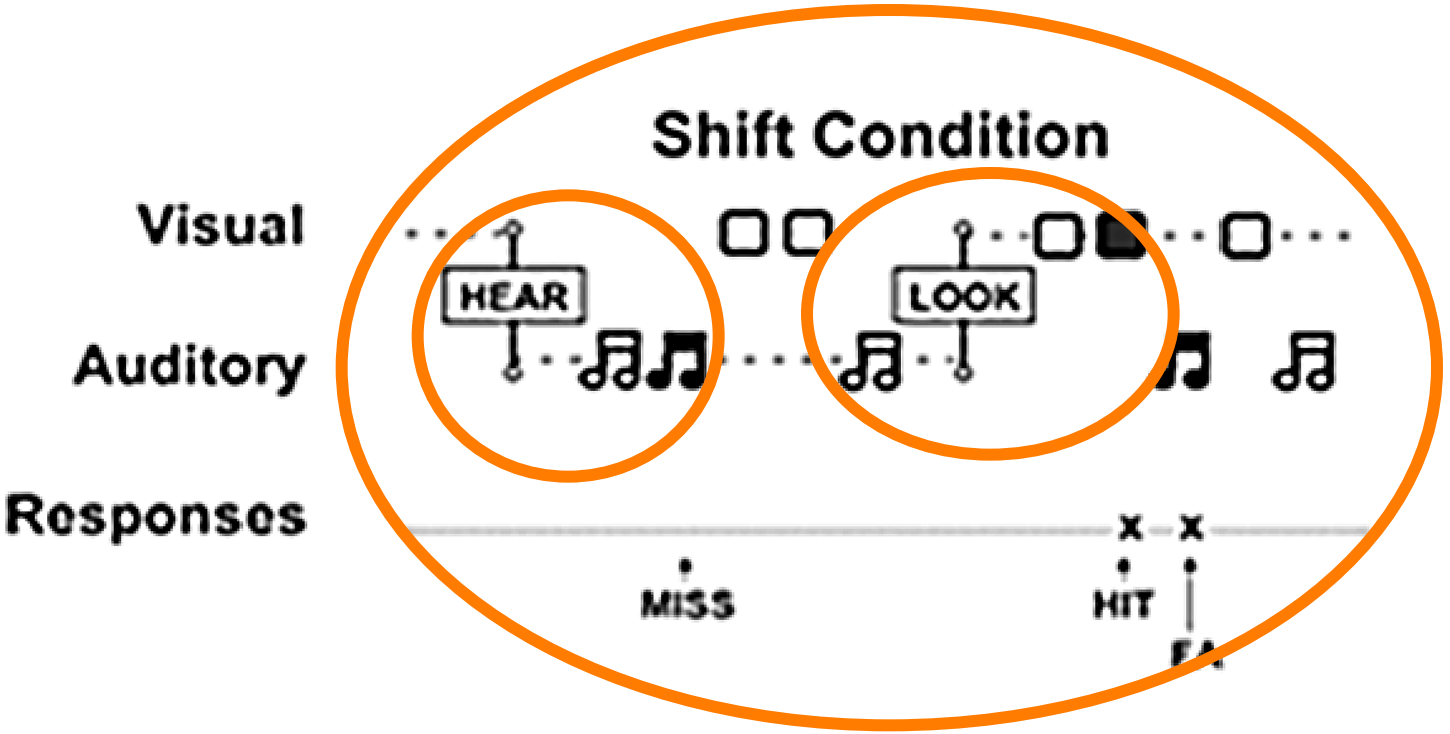


sccn.ucsd.edu/**wiki/BCILAB**

C Kothe 2011

Audiovisual Attention Shift Experiment

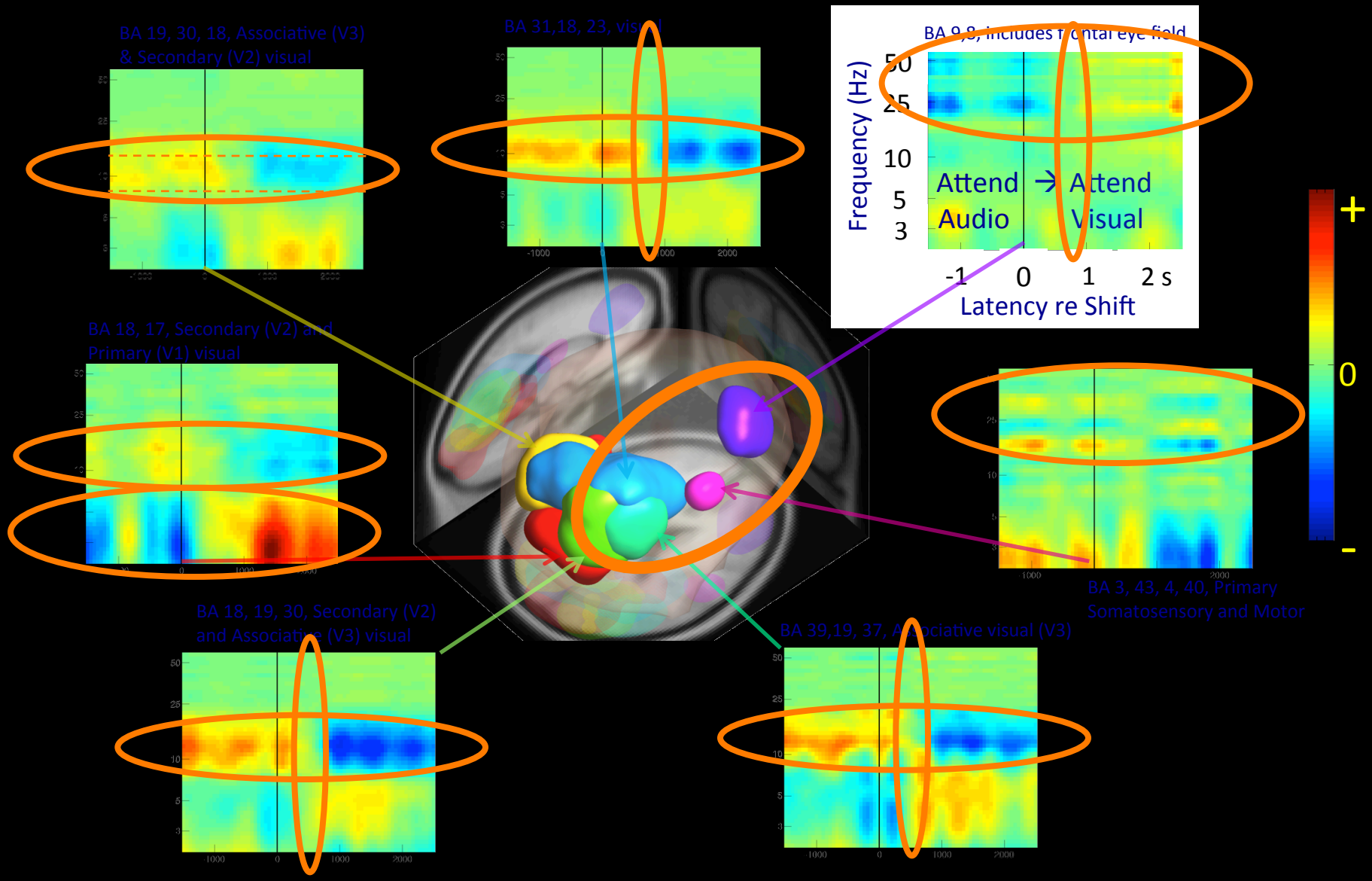
Question: What is the brain activity signature of switching between auditory and visual attention? (DAS)



J Townsend et al., 2003

An EEG Attention-Shift Network

Informative Feature Analysis (IFA)



N Bigdely-Shamlo, C Kothe, S Makeig 2011

Brain imaging during movement – How?

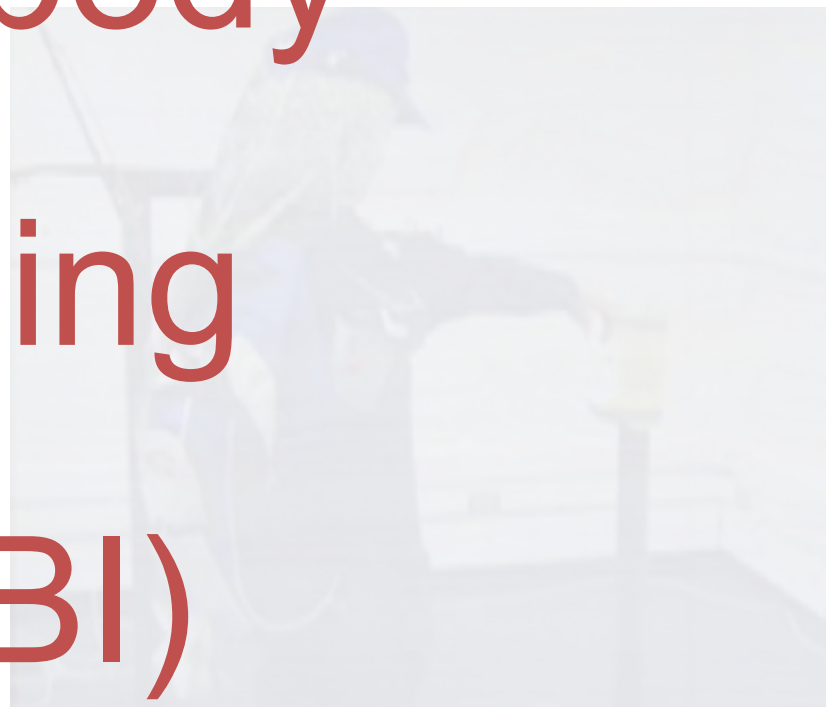
- Current advances in miniaturization, computer power, and information-based signal processing make possible a new imaging modality:

