

**3rd EEGLAB Workshop
Singapore**

Mining Event-Related Brain Dynamics - II

Scott Makeig
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Brain Electrophysiology Response Averaging

1960 →

ERF
ERP
Average



MEG
EEG

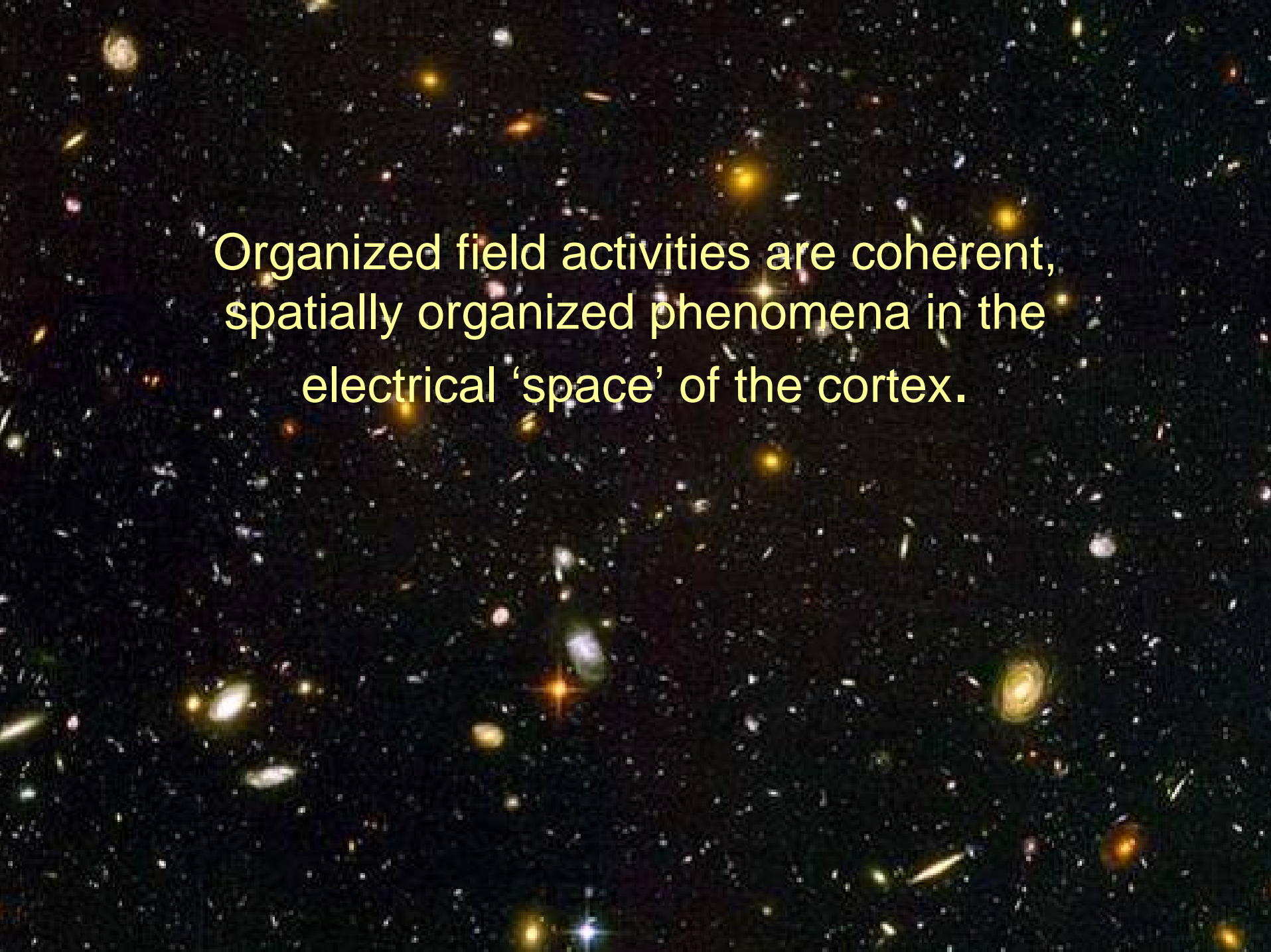


LFP

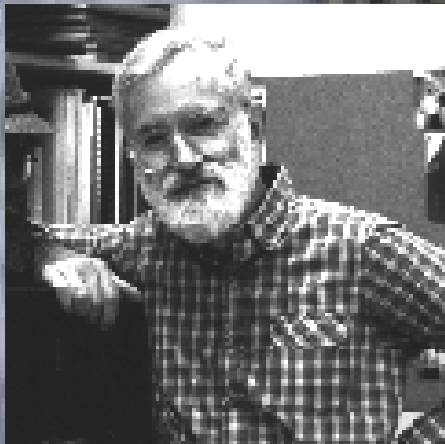


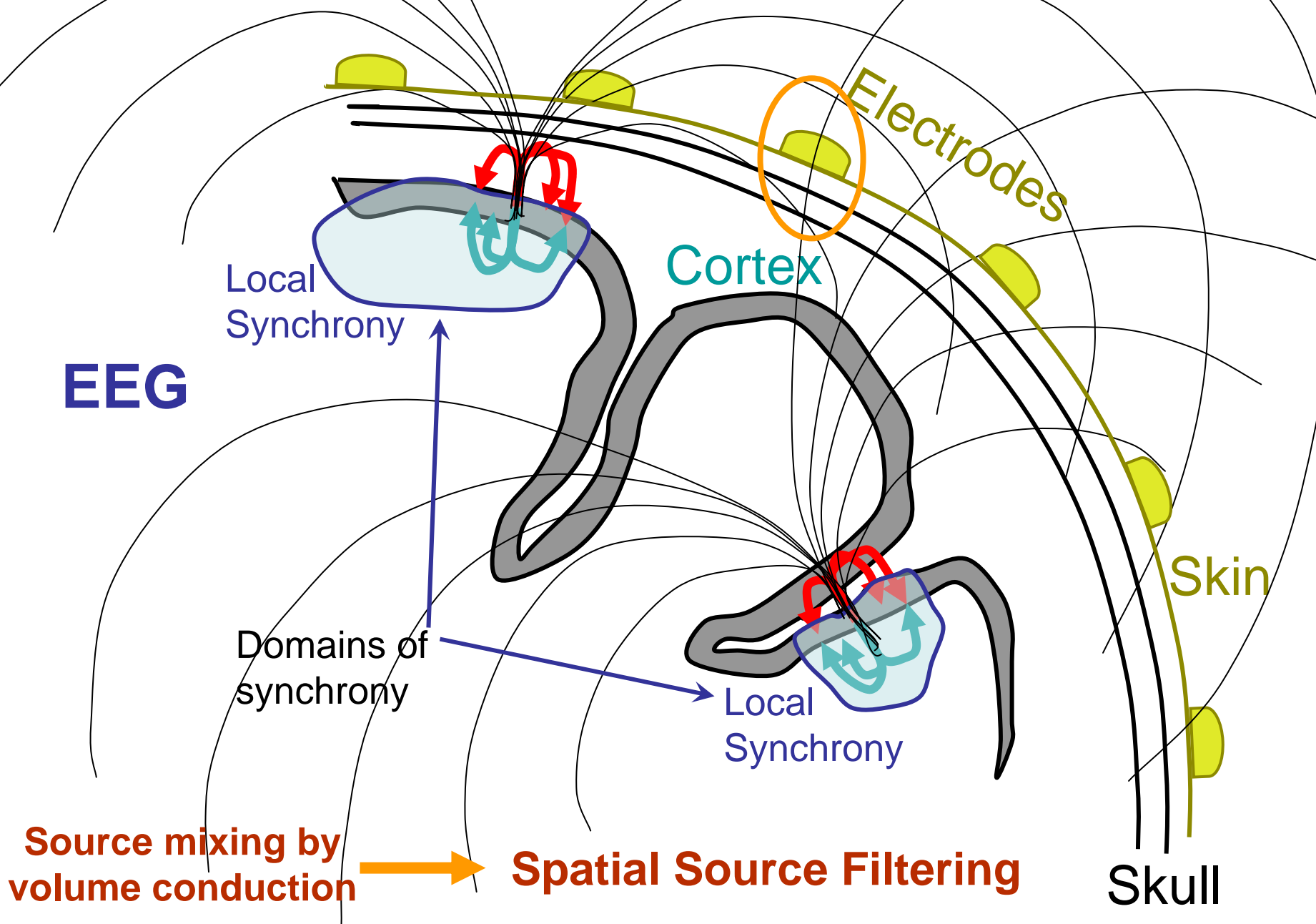
Spike
Histogram





Organized field activities are coherent,
spatially organized phenomena in the
electrical 'space' of the cortex.

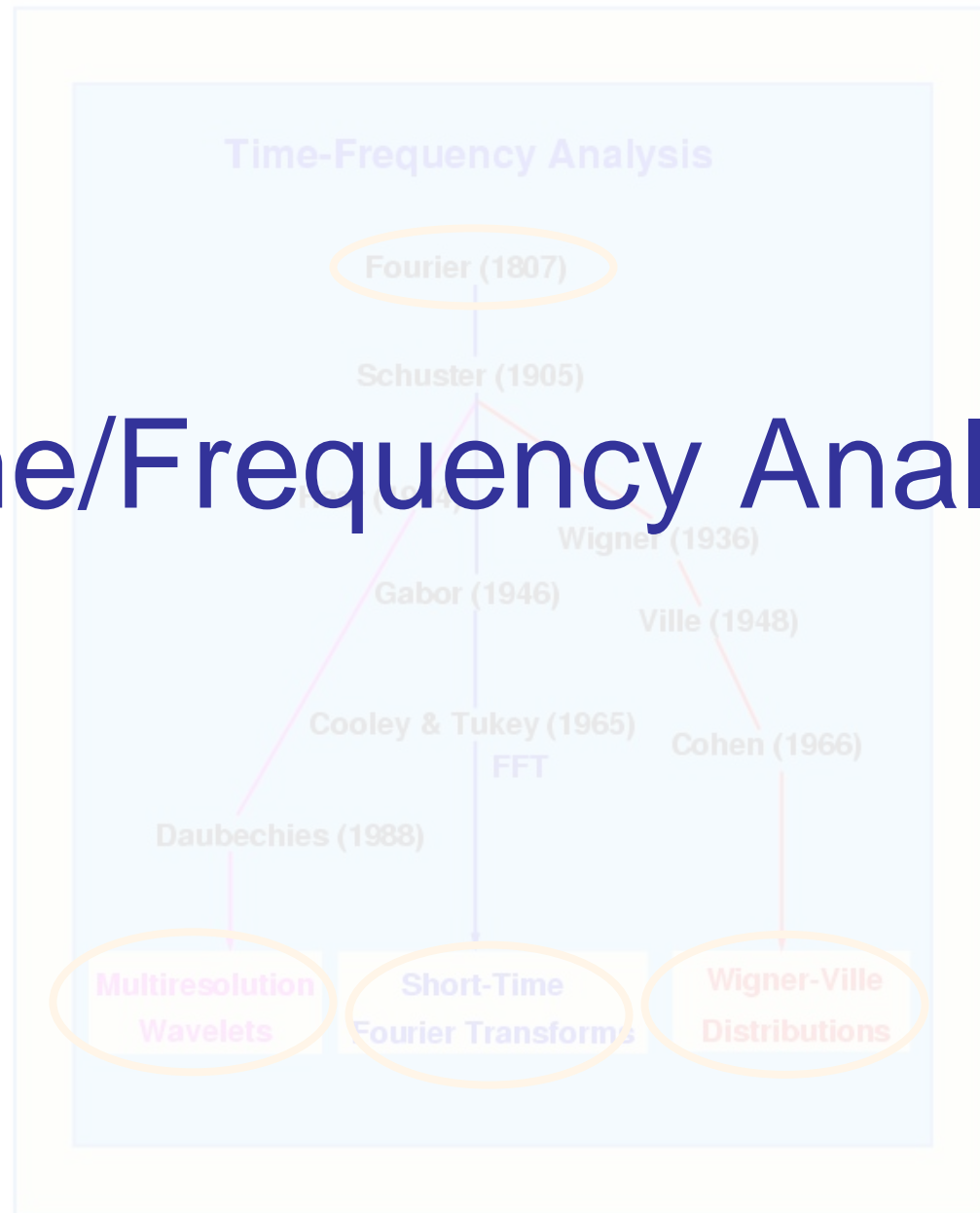




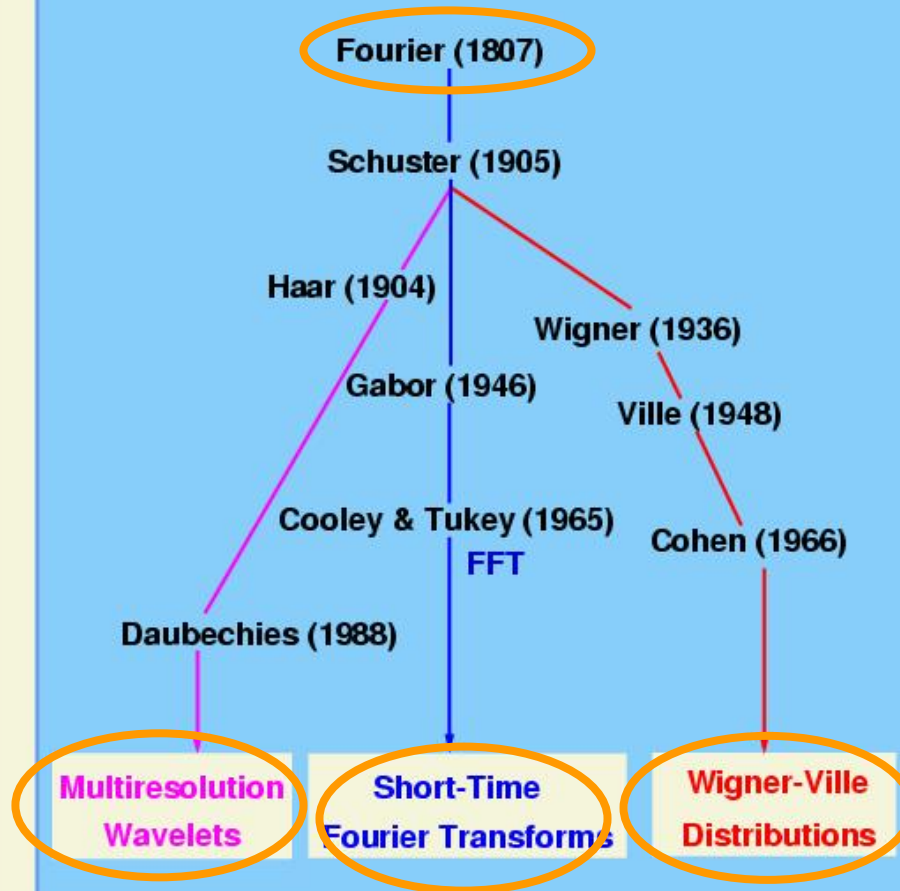
Modeling Event-Related Brain Dynamics

1. Un-mix cortical (and artifact) source contributions to the scalp electrodes using **independent component analysis** (ICA).
2. Visualize the activities of independent component (IC) sources across single trials using **ERP-image plotting**.
3. Model the event-related dynamics of the IC sources using **time/frequency analysis** (ERSP, ITC, ERC, etc.)
4. Localize the separated IC sources using **inverse source estimation**.
5. Compare similarities in IC dynamics and locations across subjects using **IC cluster analysis**.
6. Assess the reliability of differences between IC activities time-locked to conditions, groups, and/or sessions of a **study**.