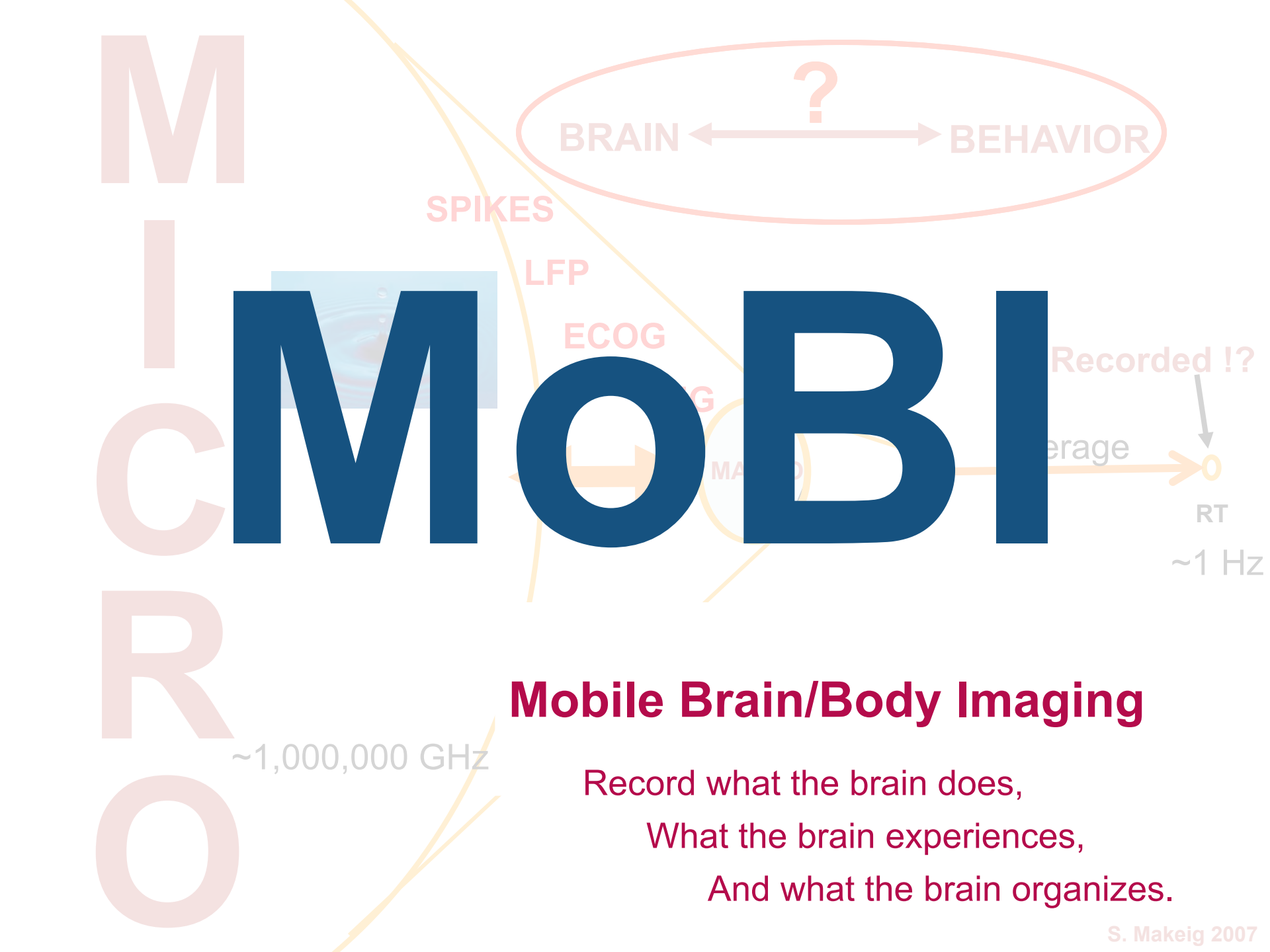
→ **Mobile Brain/Body Imaging** (MoBI)

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.





MoBI

Mobile Brain/Body Imaging

Record what the brain does,

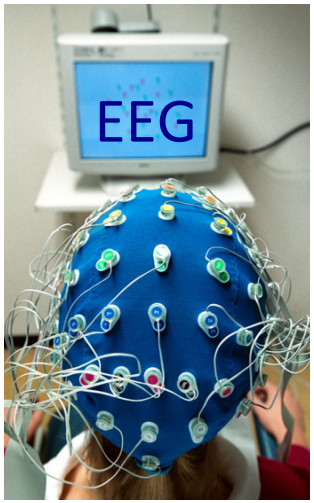
What the brain experiences,

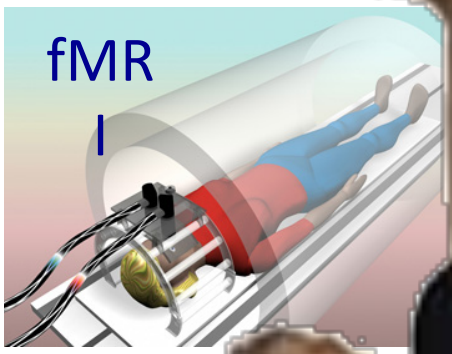
And what the brain organizes.

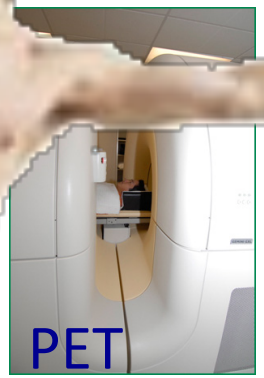
S. Makeig 2007

Brain imaging during motor behavior?

- Nearly all brain imaging studies (MEG, PET, fMRI, and EEG) are conducted in rigidly stat[illegible]ted or prone positions with only the most minimal fi[illegible]moven allowed.







Why?

- In all modalities but EEG, [illegible]ors are **heavy**.
- Muscle and movements contri[illegible]('noise') signals.

- **But this limitation is highly artificial.** Nearly all our life [illegible]lves *active movements* and *interactions* within a 3-D environment.
- → **Brain activity during free movement in 3-D space**

has never been observed or modeled!

Scott Makeig 2008

Mobile Brain/Body Imaging (MoBI)

1. Record simultaneously, during naturally motivated behavior,

What the brain does (high-density EEG)

What the brain experiences (sensory scene recording)

What the brain organizes (body & eye movements, psychophysiology)

2. Then –

Use evolving machine learning methods

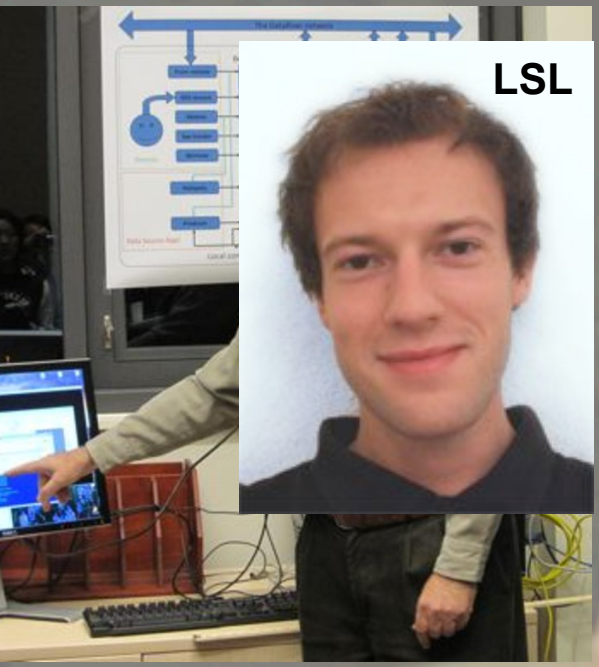
to find, model, and measure

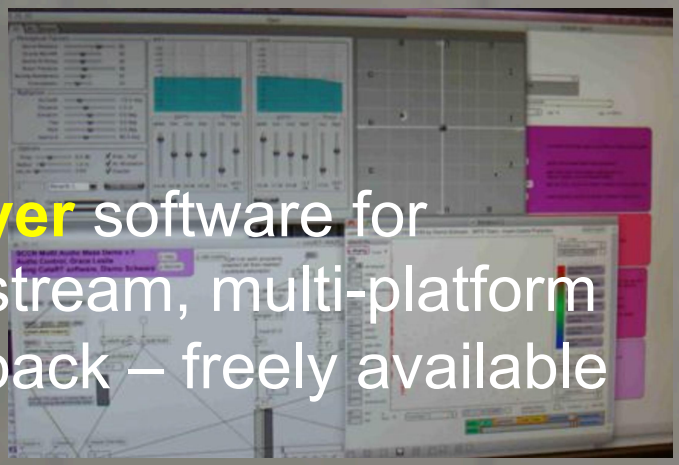
non-stationary (context- and intention-related)

functional relationships among these data modalities.

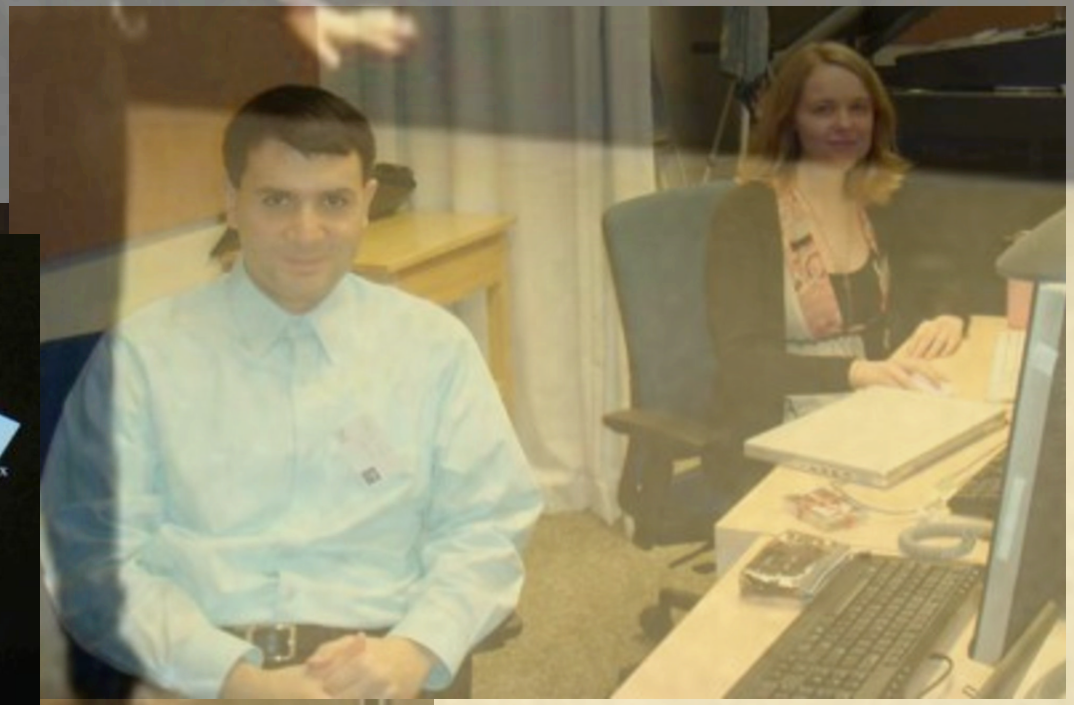
Scott Makeig, 2011

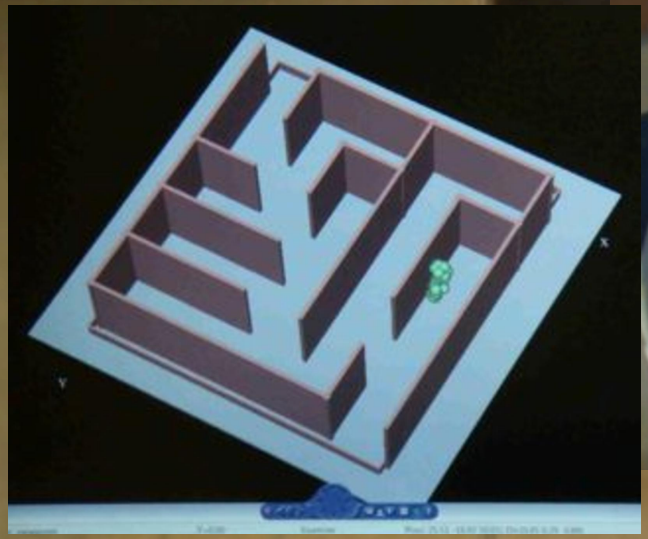
MoBI Lab at SCCN, UCSD





Lab Streaming Layer software for synchronous multi-stream, multi-platform recording and feedback – freely available on Google Code.