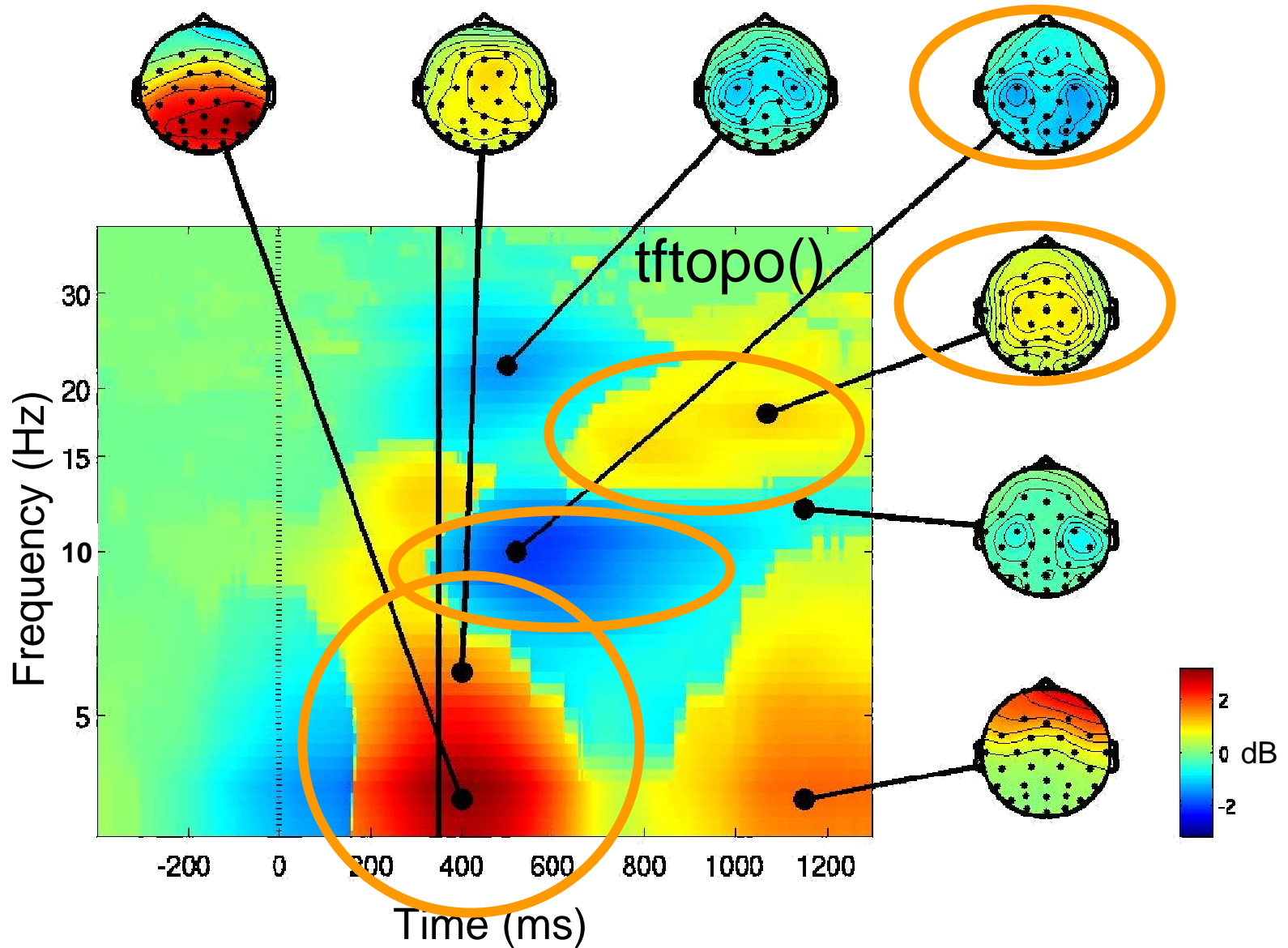
Time/Frequency Analysis



Time-Frequency Analysis



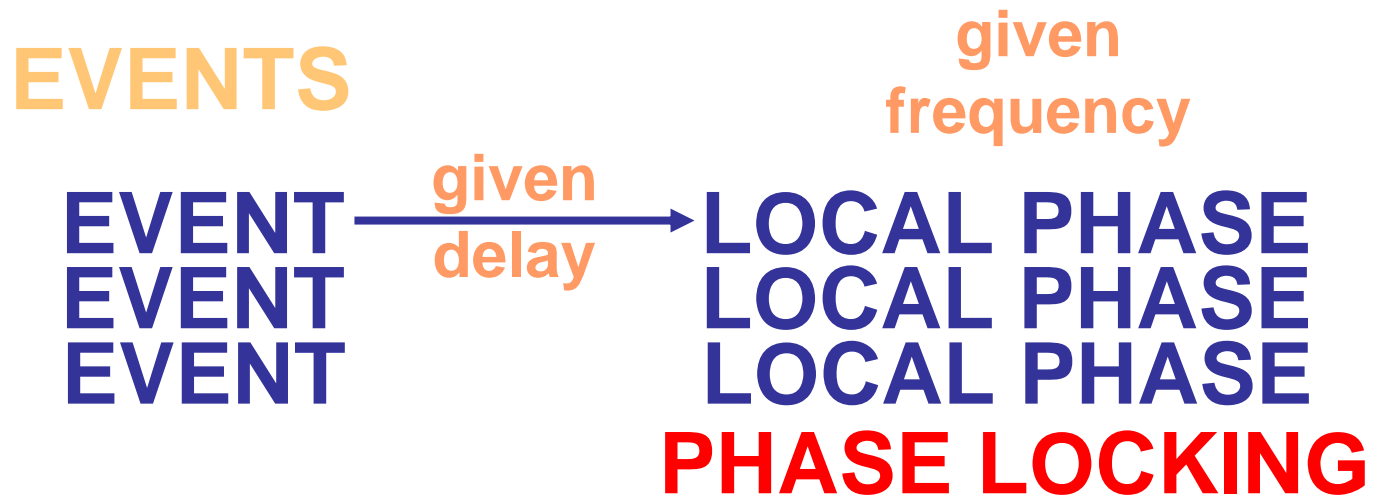
Event-Related Spectral Perturbation (ERSP)

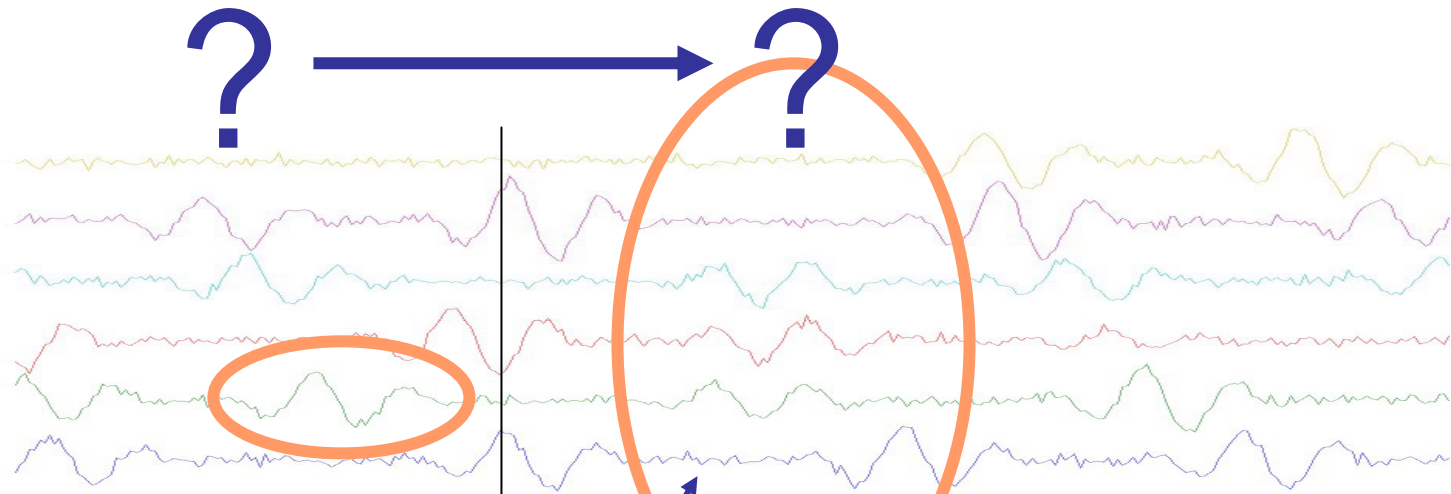


What produces event-related potential averages (ERPs)?

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

= the consistency, at each latency relative to a set of time-locking events, of the **local phase** of a physiological process across a set of event-related epochs.





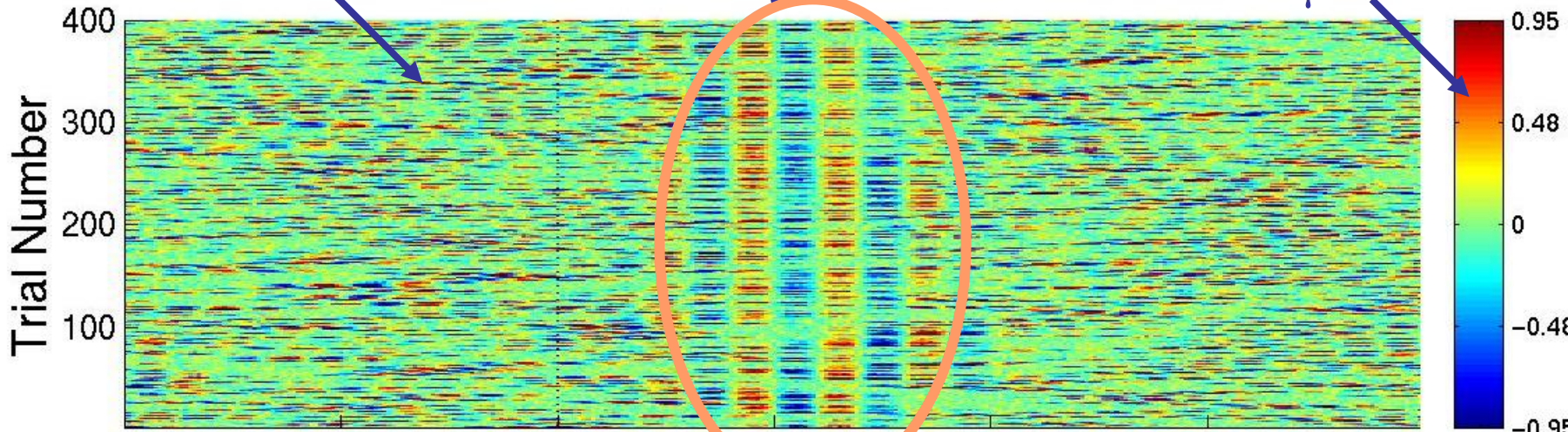
INTER-TRIAL COHERENCE
(=“phase resetting”?)

Simulated data trials

SINGLE TRIALS

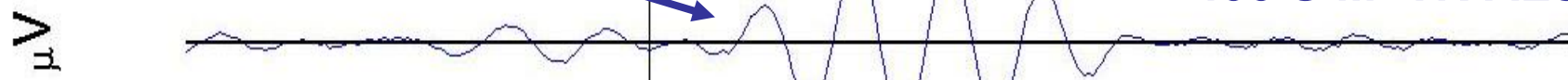
ERP-image Plot

μV



AVERAGE ERP

400 SIM. TRIALS ...



NO AMPLITUDE INCREASE

-9.433 dB

P = 0.02



INTER-TRIAL COHERENCE

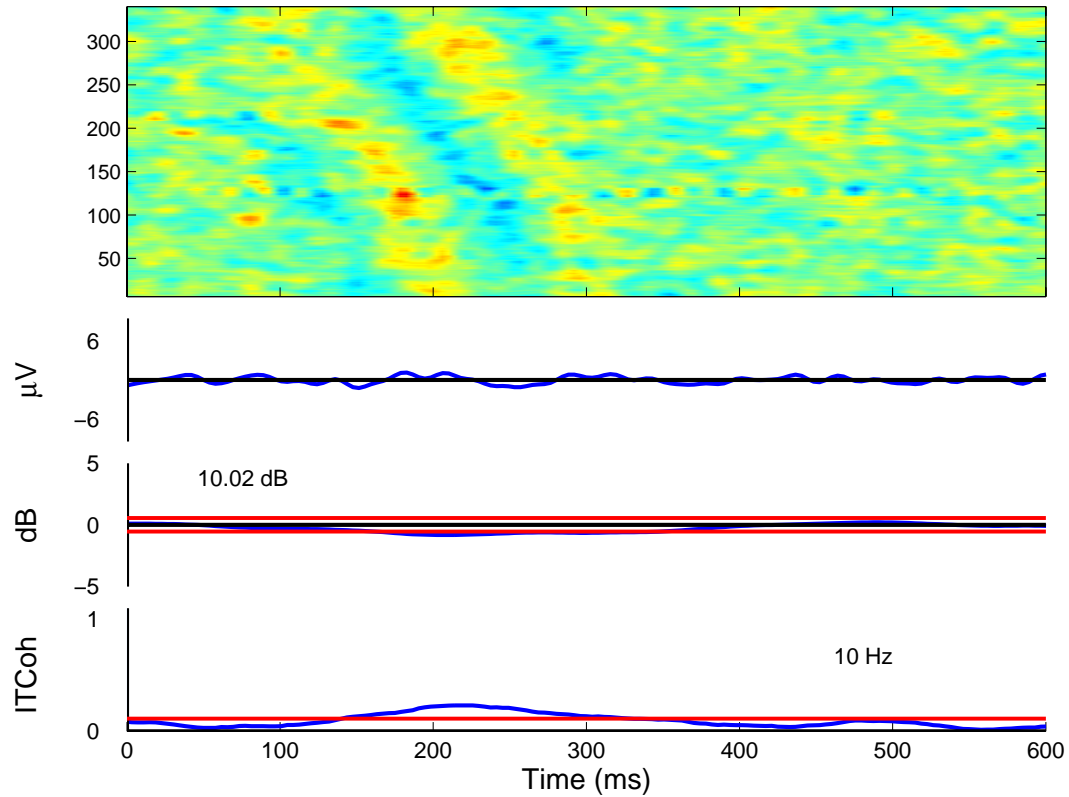
5 Hz

P = 0.02

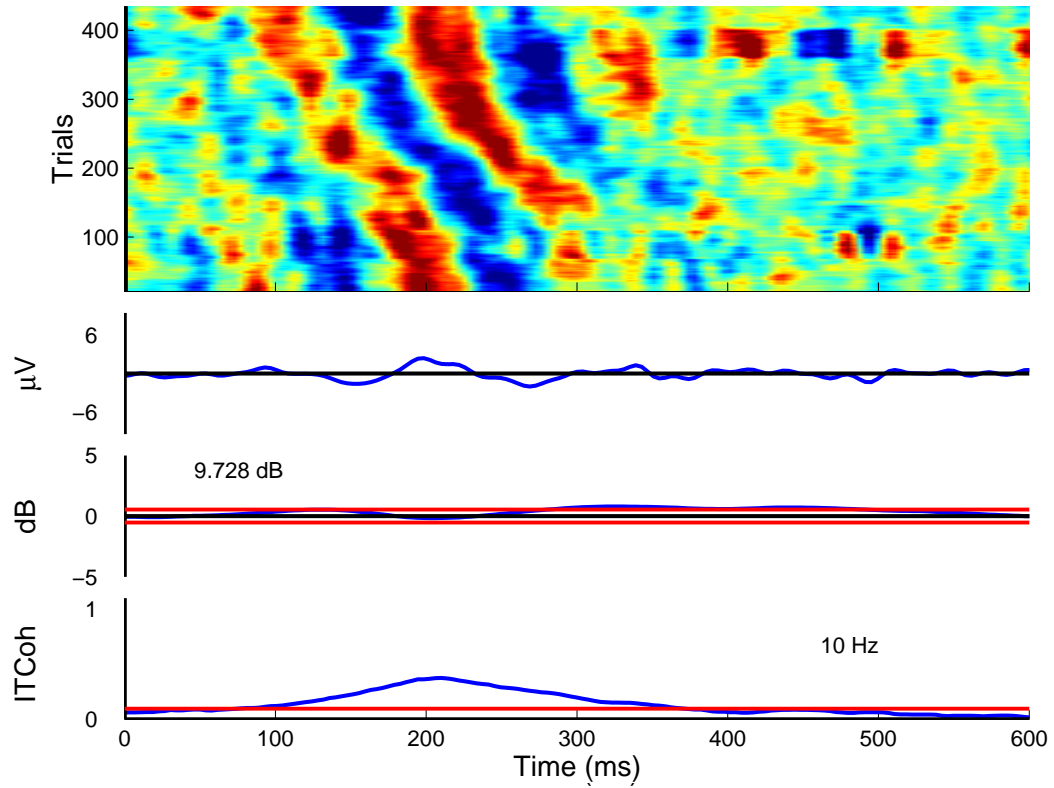


Time (ms)