http://thesciencenetwork.org/programs/inc-sccn-open-house/inc-sccn-open-house-hi-lite-reel

S Makeig & M Miyakoshi, 20112

MoBI Lab: Two-Person Mirroring Experiment

Photo: T Bel Bahar & E Tumer, 2011

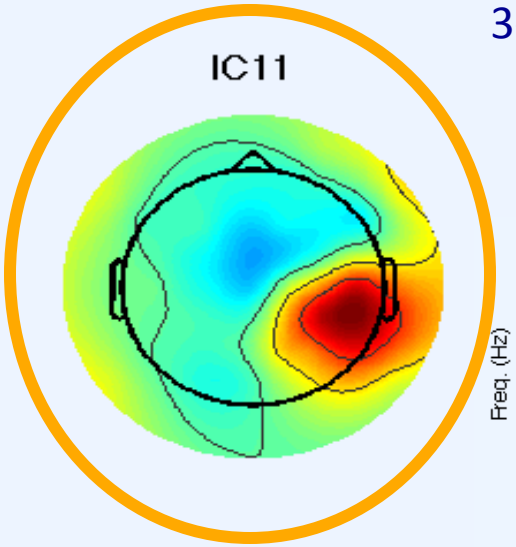
Development of Shared Attention –
A Mom and Child MoBI Experiment

Gedeon Deak et al., 2011

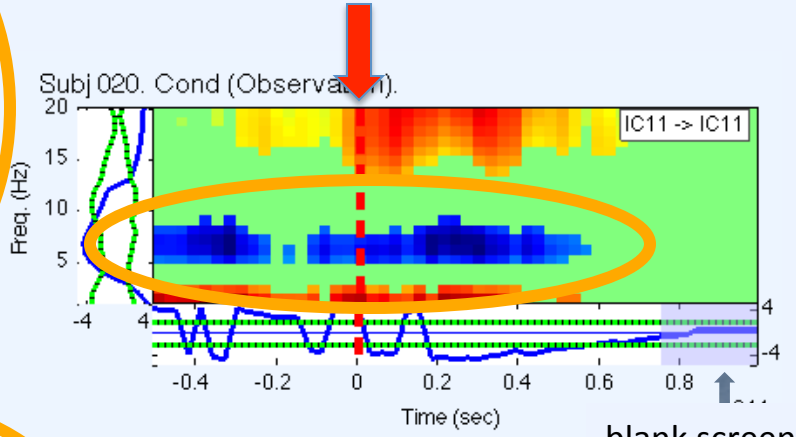
Development of Shared Attention – A Mom and Child MoBI Experiment

Gedeon Deak et al., 2011

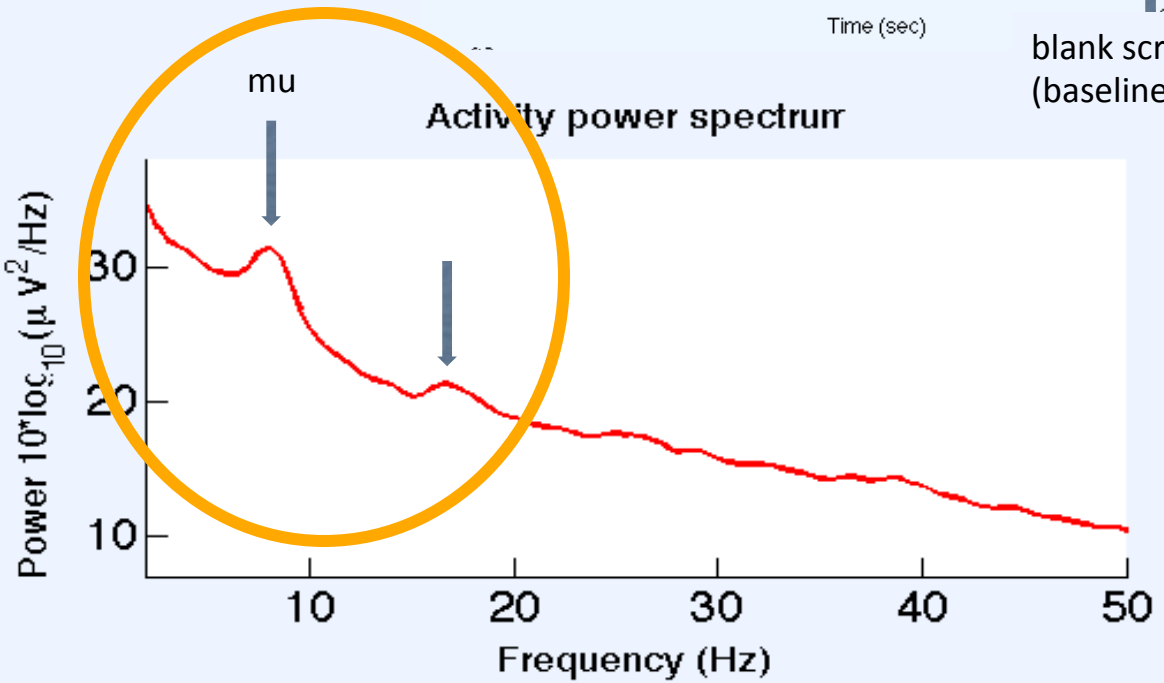
3-yr old child – Reward Observation



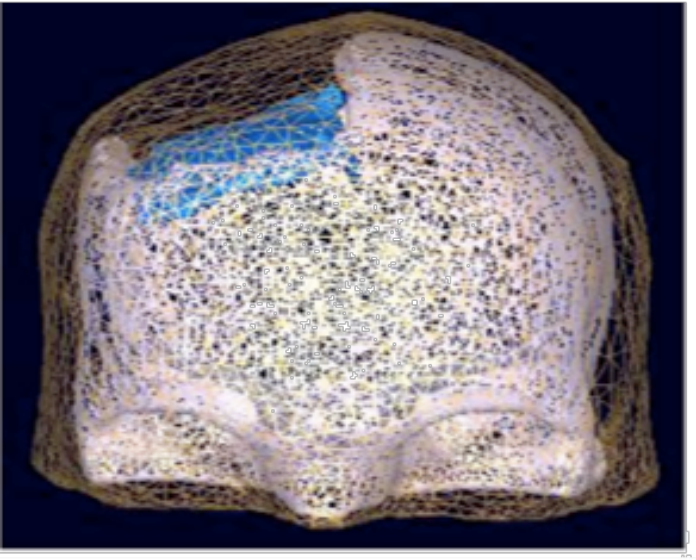
Mother Pops the Bubble!



blank screen (baseline)



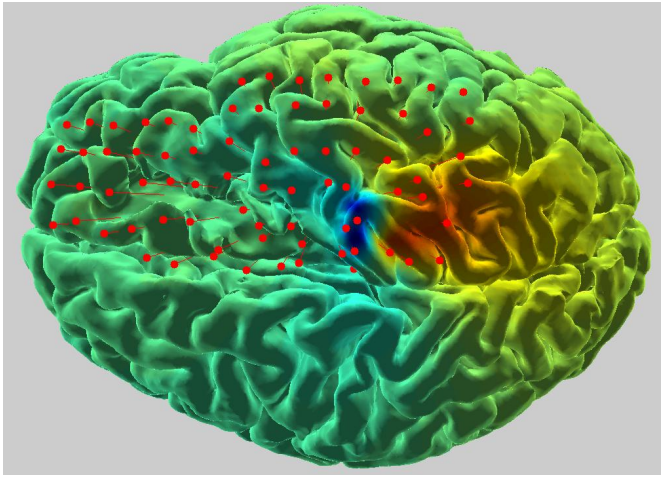
Yu Liao, T Mullen ,S Makeig, G. Deak 2011

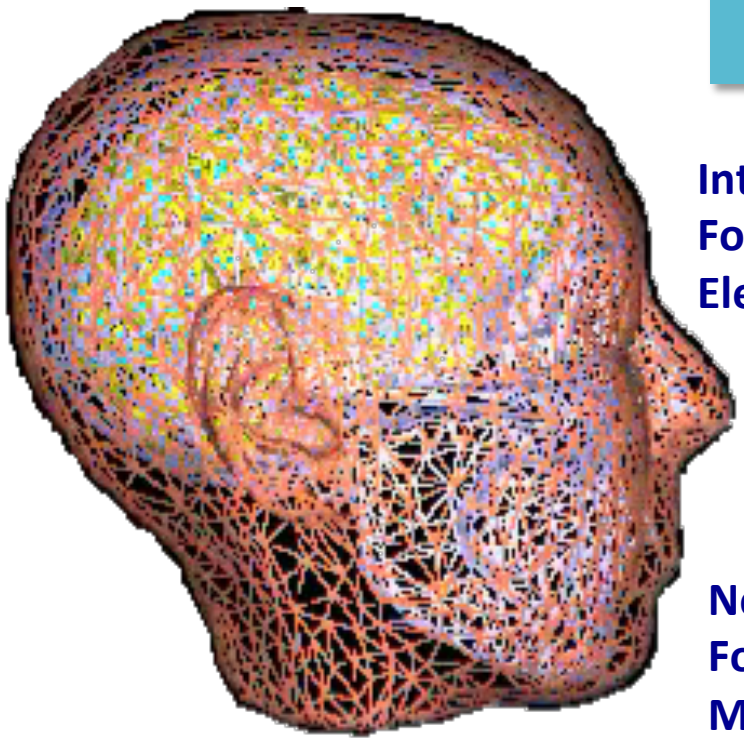


Invasively Monitored Head -- Forward Electrical Model

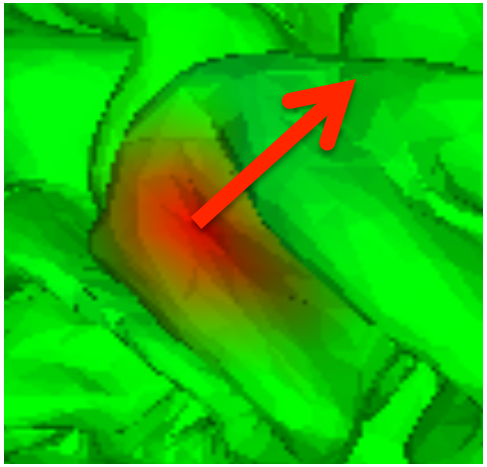
Electrical Brain Source Analysis for ECoG

Independent Component Source of ECiG Data





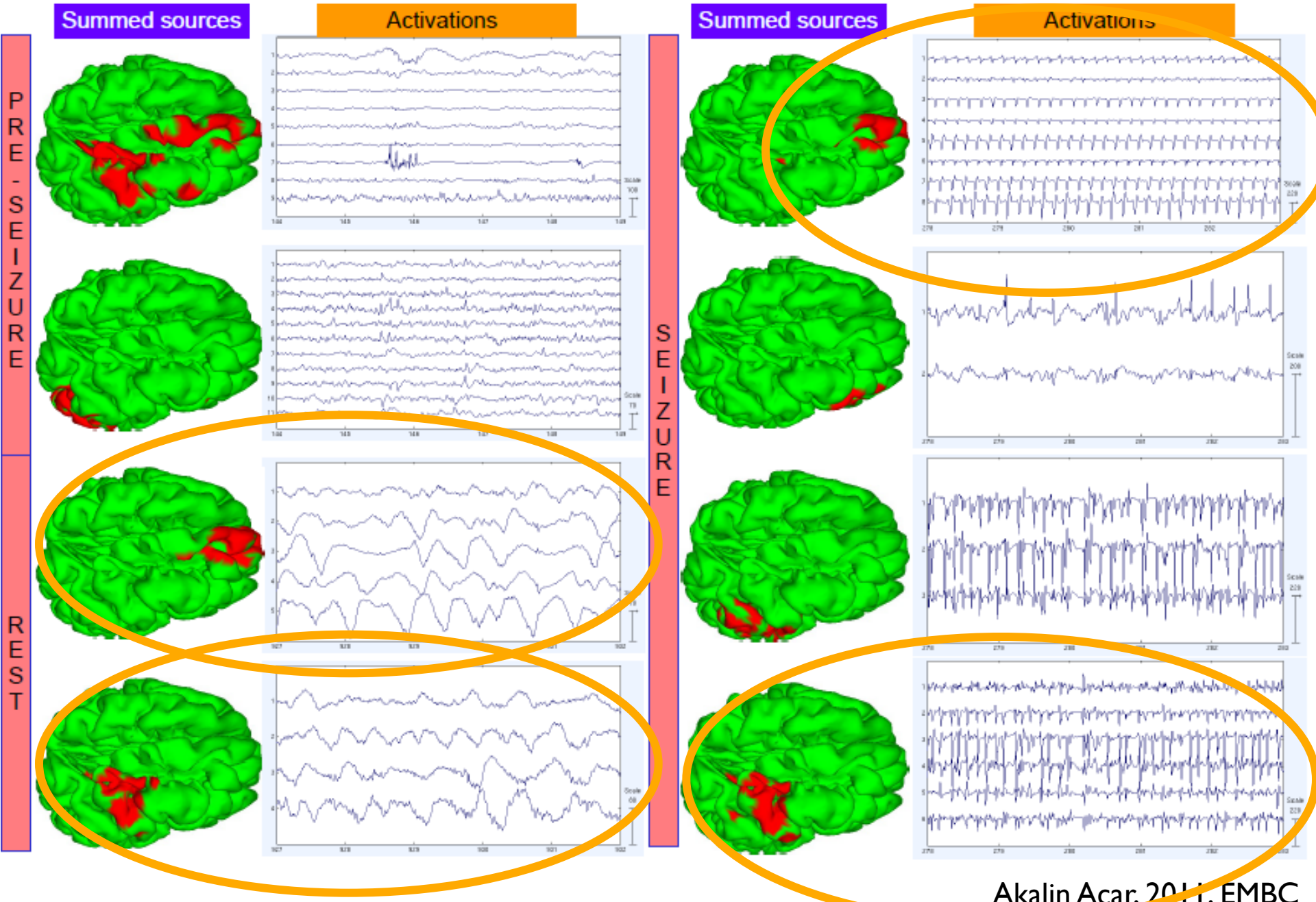
Intact Head -- Forward Electrical Model



Source Patch in Sulcus Estimated using the Forward Head Model

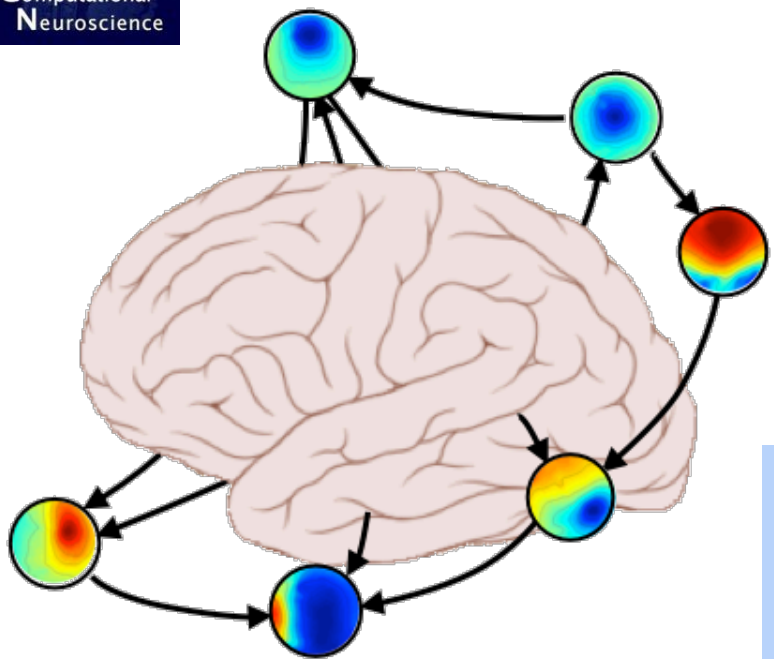
Neuroelectromagnetic Forward Head Modeling Toolbox (NFT)

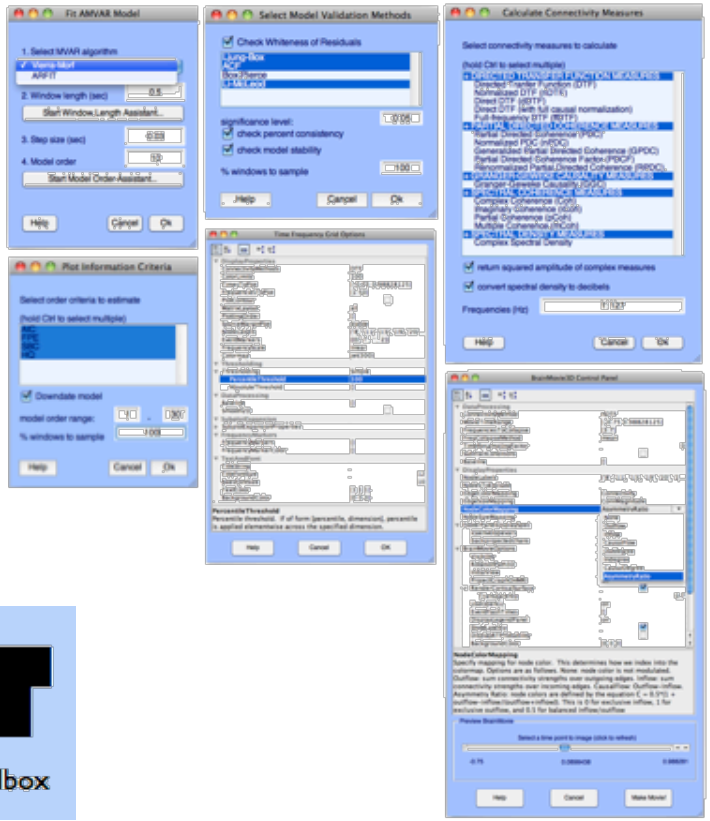
Akalin Acar, Palmer, Makeig, 2009



Akalin Acar, 2011, EMBC

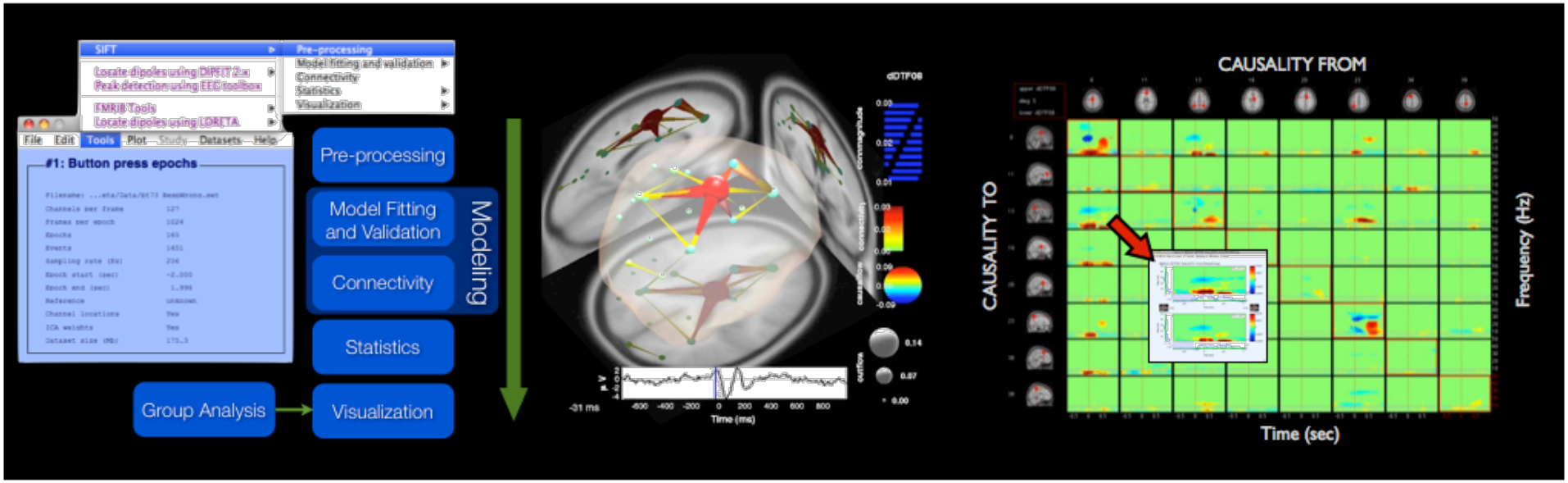
Swartz Center for Computational Neuroscience