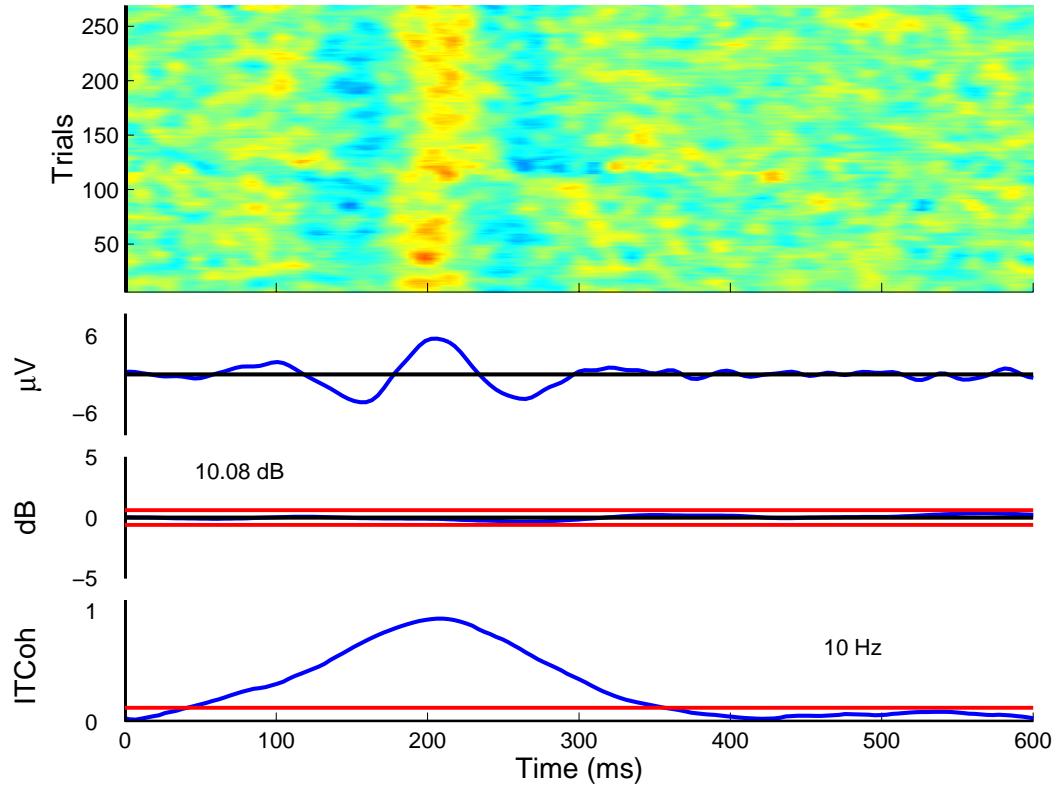
Phase-locking creates the ERP



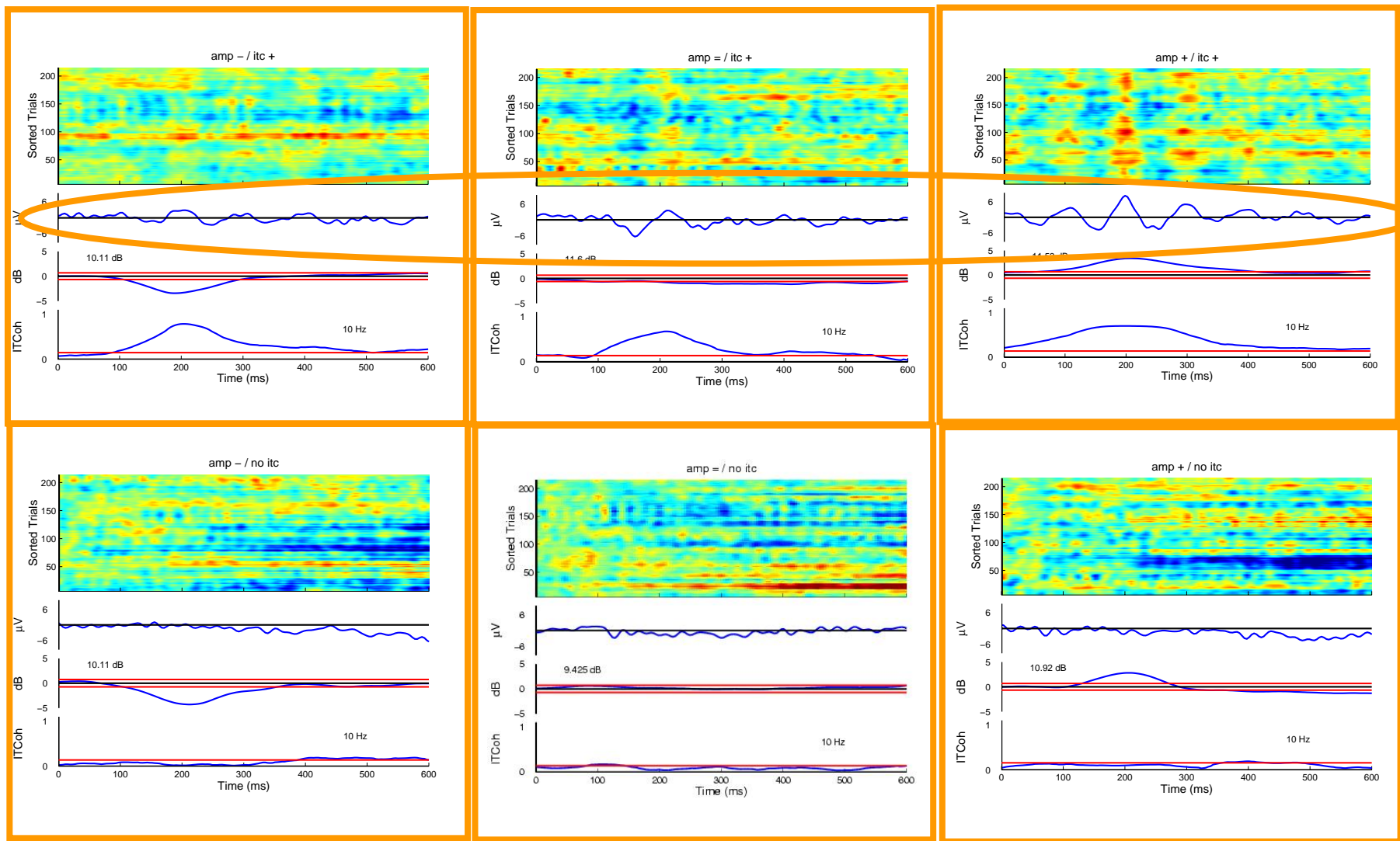
Phase-locking creates the ERP



Phase-locking creates the ERP



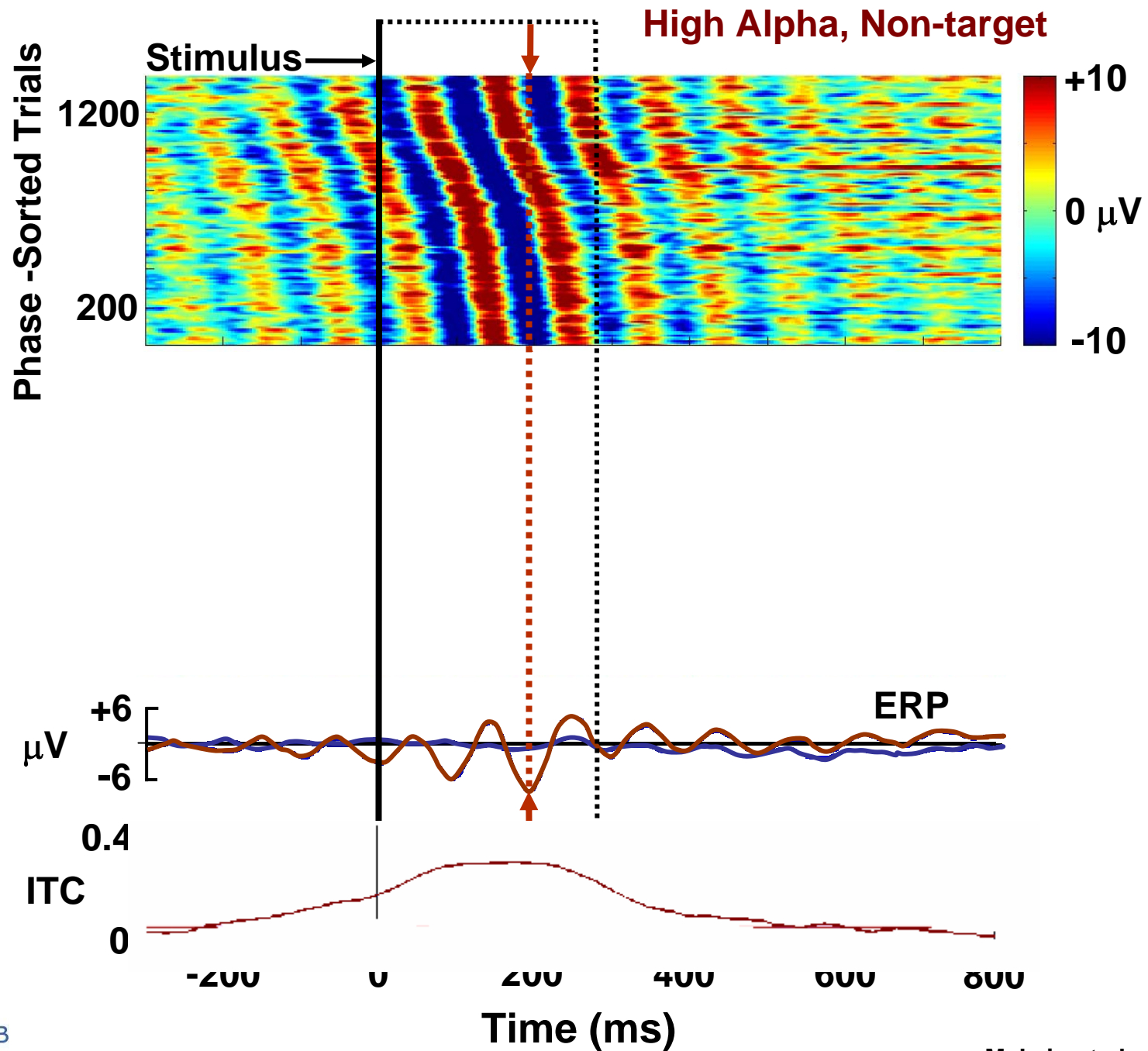
Simulation - Phase locking creates ERPs



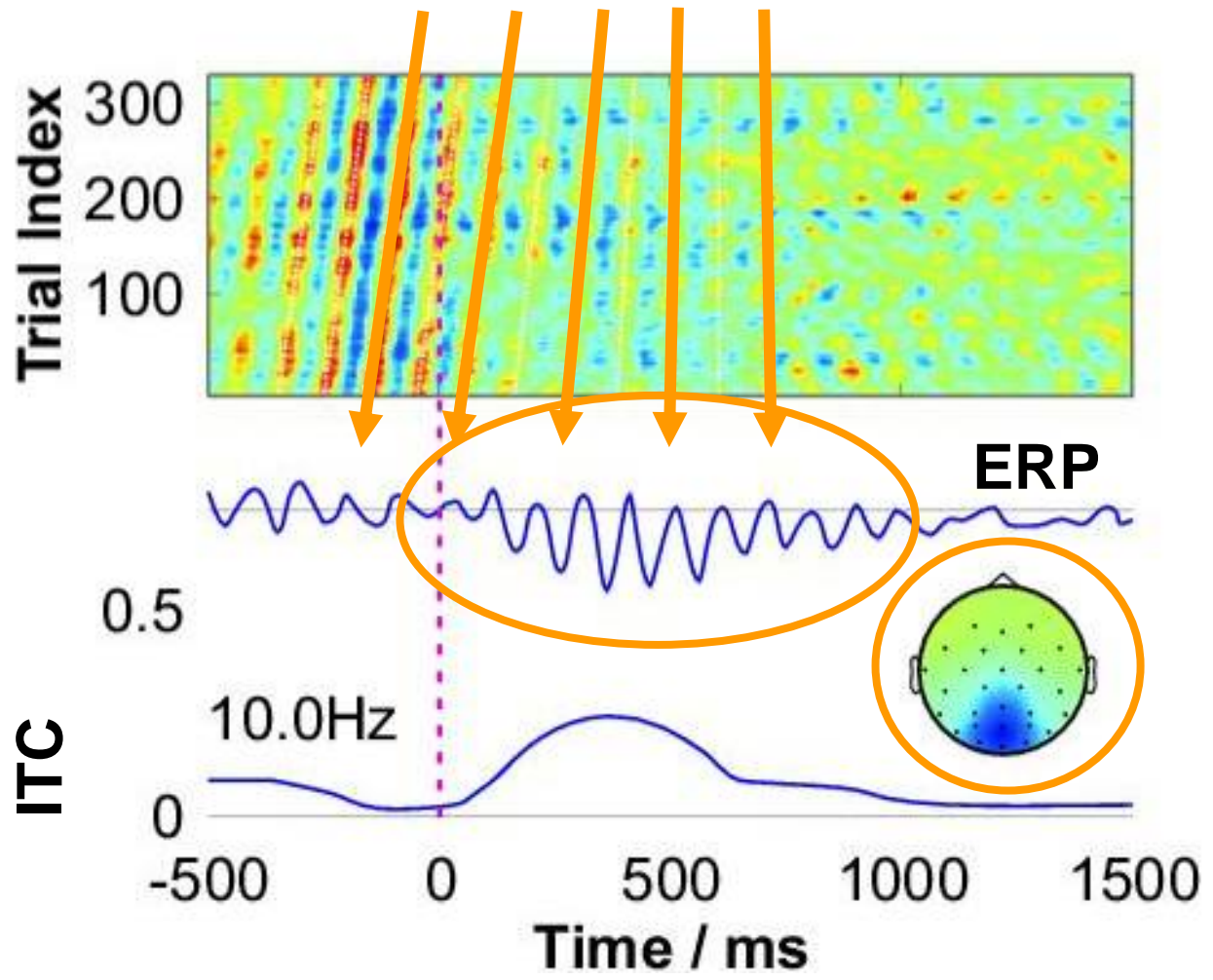
ERD

Baseline

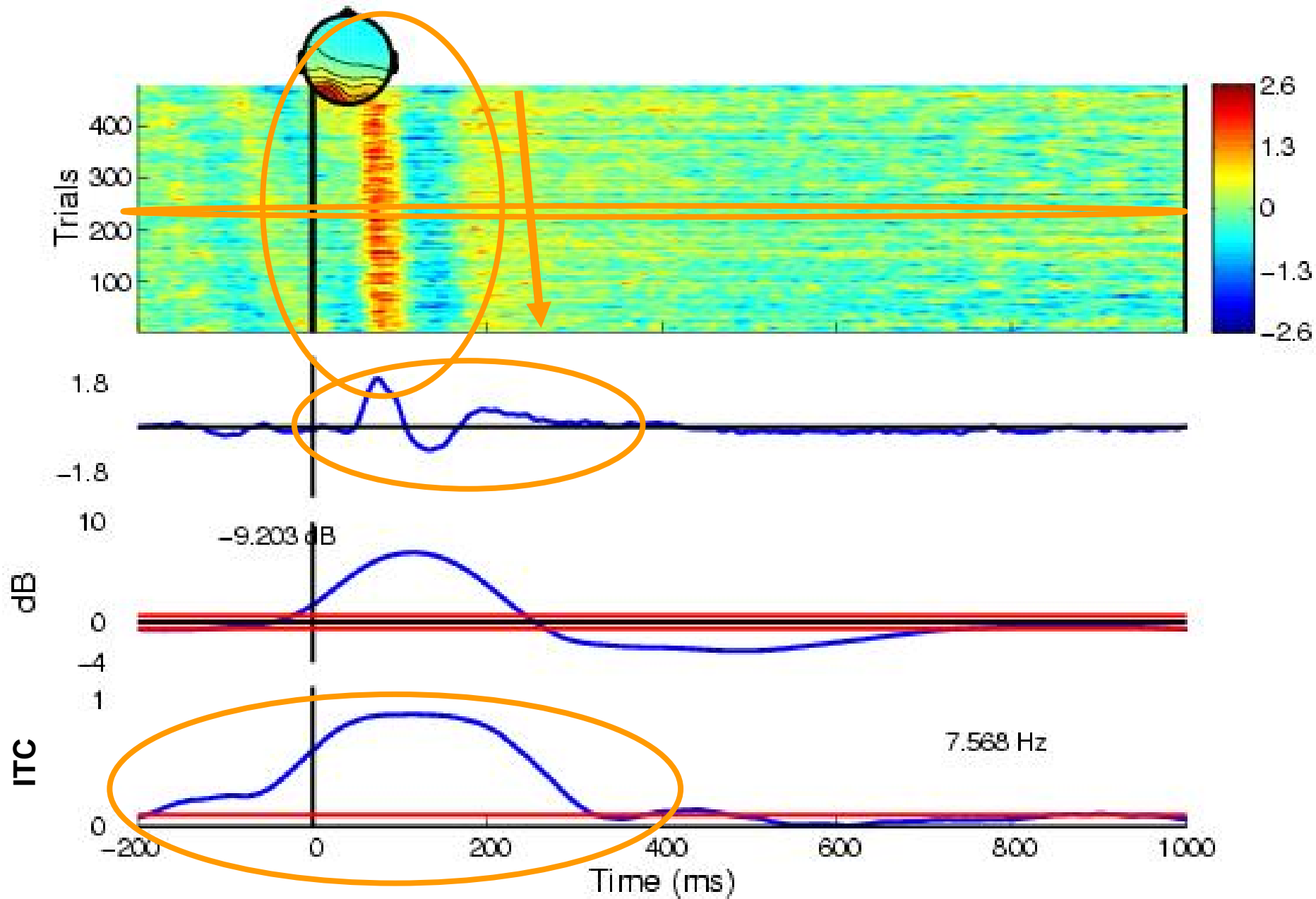
ERS



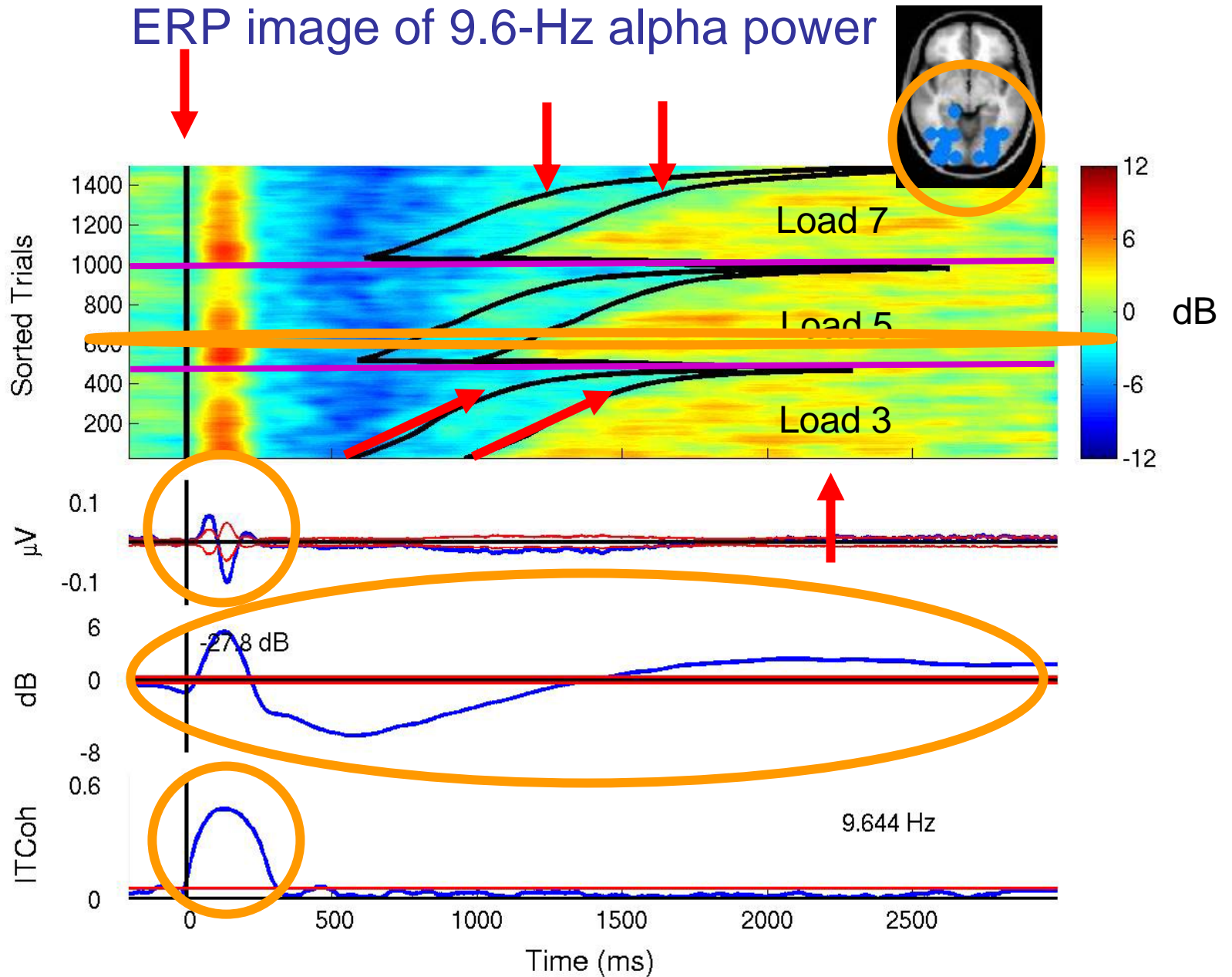
“True” PPR (visual ‘alpha ringing’)



'Pure' ERP



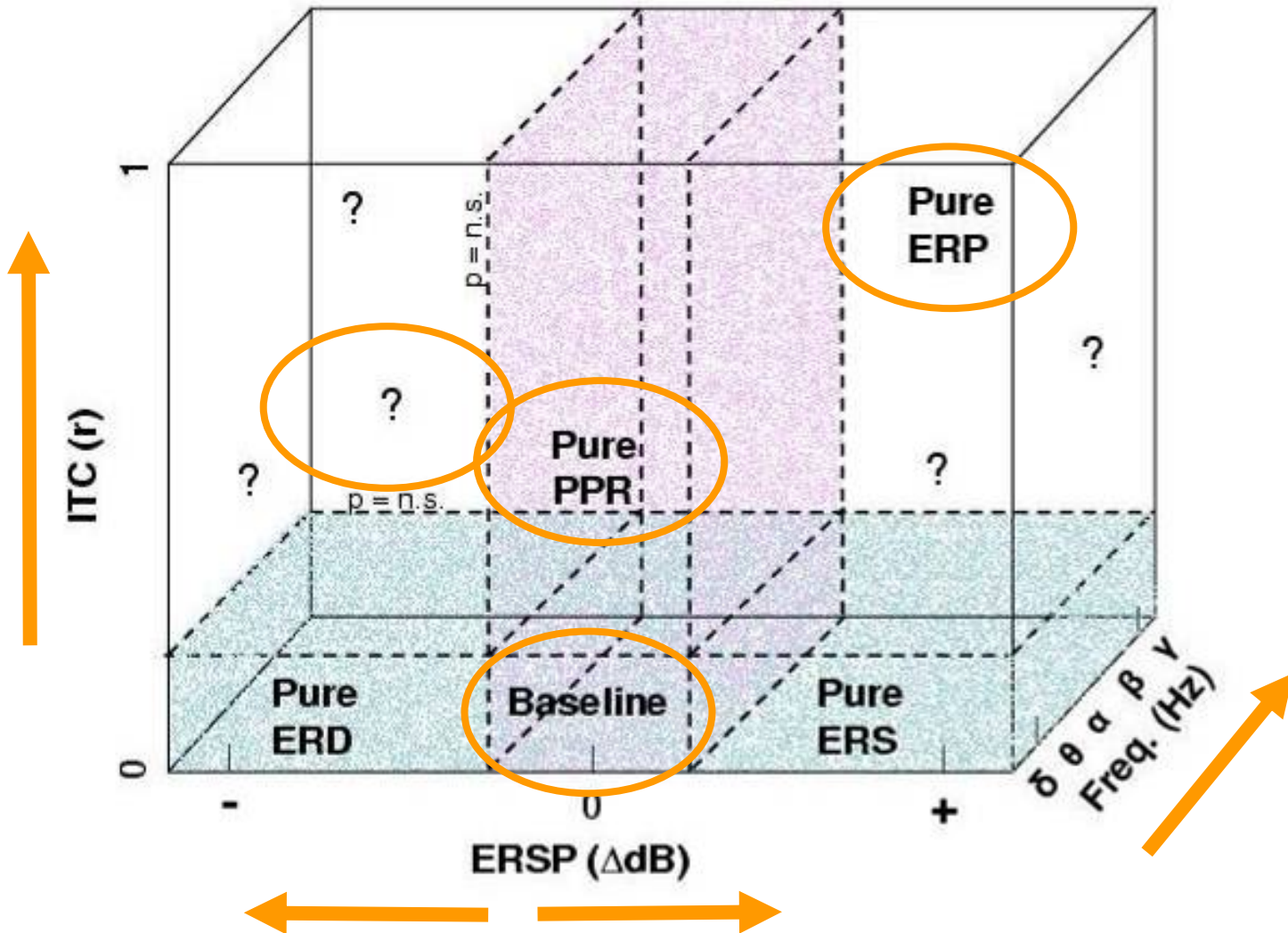
ERP image of 9.6-Hz alpha power



No single measure captures the event-related brain dynamics

- **ERP** ← Is a given ERP feature a 'true' ERP, or 'phase resetting', or both (ITC) !? Does it coincide with an EEG power increase or decrease (ERSP) ?
- **ITC** ← No amplitude effects (ERSP & ERP)!
- **ERSP** ← Does not show phase statistics (ITC). Is a given power increase also in the ERP, or not?
- But, are these measures enough?? **No!**
- **For one – they are again (blind) trial averages!**

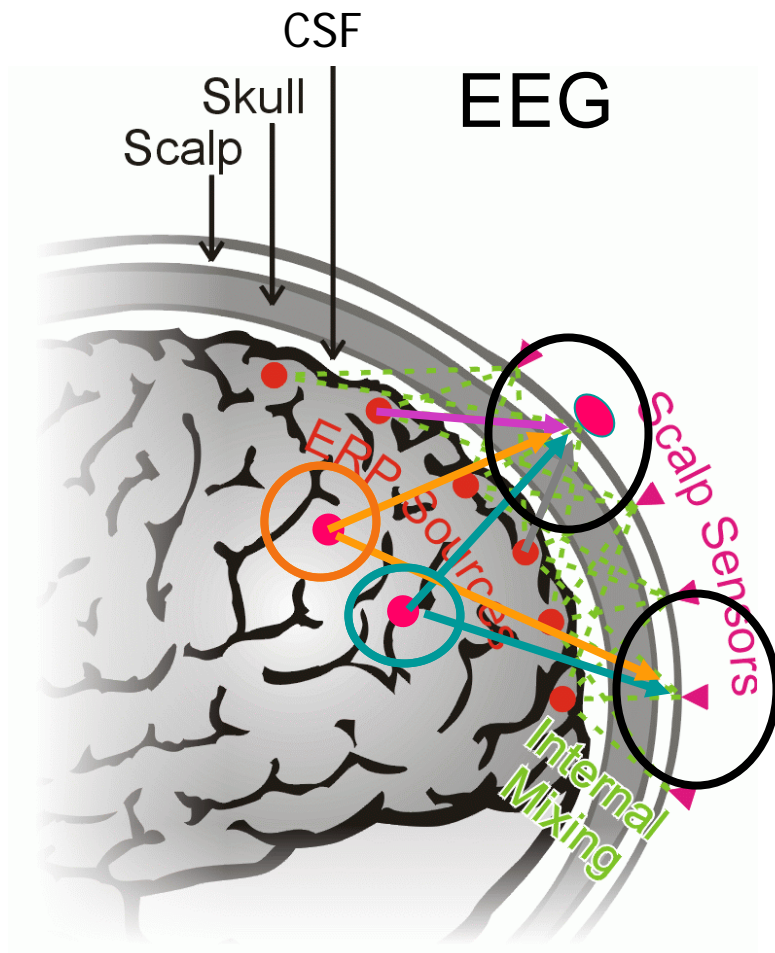
Event-Related Brain Dynamic State Space



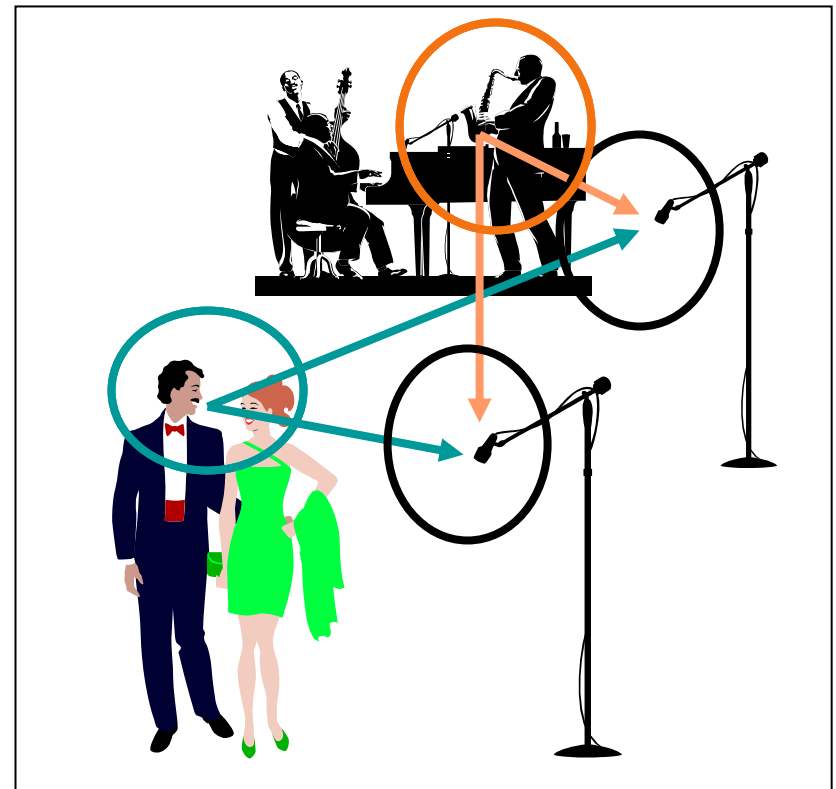
ICA asks the question,
Independent
“**What** distinct EEG processes occur
Component
in the data –
either within the brain or outside it?”
Analysis