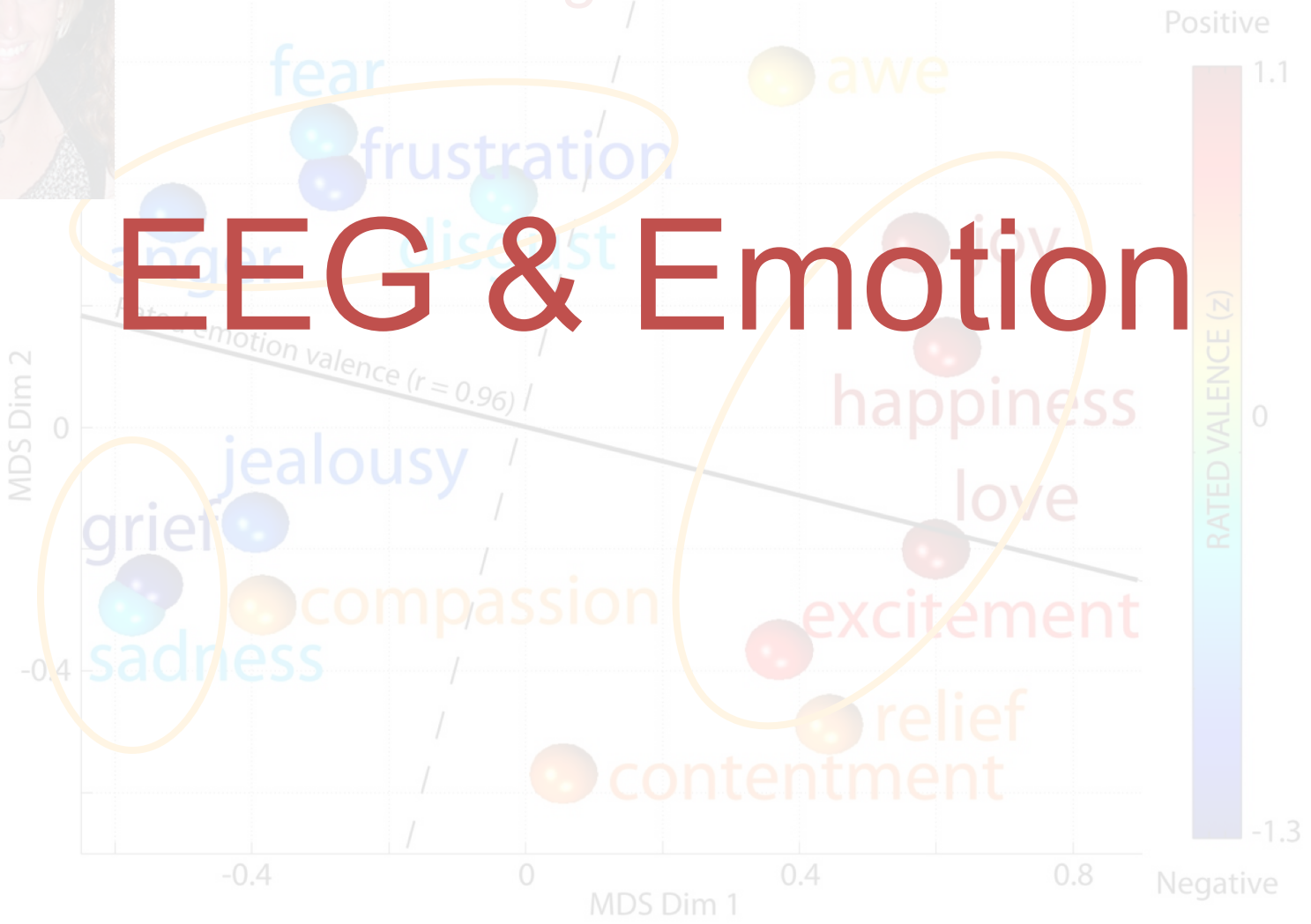
SIFT

Source Information Flow Toolbox



EEG & Emotion

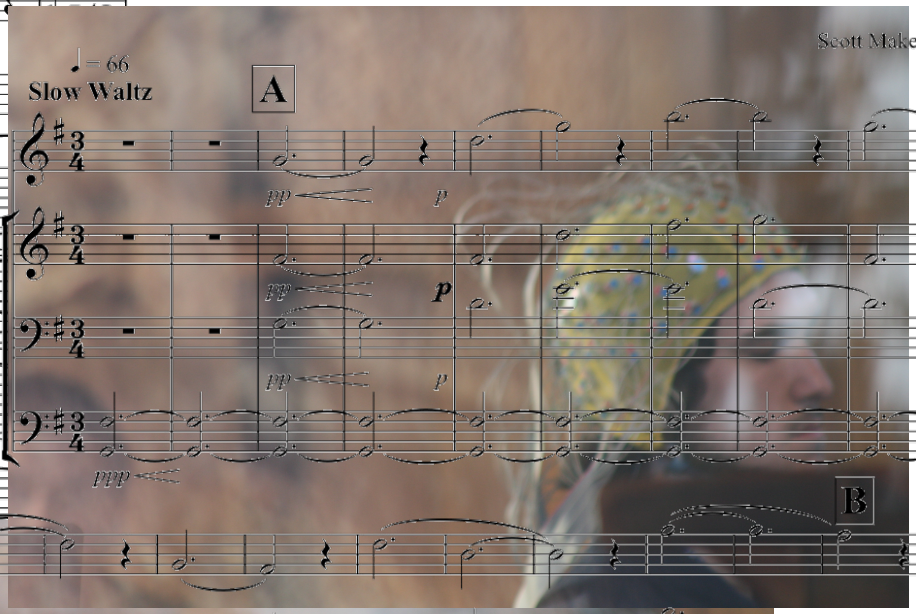
Changes in distribution of broadband high-frequency EEG power with imagined emotion



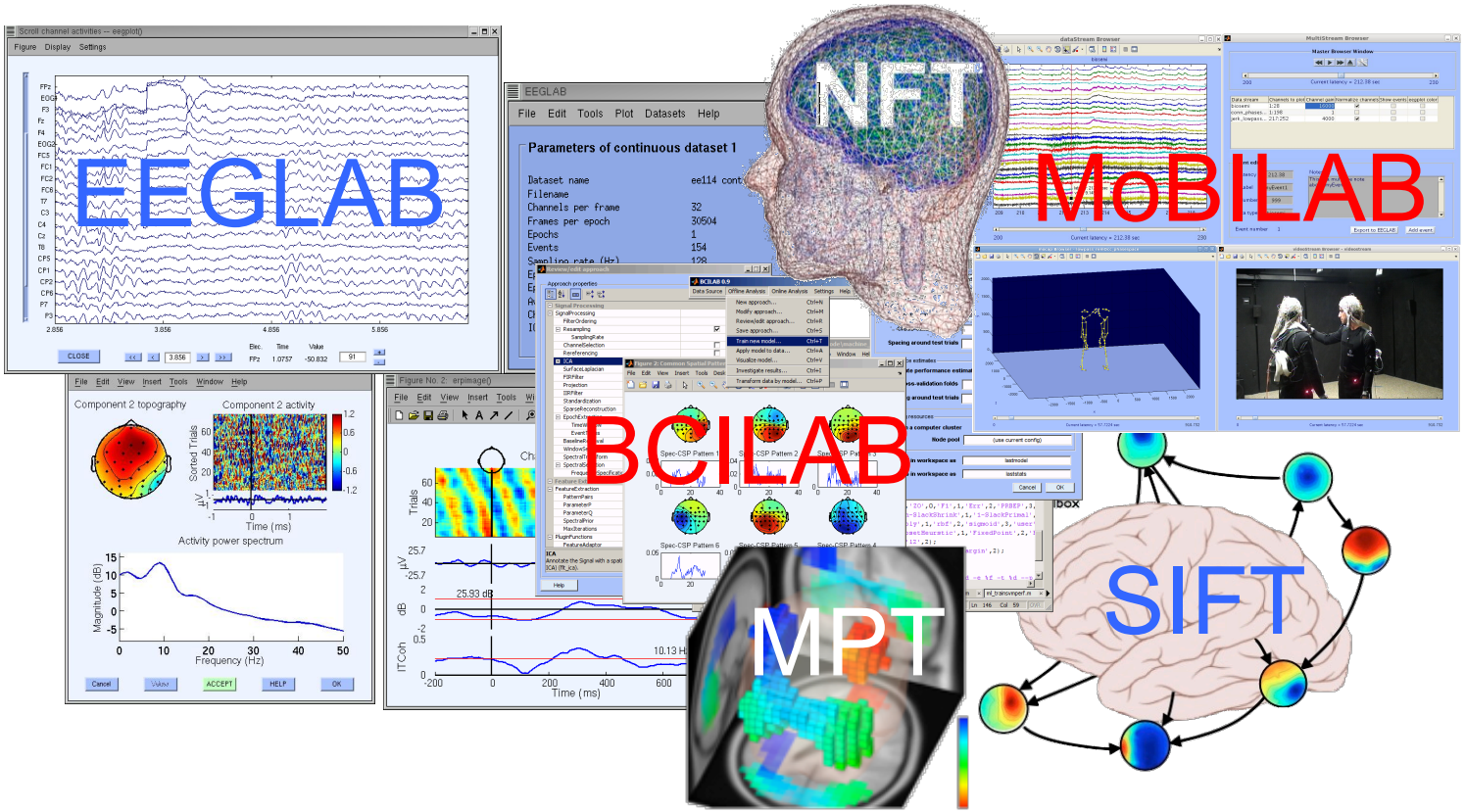
Julie Onton & Scott Makeig, *Frontiers in Human Neuroscience*, 2009

JUST: A quartet suite for flute, violin, cello, and brain

Fourth International BCI Meeting
Asilomar Meeting Grounds, Pacific Grove, CA
June, 2010



SCCN Open Source Software Tools for MATLAB



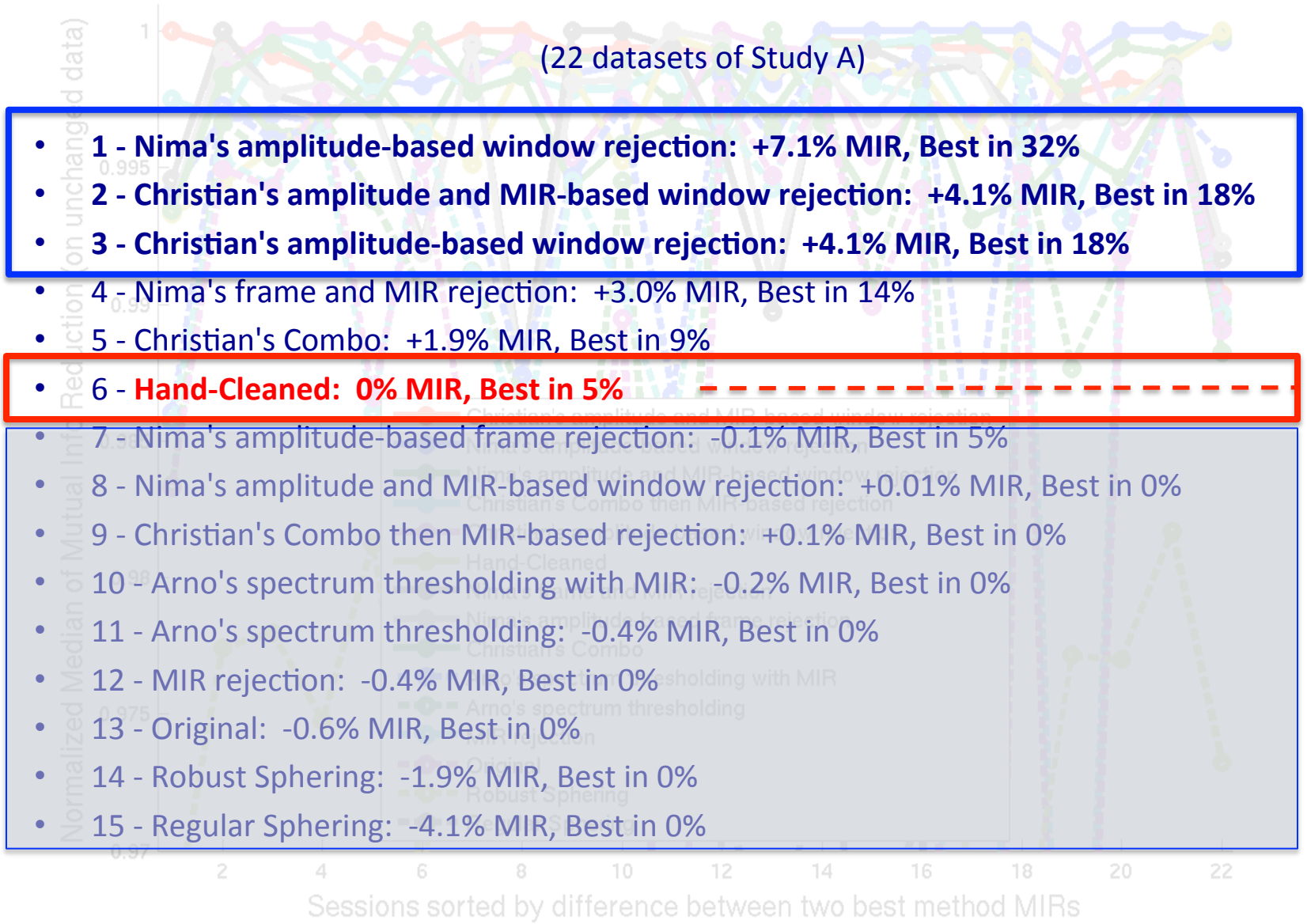
Tools available -- but a two-cultures problem …