ICA asks the question,
**“What distinct EEG processes occur
in the data –
either within the brain or outside it?”**

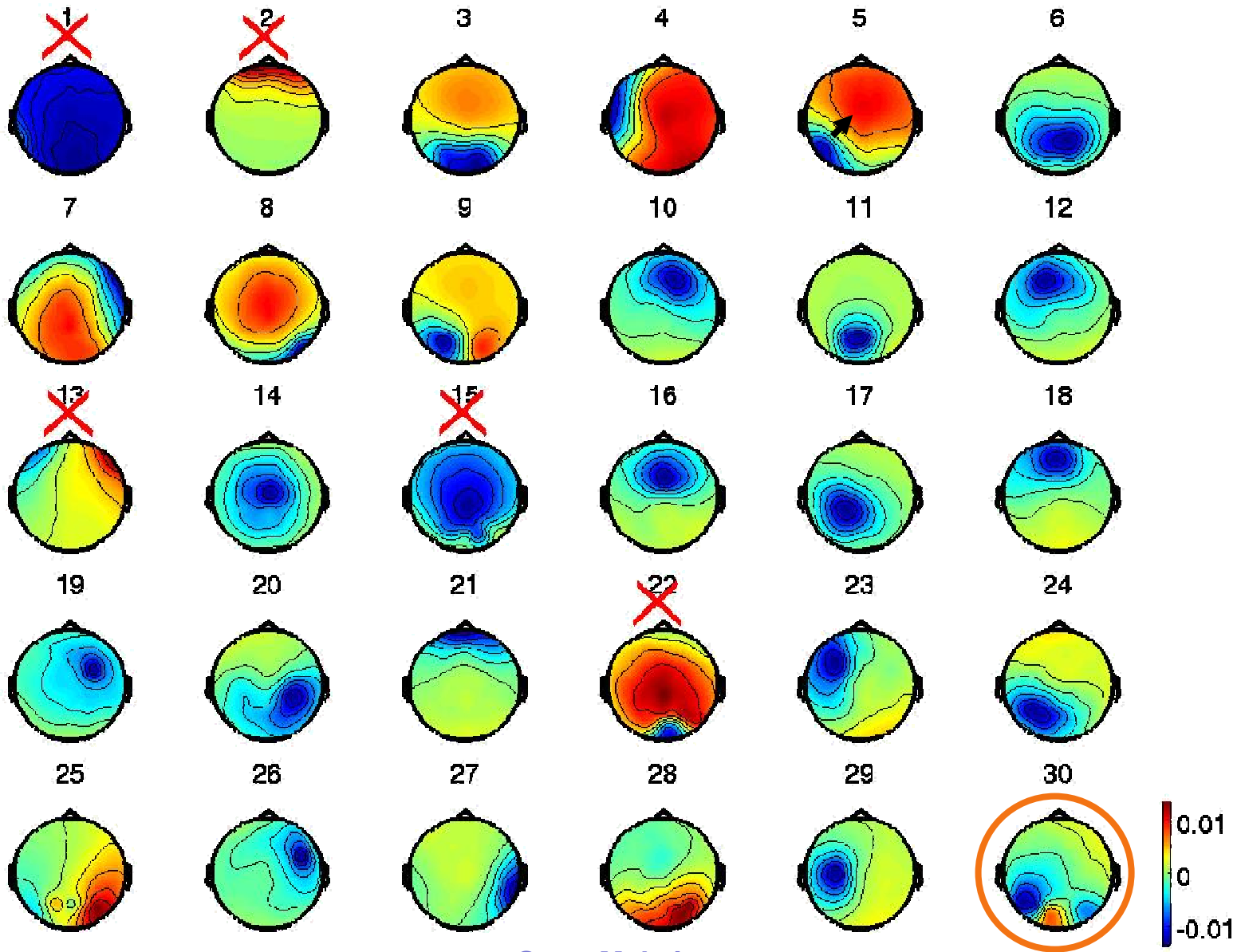
Blind EEG Source Separation by ICA



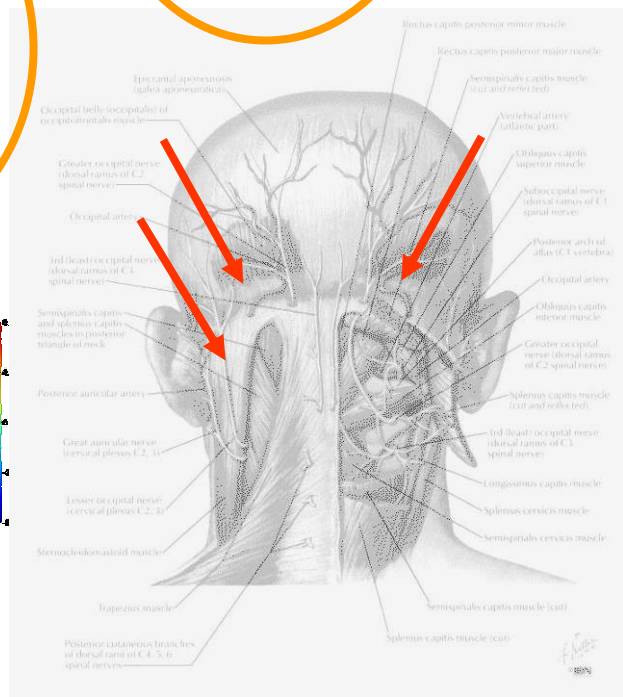
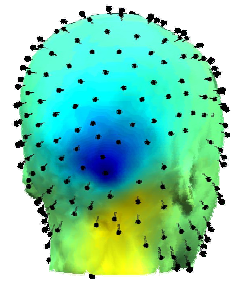
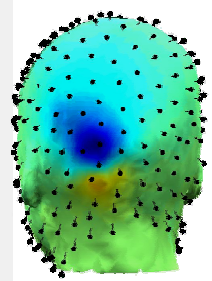
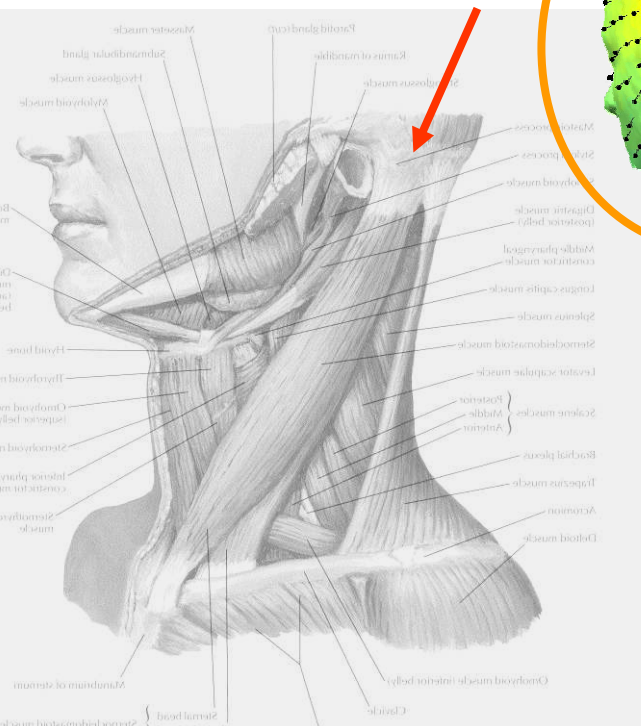
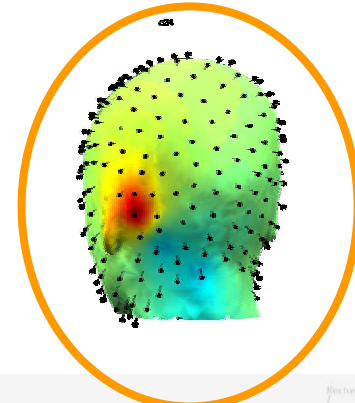
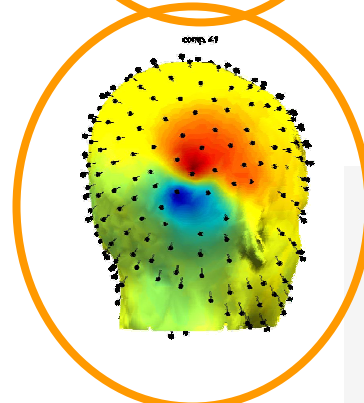
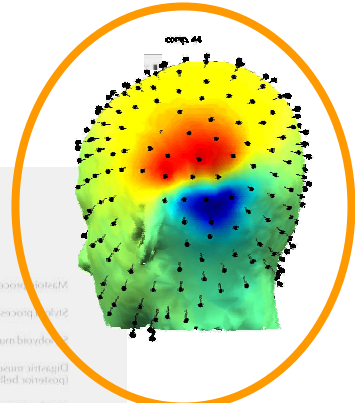
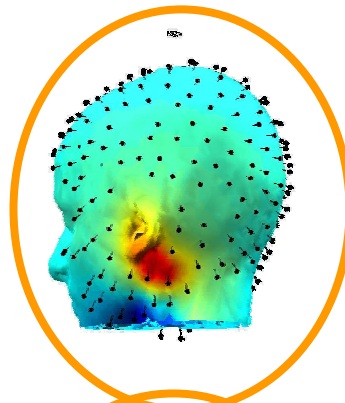
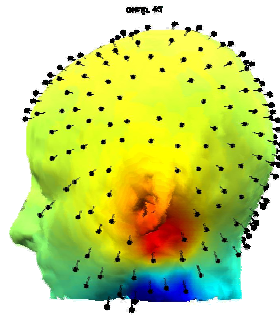
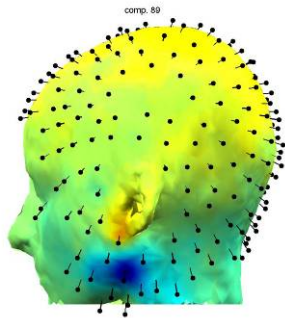
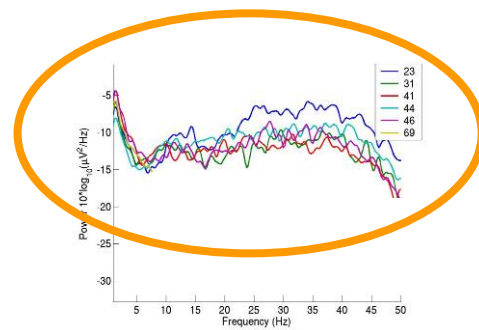
Cocktail Party



Largest 30 Independent Components (1 subject)