S Makeig, 2012

Comparing ICA cleaning methods

(22 datasets of Study A)

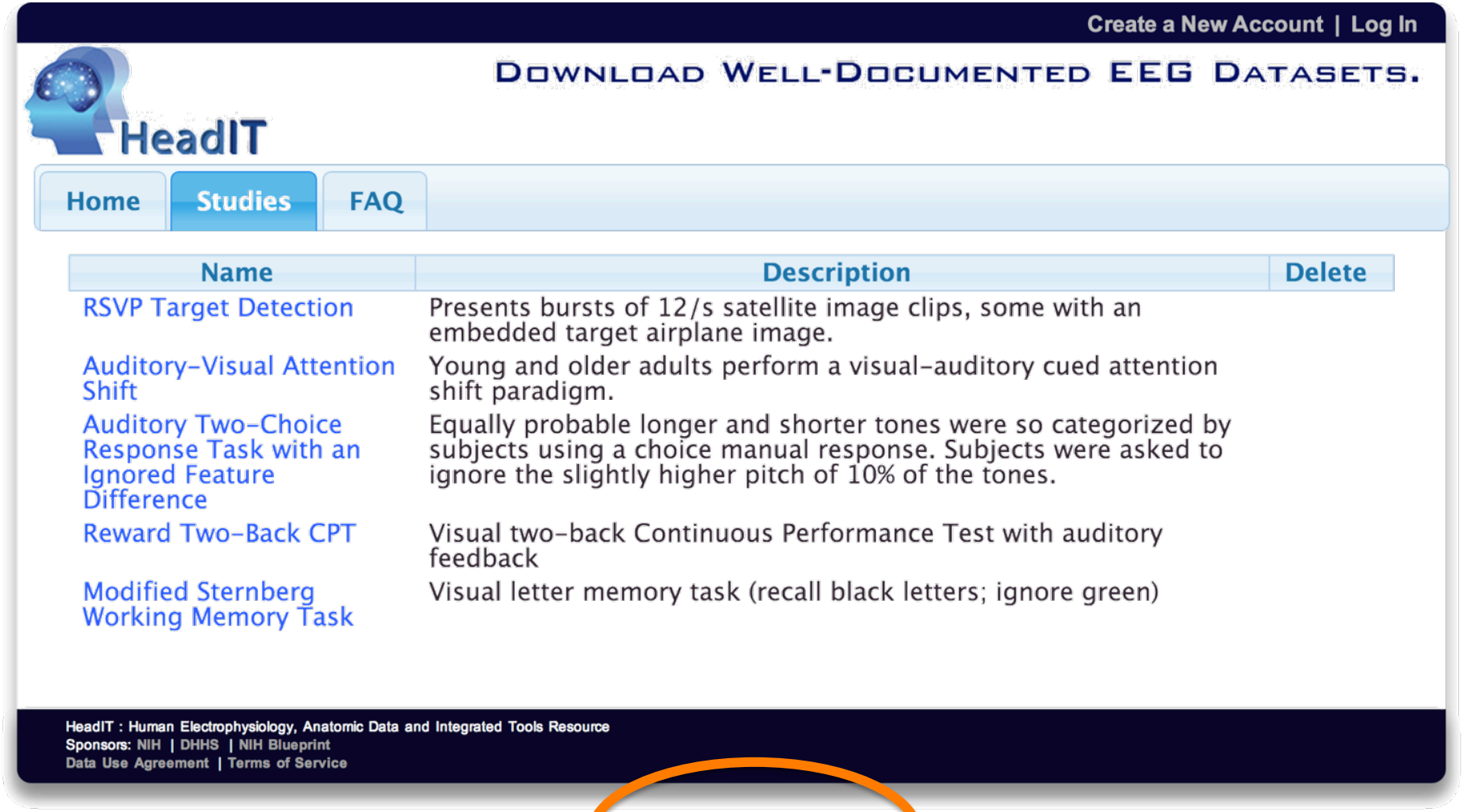
- **1 - Nima's amplitude-based window rejection: +7.1% MIR, Best in 32%**
- **2 - Christian's amplitude and MIR-based window rejection: +4.1% MIR, Best in 18%**
- **3 - Christian's amplitude-based window rejection: +4.1% MIR, Best in 18%**
- 4 - Nima's frame and MIR rejection: +3.0% MIR, Best in 14%
- 5 - Christian's Combo: +1.9% MIR, Best in 9%
- 6 - **Hand-Cleaned: 0% MIR, Best in 5%**
- 7 - Nima's amplitude-based frame rejection: -0.1% MIR, Best in 5%
- 8 - Nima's amplitude and MIR-based window rejection: +0.01% MIR, Best in 0%
- 9 - Christian's Combo then MIR-based rejection: +0.1% MIR, Best in 0%
- 10 - Arno's spectrum thresholding with MIR: -0.2% MIR, Best in 0%
- 11 - Arno's spectrum thresholding: -0.4% MIR, Best in 0%
- 12 - MIR rejection: -0.4% MIR, Best in 0%
- 13 - Original: -0.6% MIR, Best in 0%
- 14 - Robust Sphering: -1.9% MIR, Best in 0%
- 15 - Regular Sphering: -4.1% MIR, Best in 0%



Nima Bigdely Shamlo,

HeadIT

A Human Electrophysiology, Anatomic Data, and Integrated Tools Resource



HeadIT.org

Hierarchical Event Descriptors (HED Tagging)

Introduced during data collection

Number of HED tagged LSIE events: 149,006

Sample tag hierarchy (counts):

Stimulus (8338)
- Visual (5158)
  - Shape (2213)
  - 3D Object (1251)
    - Trash can (256)
    - Doll (204)
    - Office chair (197)
    - Sofa (192)
    - Mailbox (187)
    - Tire stack (171)
- Language (286)
  - Sentence (286)
- Indicator Light (1408)

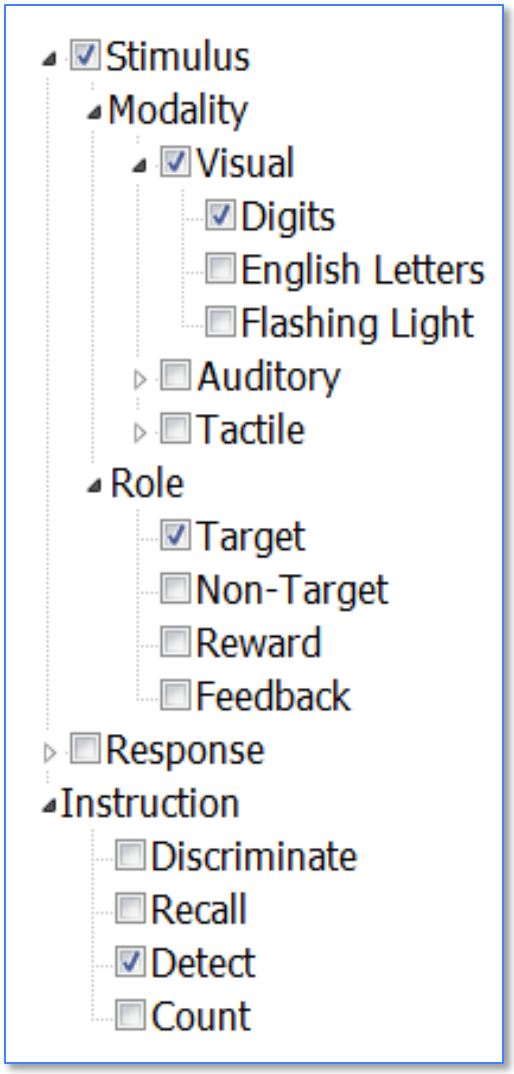
Feedback (3180)
- Penalty (1915)
- Reward (1265)

Response (862)
- Button Press (656)
- Touch Screen (515)
- Speech (206)

Game State (190)
- Stress Level (190)