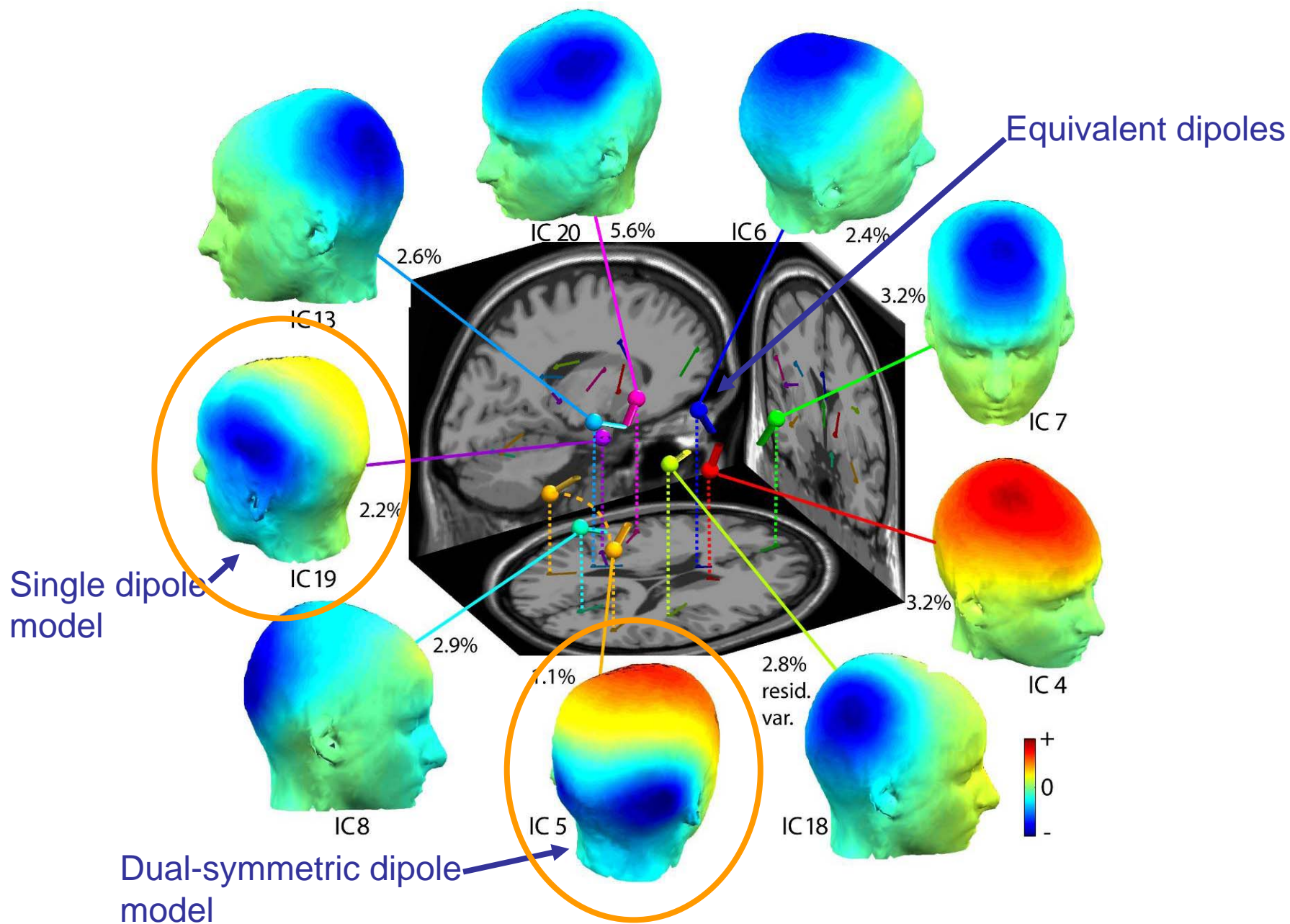


Same Session - Some Independent Muscle Components

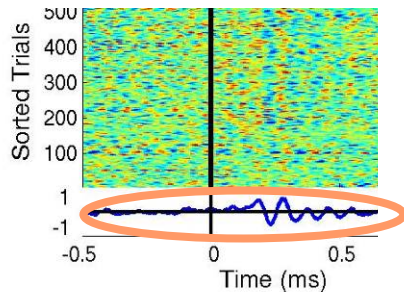
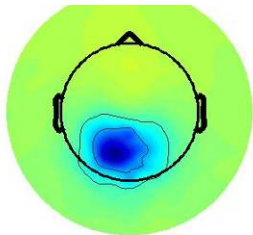
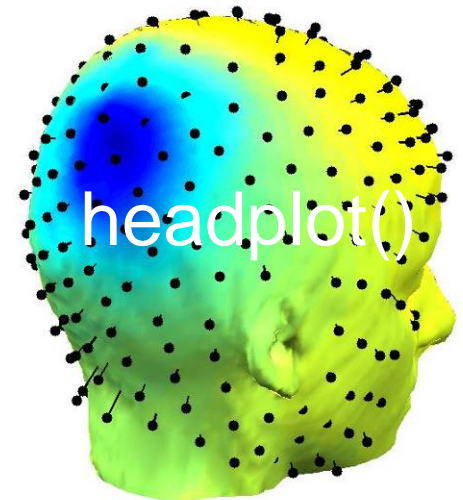
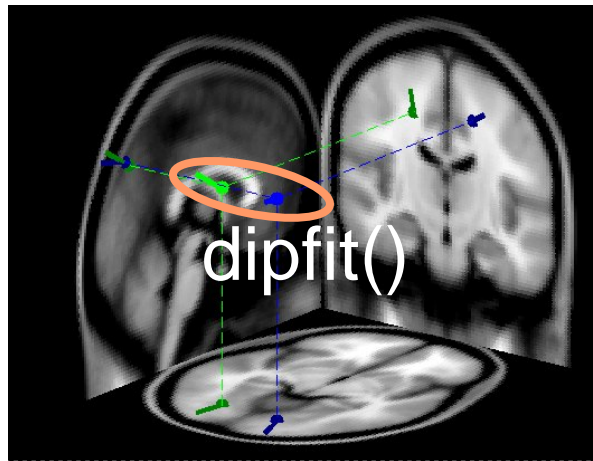
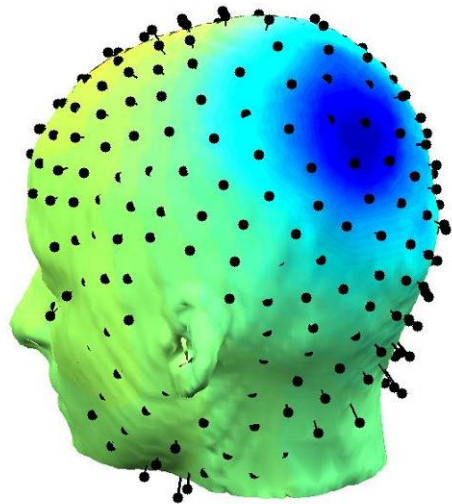


Scott Makeig
vent-Related Brain Dynamics II

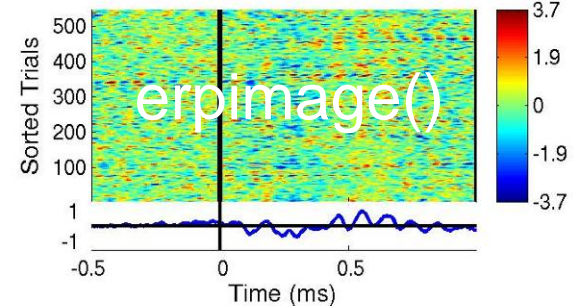
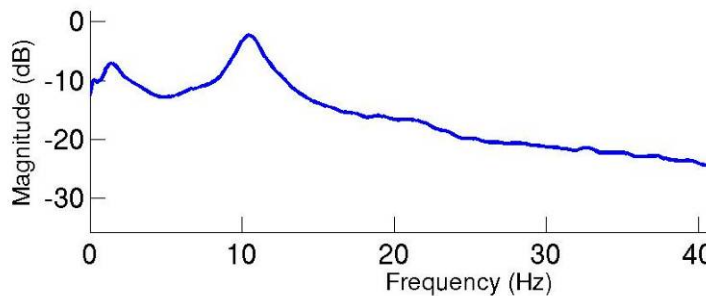
Simultaneously active dipolar independent components



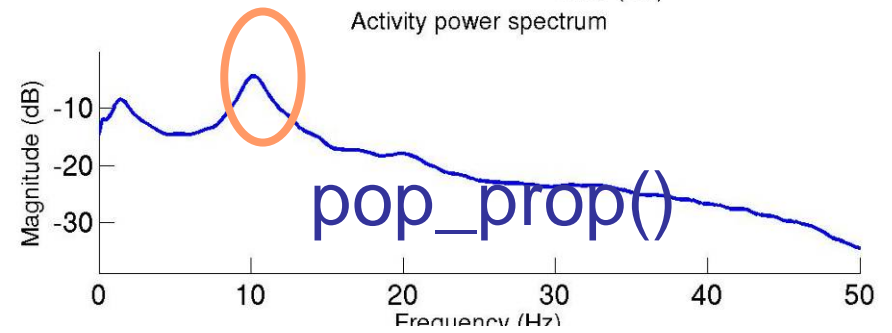
Single Session - Two Maximally Independent Central Alpha Processes



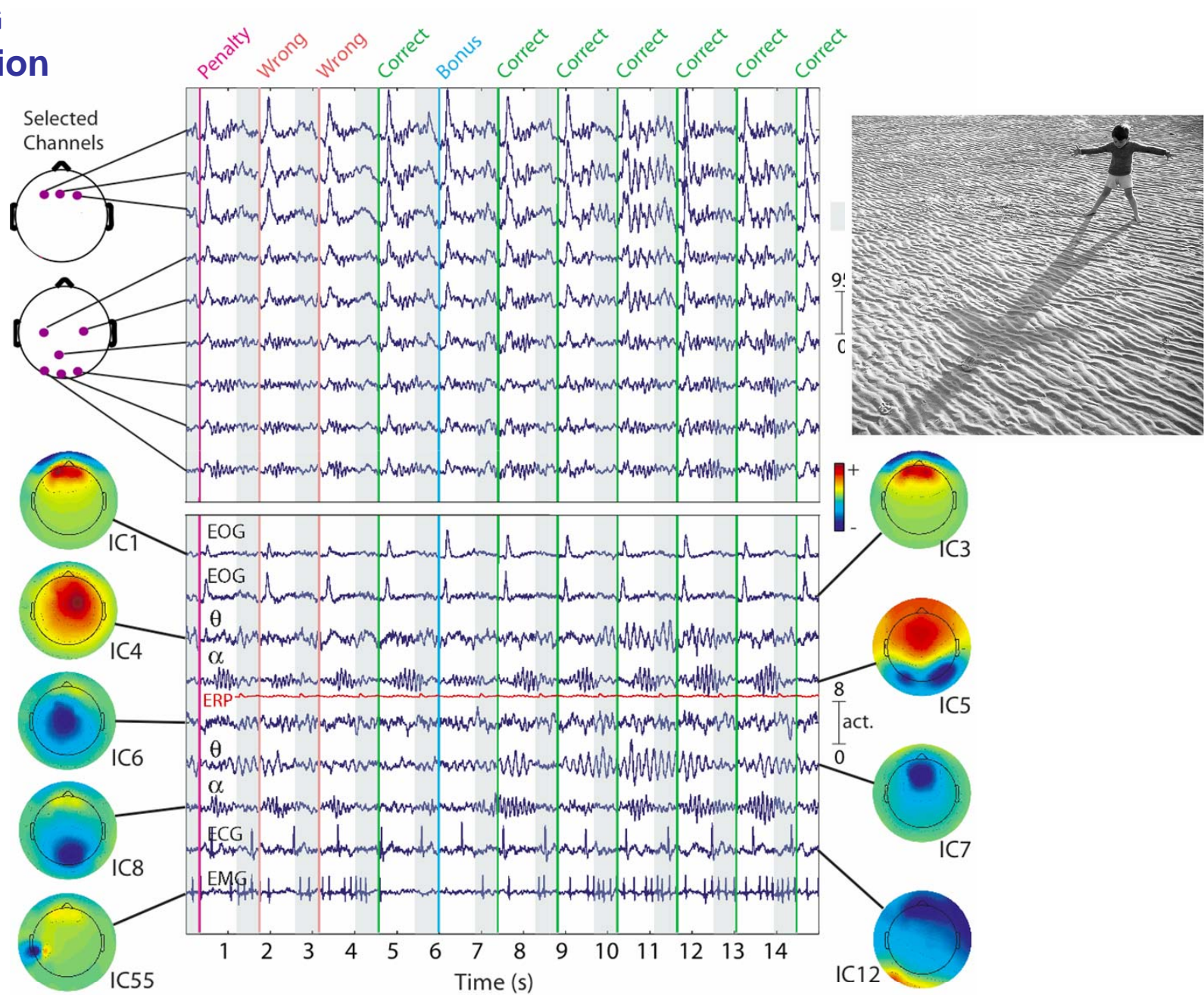
Activity power spectrum

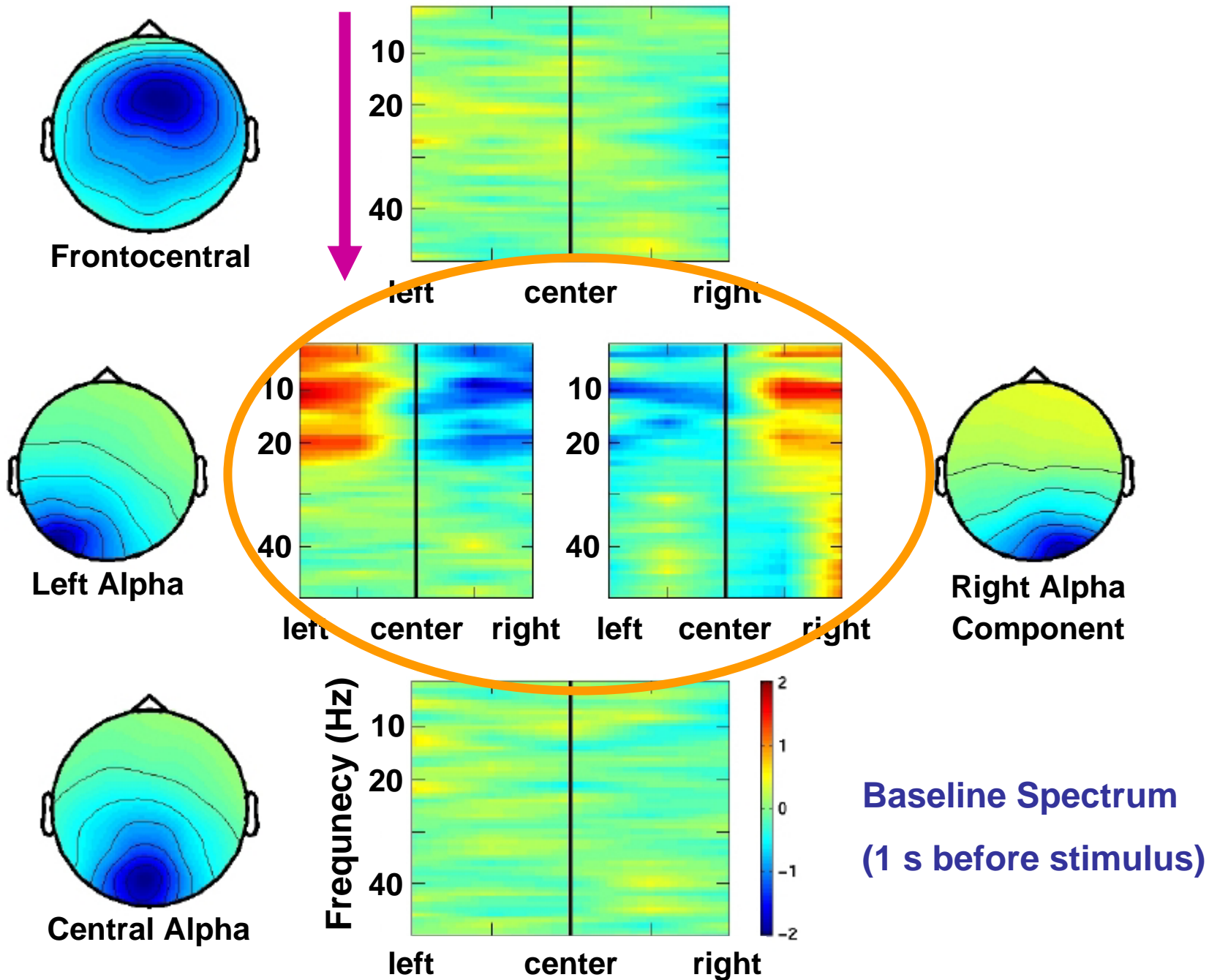


Activity power spectrum



Sample EEG Decomposition





IC Stability I

Data

- 14 subjects performing a memory task
- 71 electrodes
- > 300,000 data points per dataset

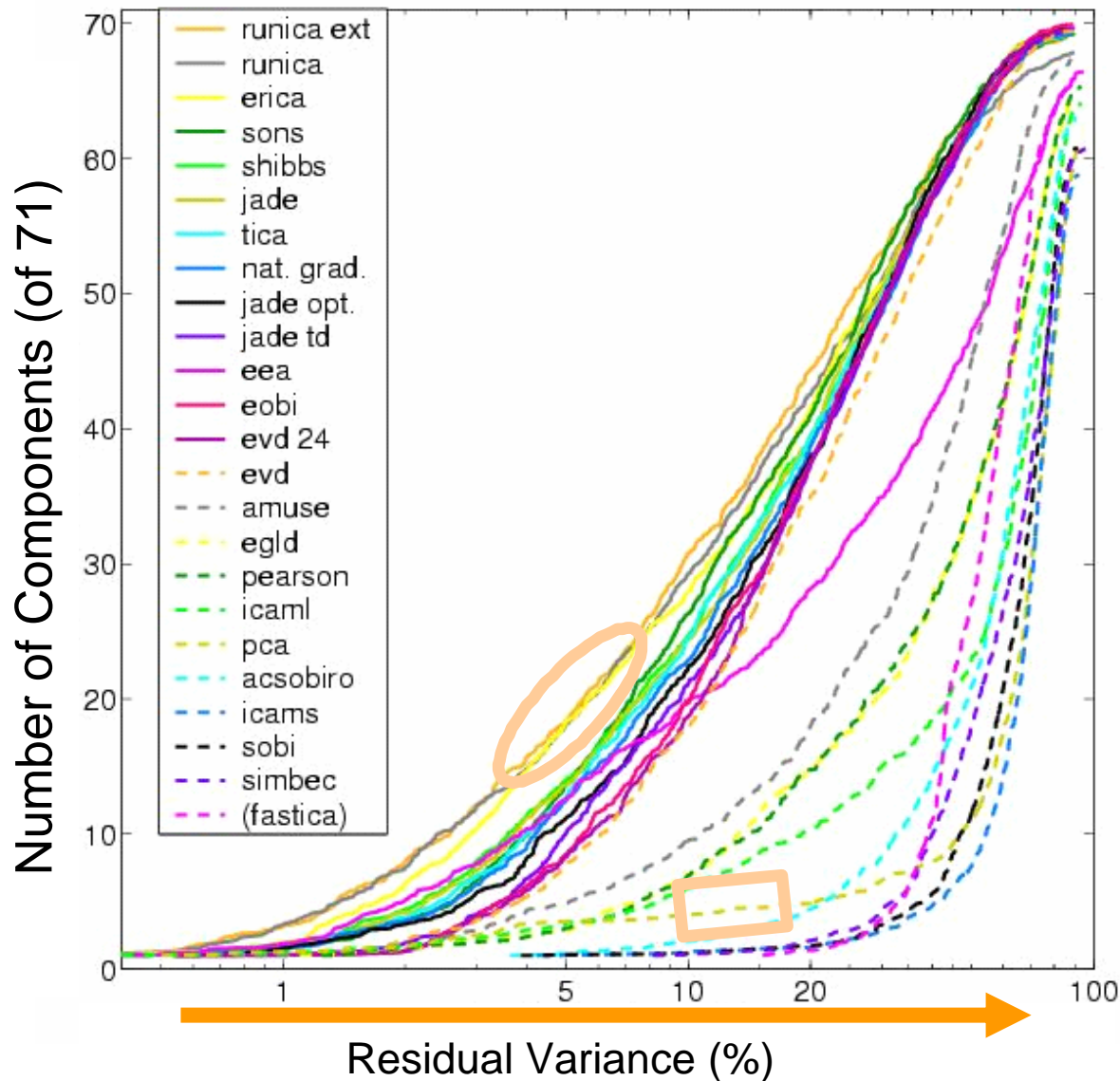
Decomposition

- 23 ICA algorithms, plus PCA and Promax

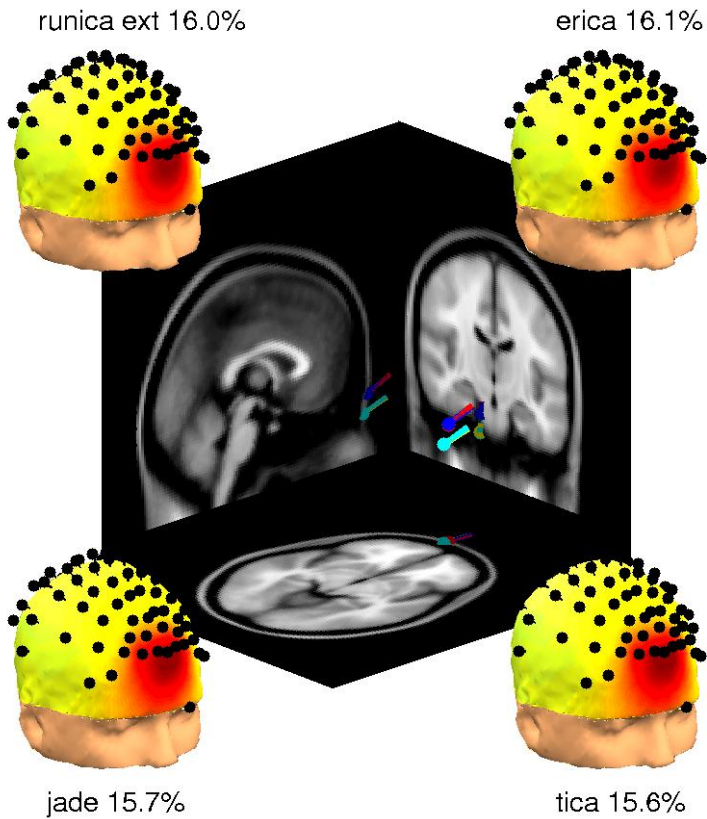
Analysis

- Localized all components with a single equivalent dipole model.
- Sorted components by residual variance of the dipole model w.r.t the component map.