…

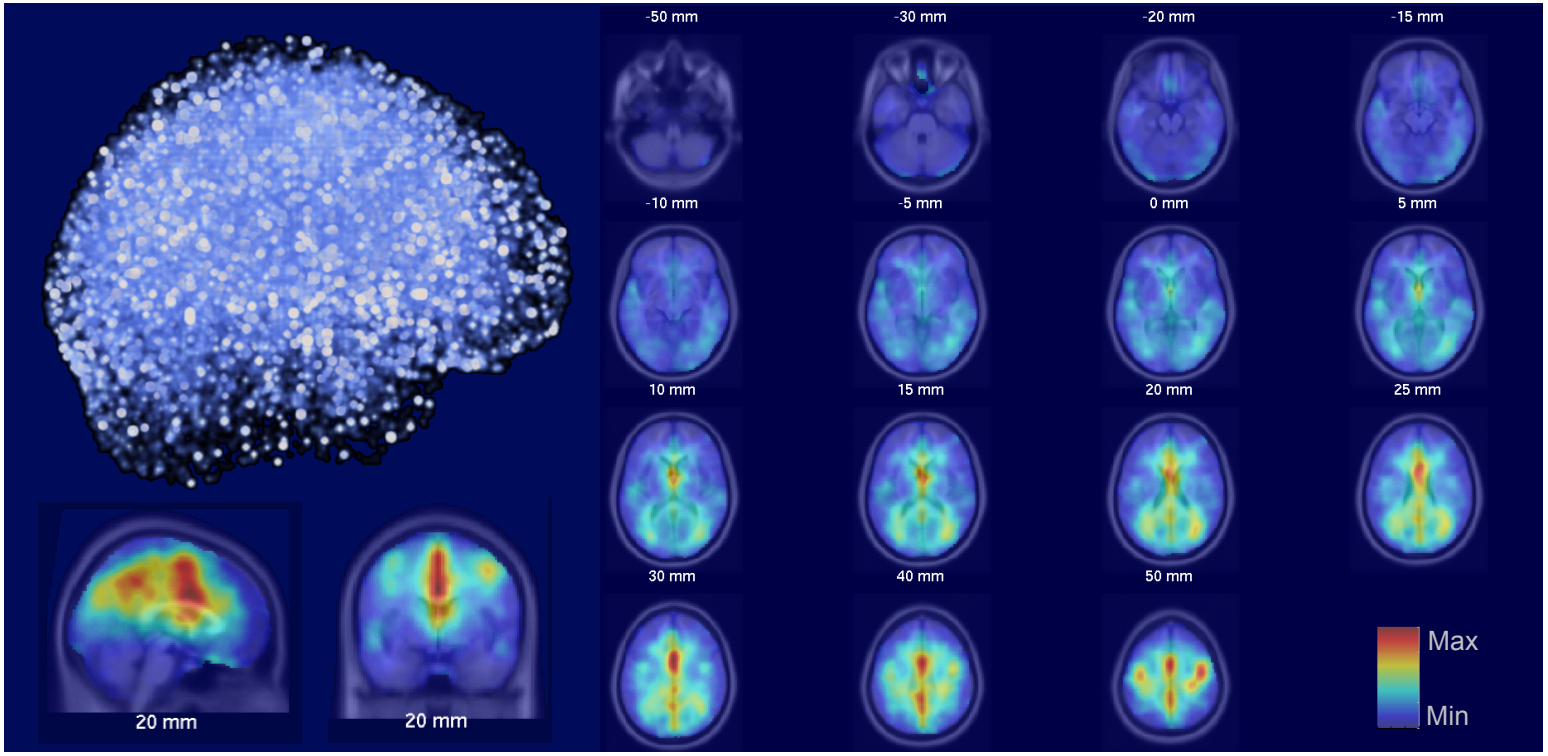
Added after data collection



Nima Bigdely Shamlo & S Makeig, 2012

A ‘Big Data-style’ EEG Source Analysis: Dipole Density

To learn about the distribution of ICA sources, 135,794 equivalent dipole models of independent components, drawn from thousands of ICA-decomposed EEG datasets, were projected into a common template brain space.

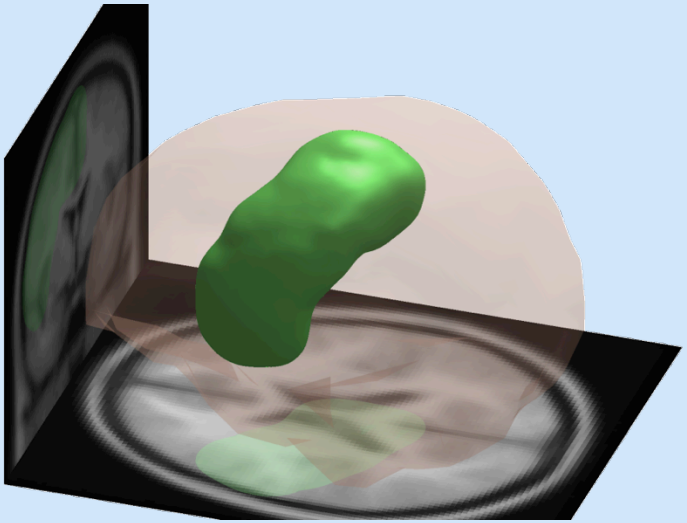


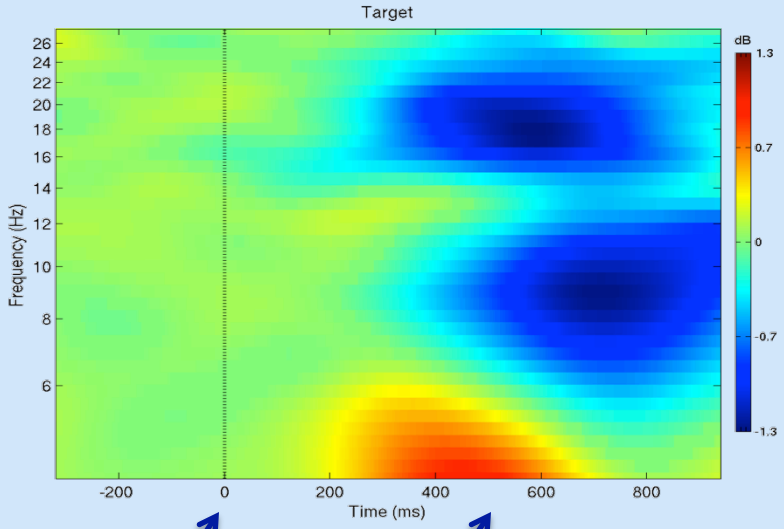
Nima Bigdely-Shamlo, Kay Robbins, Christian Kothe, Jessica His, Scott Makeig, 2013

Source Measure Search: A Feasibility Demonstration

RSVP Experiment Search Query:

Source ROI: L Precentral Gyrus + Source ERSP

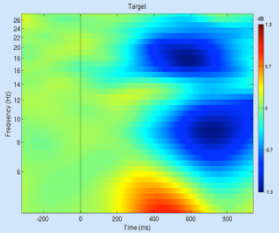


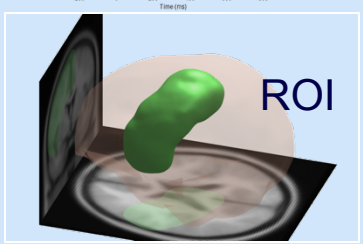


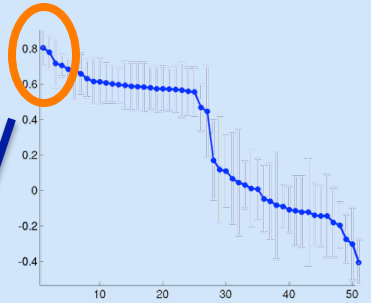
Target stimulus

Covertly increment target count leading to (delayed) button press

RSVP Measure Search Query:







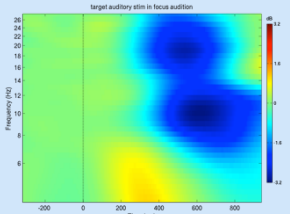
Sorted measure similarities

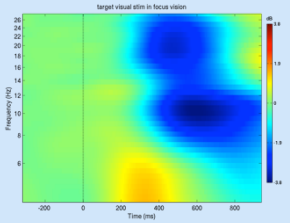
Top Measure Search Results:

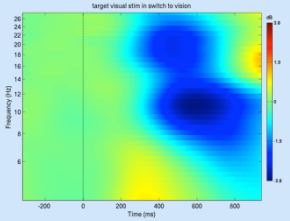
1. Auditory targets in ‘focus/hear’ Attention Switch followed by speeded right hand button press

2. Visual targets in ‘focus/look’ Attention Switch followed by speeded right hand button press

3. Visual targets in ‘switch/to-look’ Attention Switch followed by speeded right hand button press



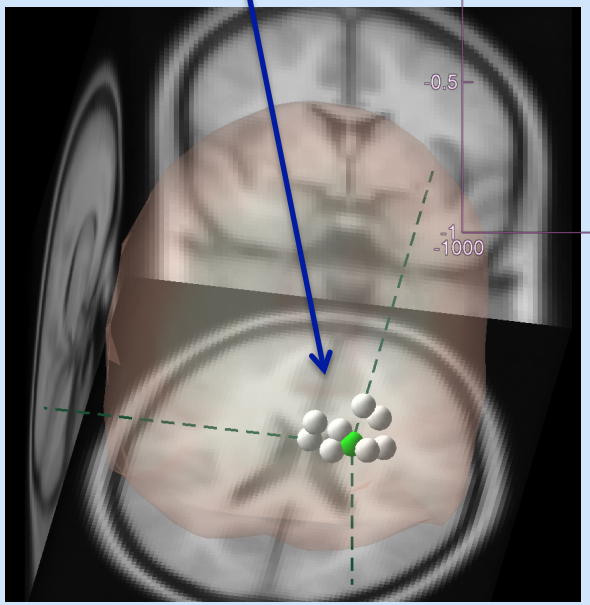


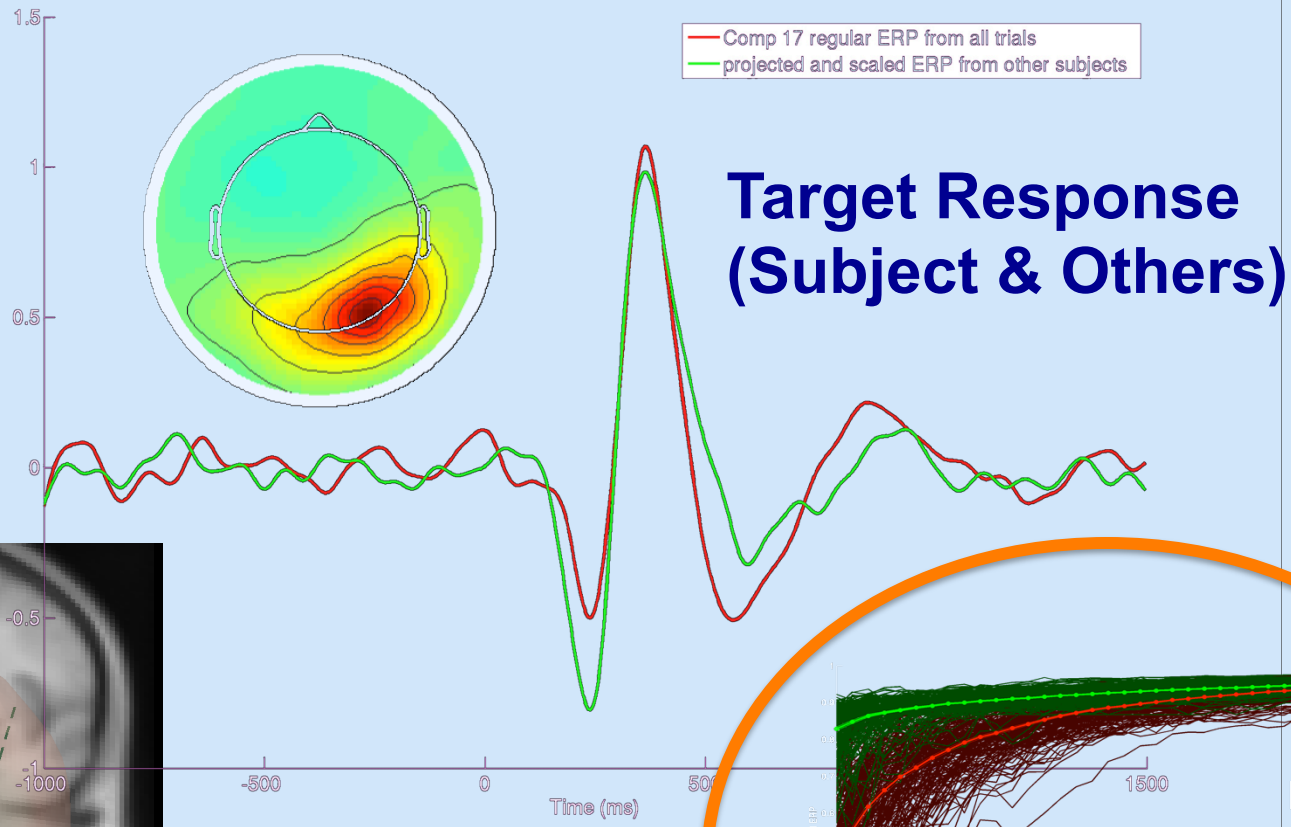


Commonalities: Speeded recognition of Target stimuli leading to **either an immediate or delayed** subject button press response!

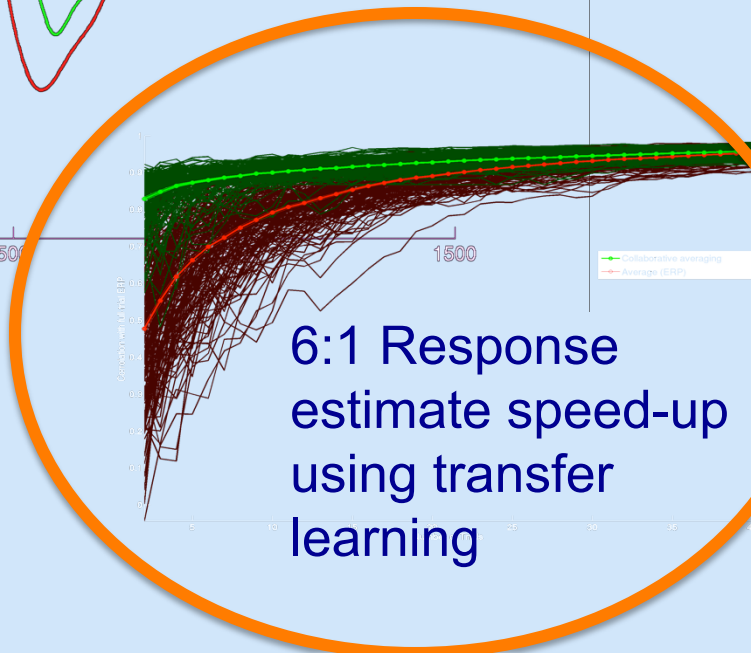
Predictive-Model Transfer Learning

EEG Source Cluster (Subject & Others)





Target Response (Subject & Others)

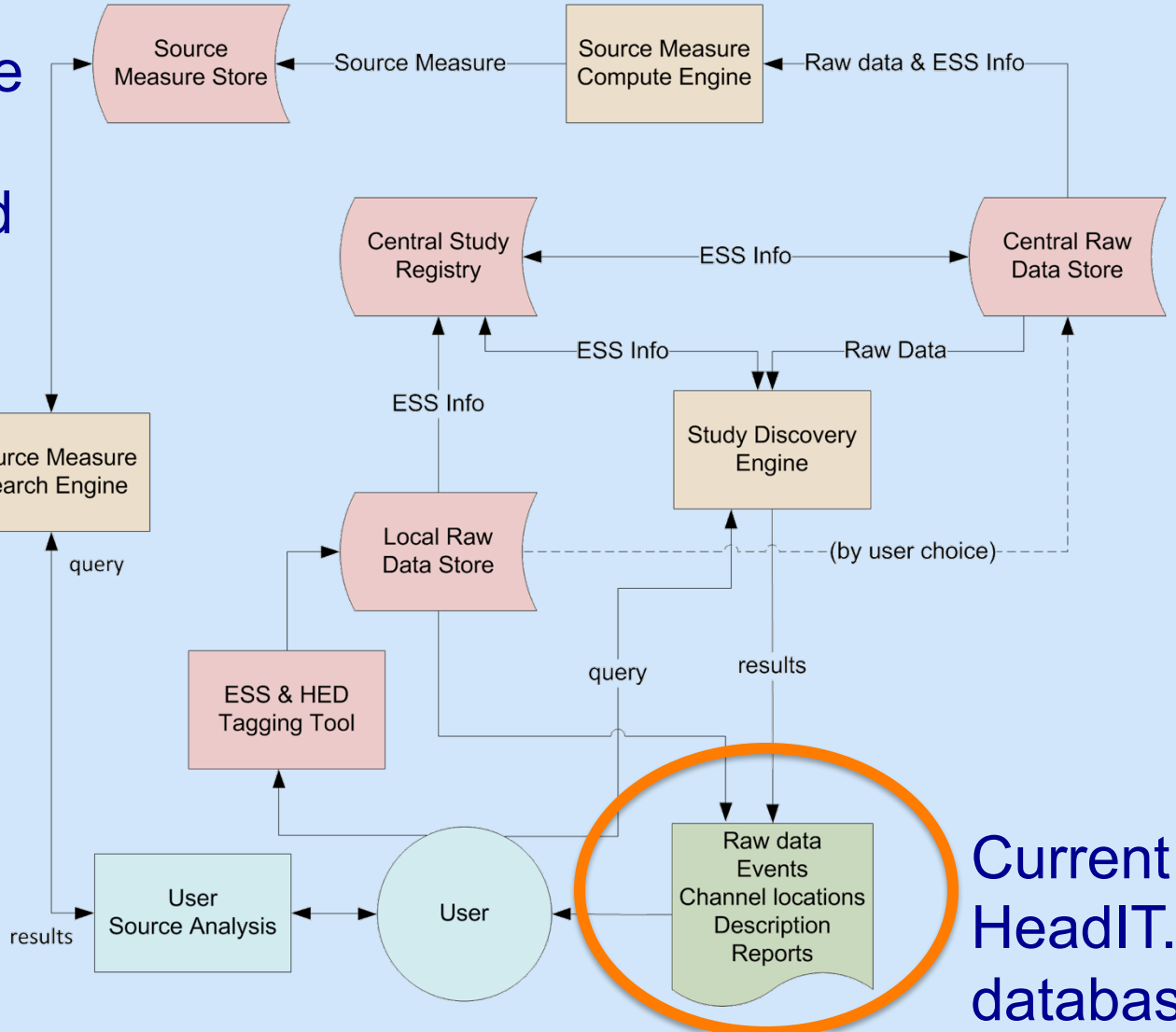


6:1 Response estimate speed-up using transfer learning

N Bigdely-Shamlo & S Makeig 2013

Proposed
Brain Cloud

Some of the needed Brain Cloud facilities:



Current HeadIT.org database

R&D

Training

Rehab

Science

Medical

CCC

Cloud computing
Transfer learning

The BRAIN CLOUD

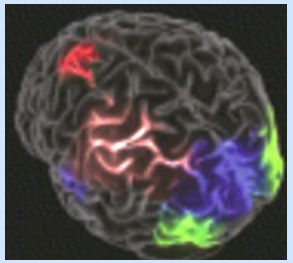
Data Integration
Data Analytics

HCI

Commercial

Networking

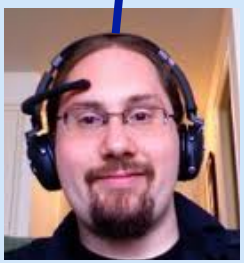
(Local fog servers)



↑Data:

PDAs:

Sensors:



EEG
Physio
Mocap
Scene
Tasking
Subj. ID
Context

Source-Resolved Mobile Brain/Body Imaging

S. Makeig, 2013

Embodied Cognition & Agency

Brain processes

have evolved and function

to optimize the ***outcome***

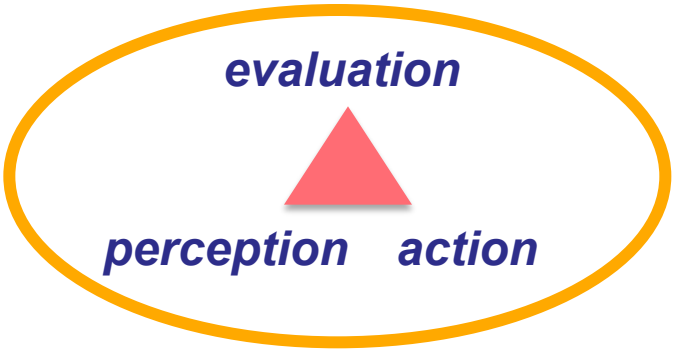
of the ***behavior***

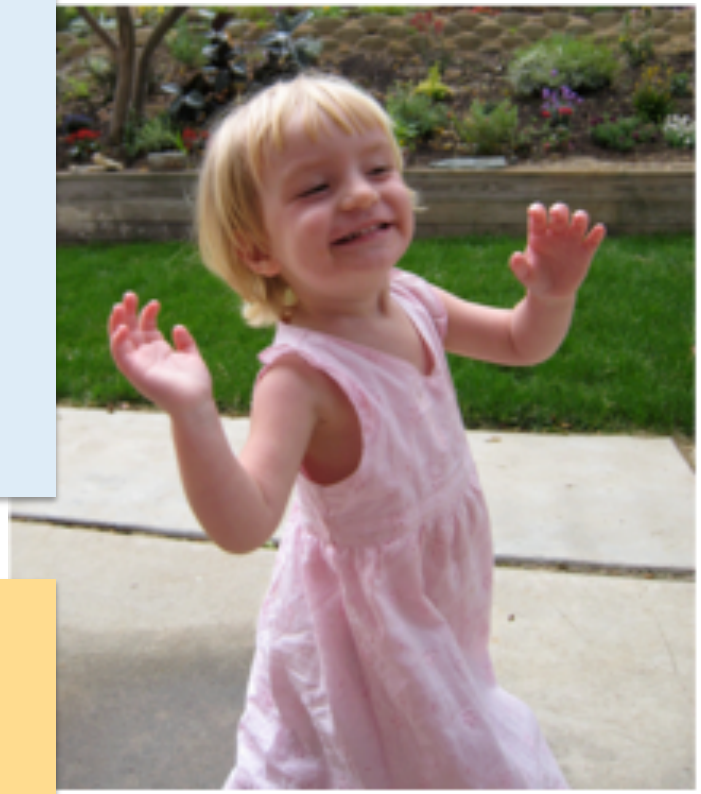
the brain organizes

in response to

perceived challenges

and opportunities.





Brains seize the opportunity of the moment!

S Makeig 2010

The Beginning

fEEG, BCI, MoBI …