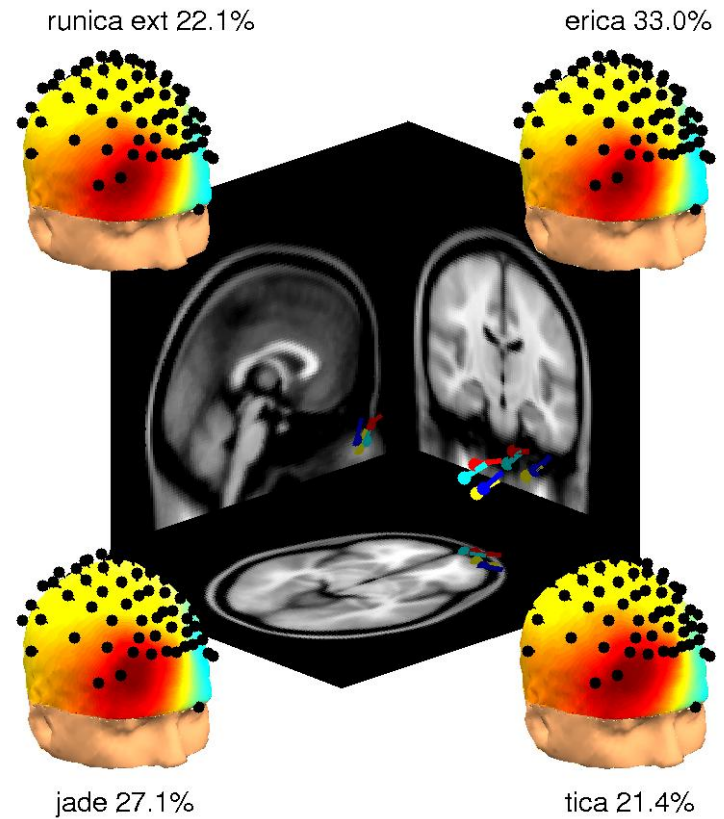
Decomposition Quality Across Algorithms



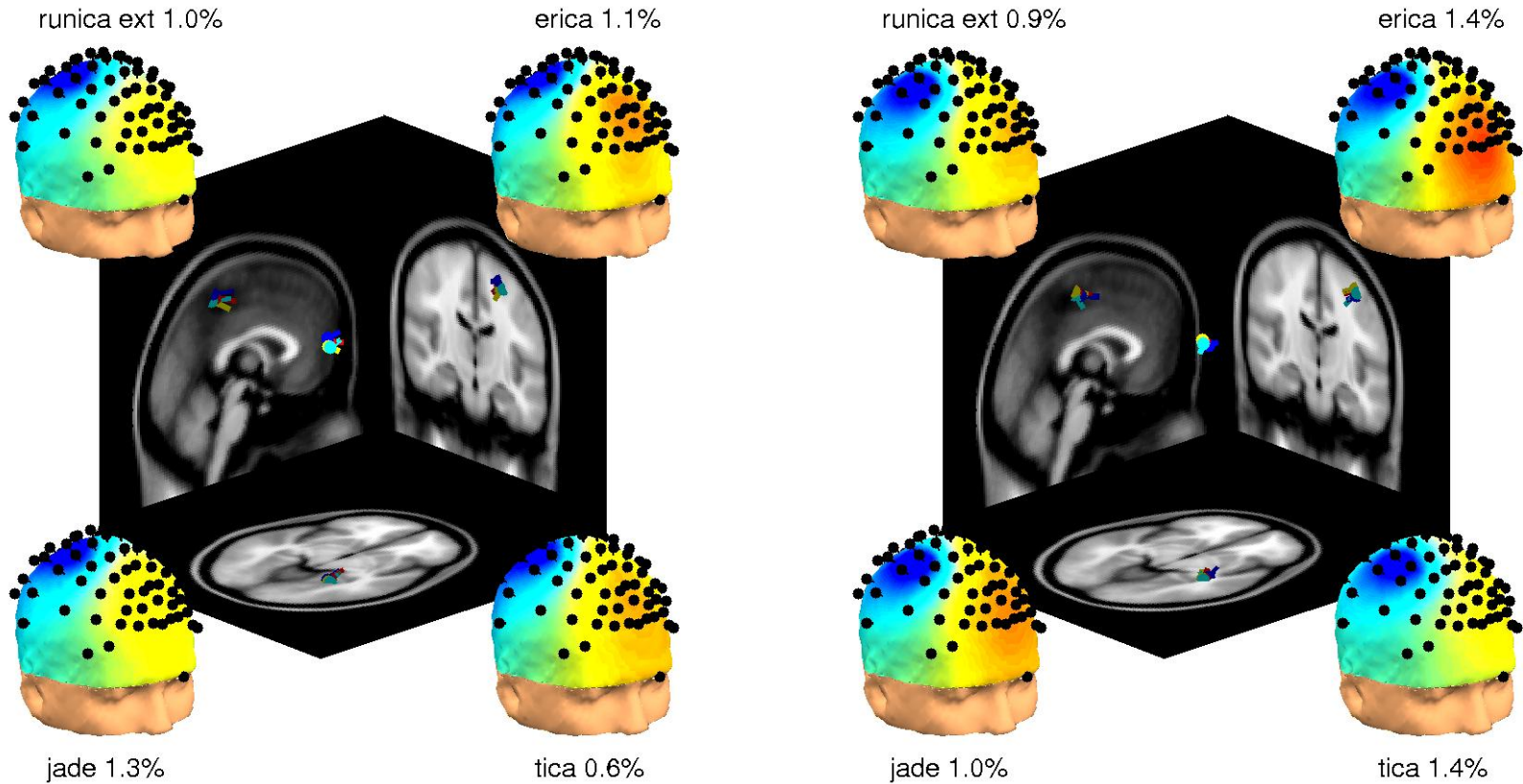
Blinks



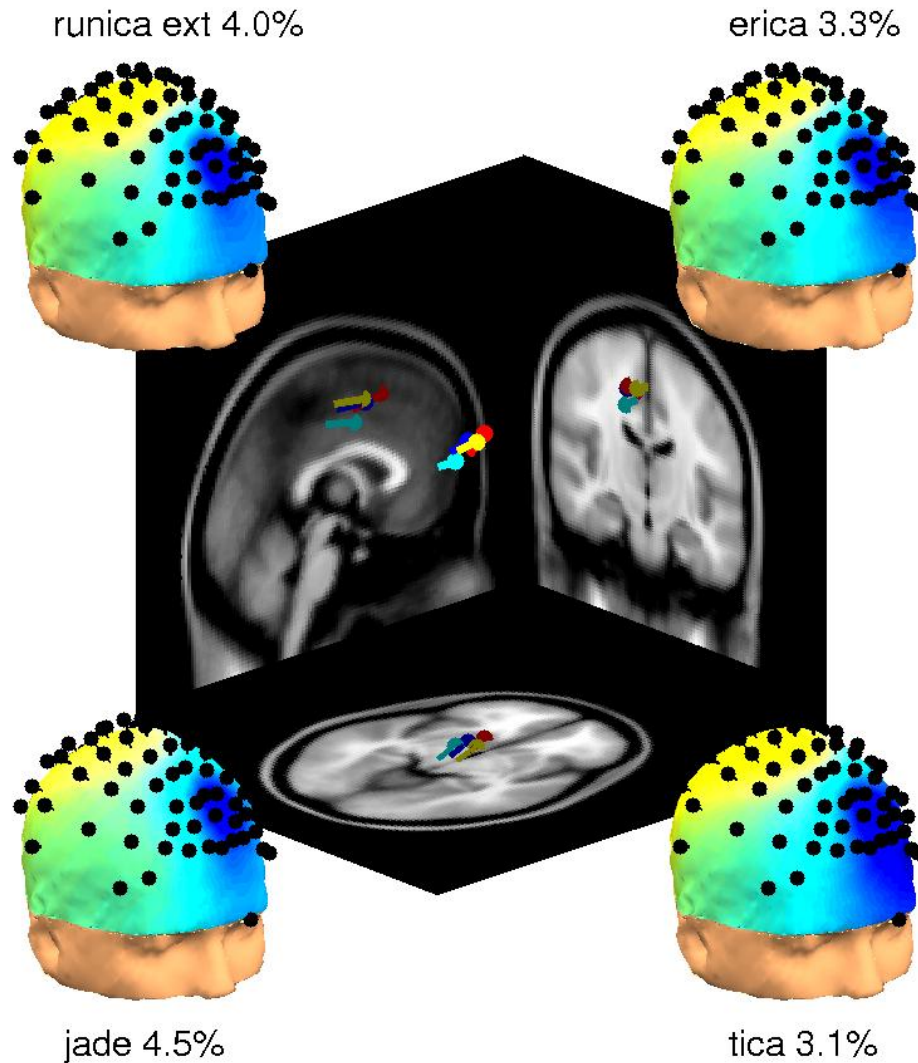
Lateral eye movements



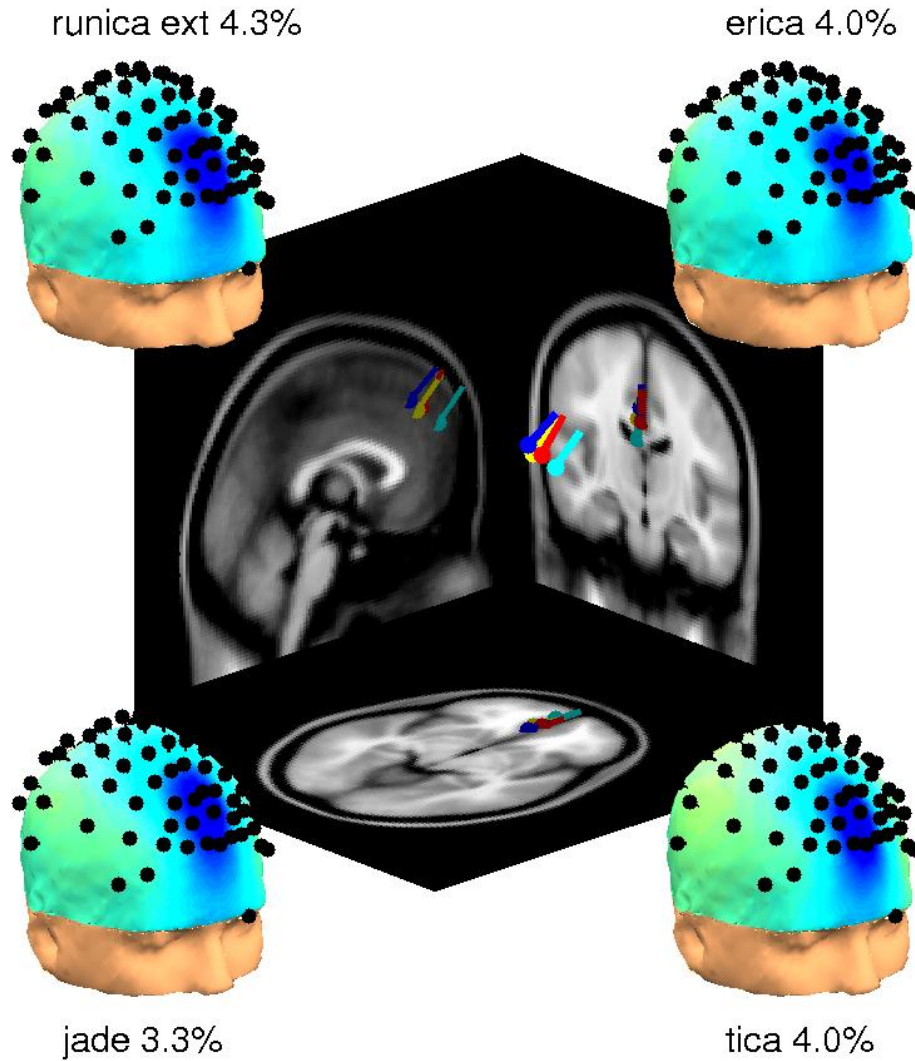
Right Mu components



Left hemisphere Mu component

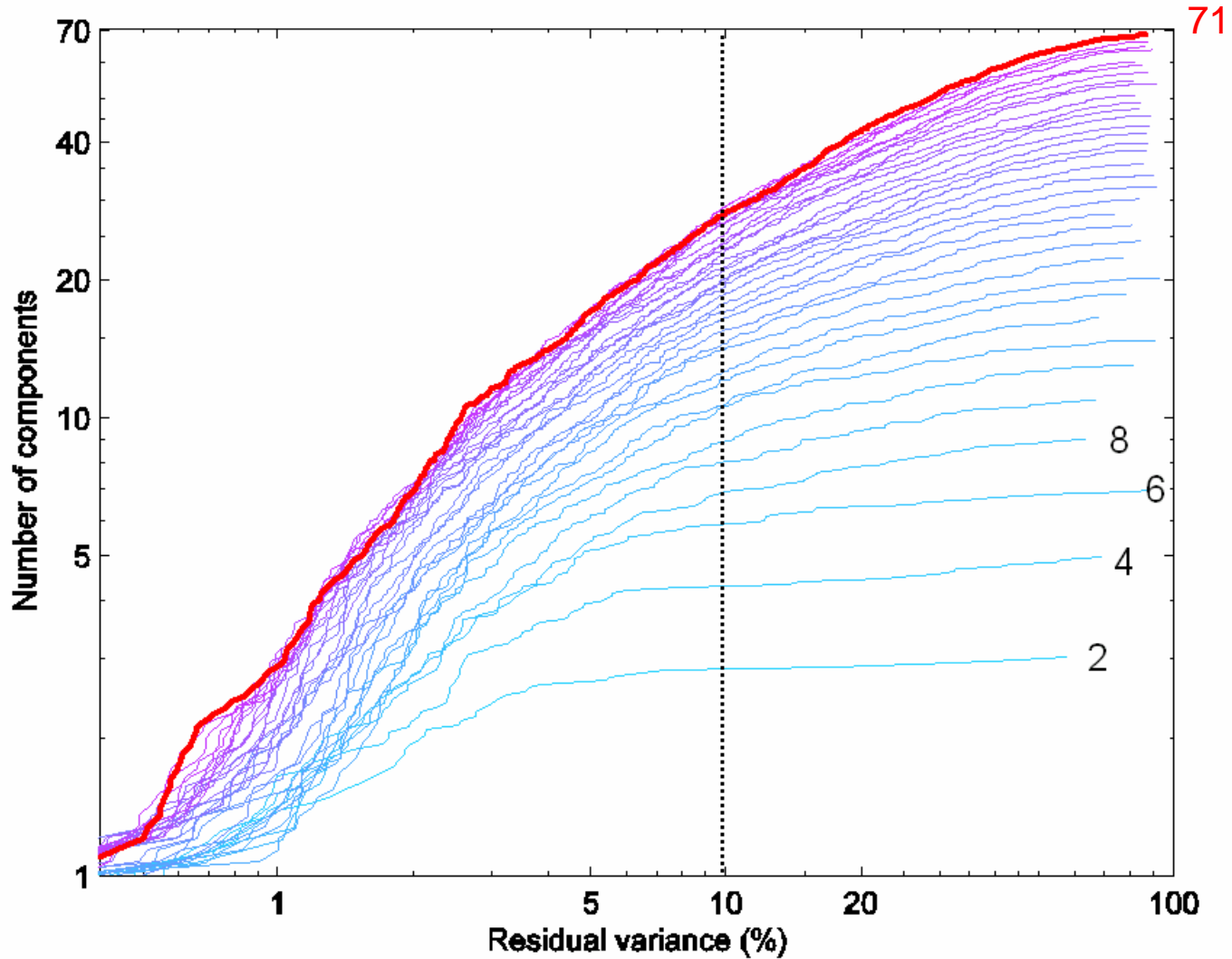


Frontal midline theta



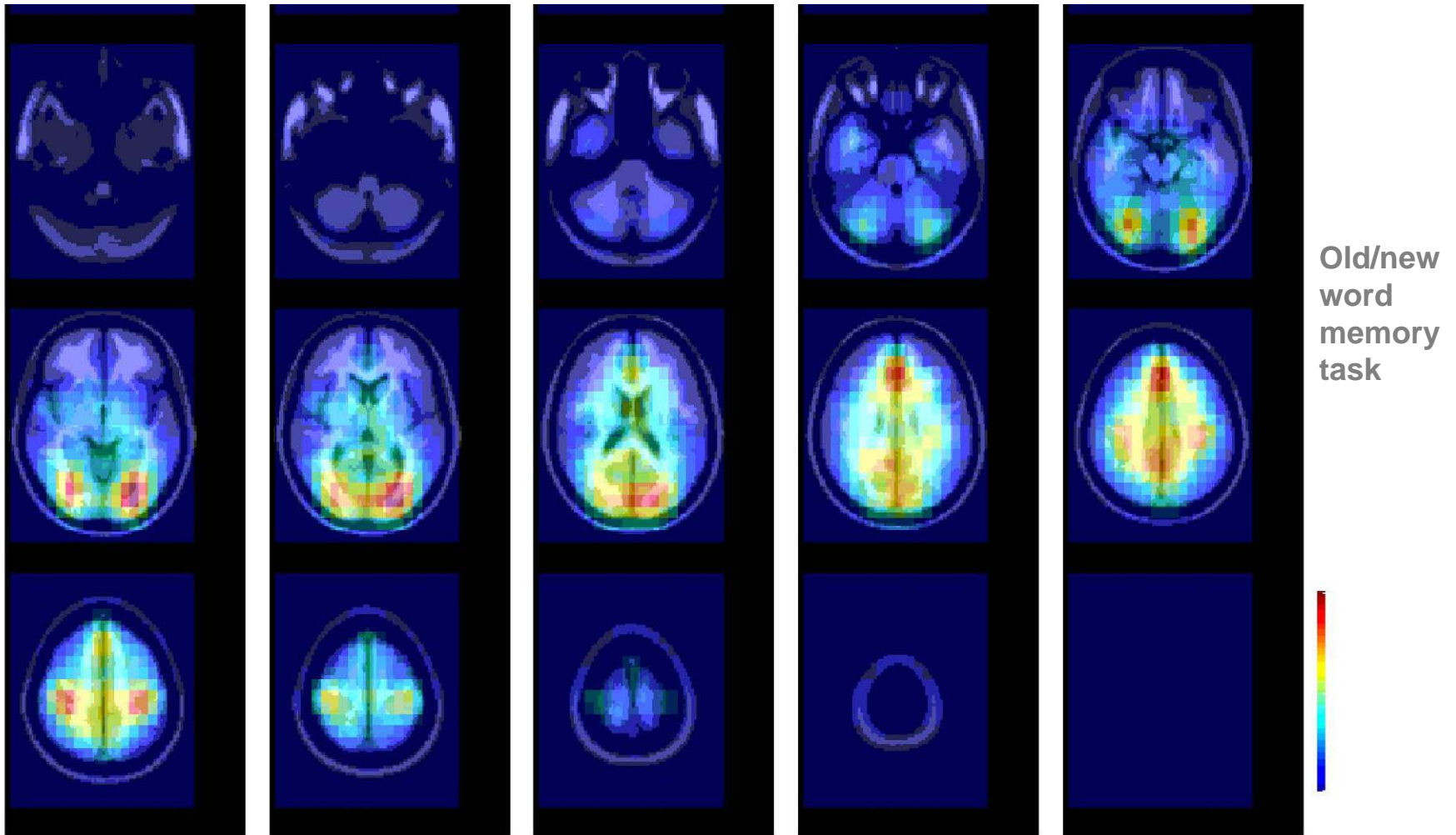
Effects of PCA dimension reduction

Effects of PCA Dimension Reduction on Dipolarity of the ICA Decomposition

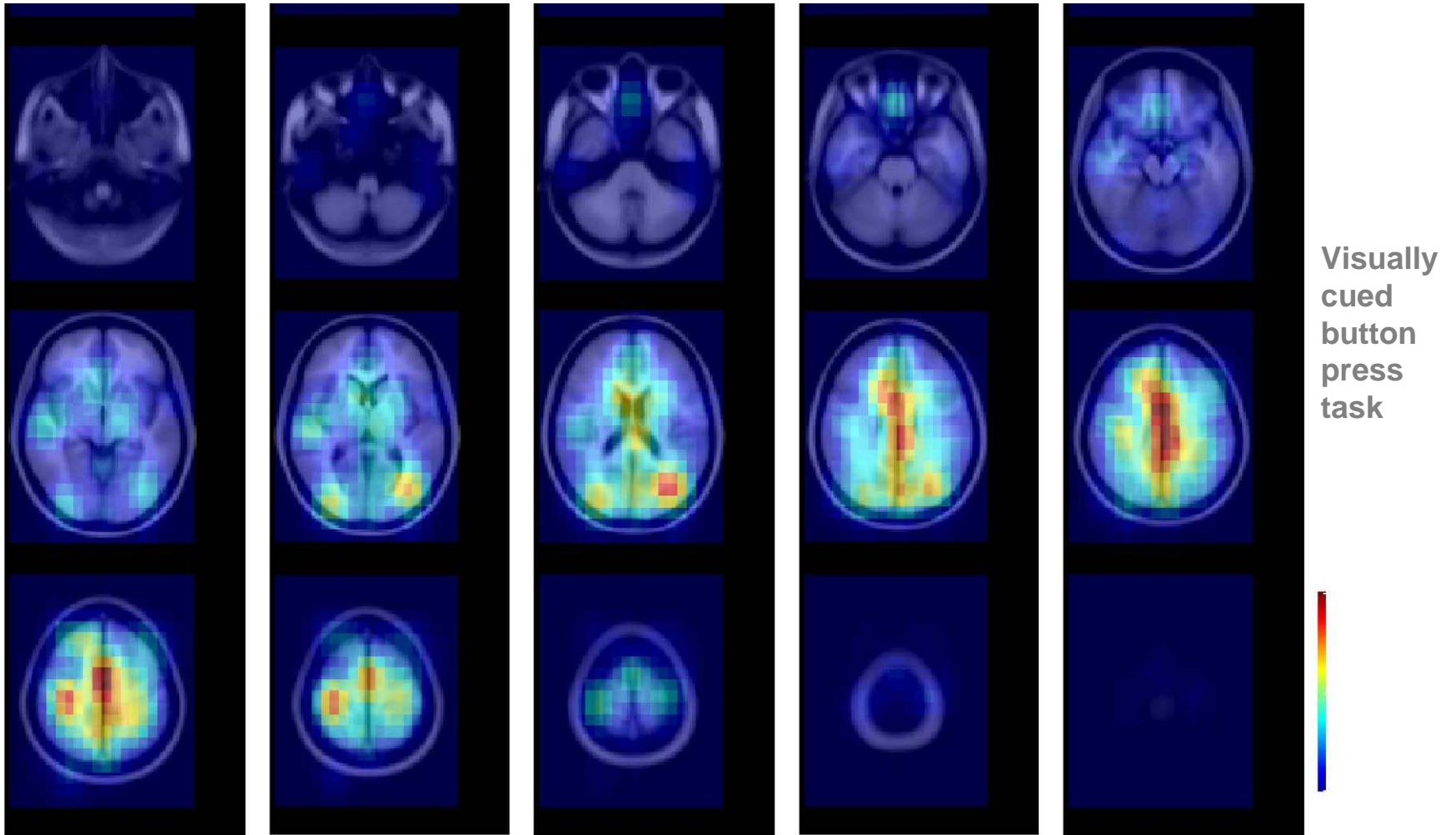


Does EEG always originate in the same cortical locations?

Equivalent-dipole density



Equivalent-dipole density

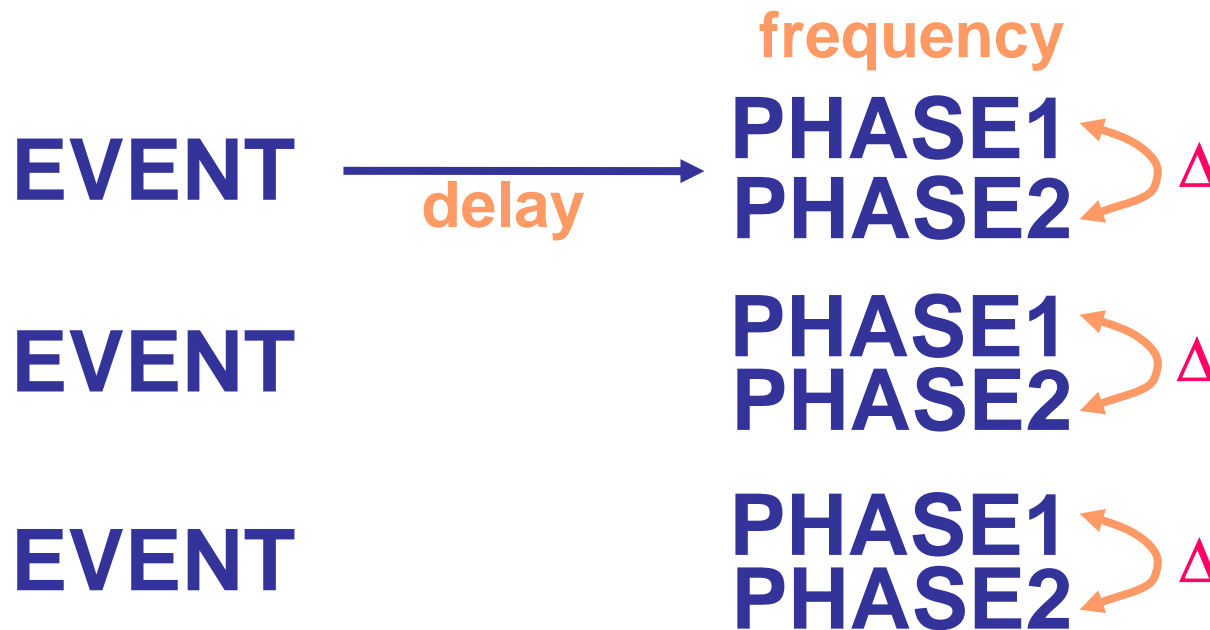


IC coherence

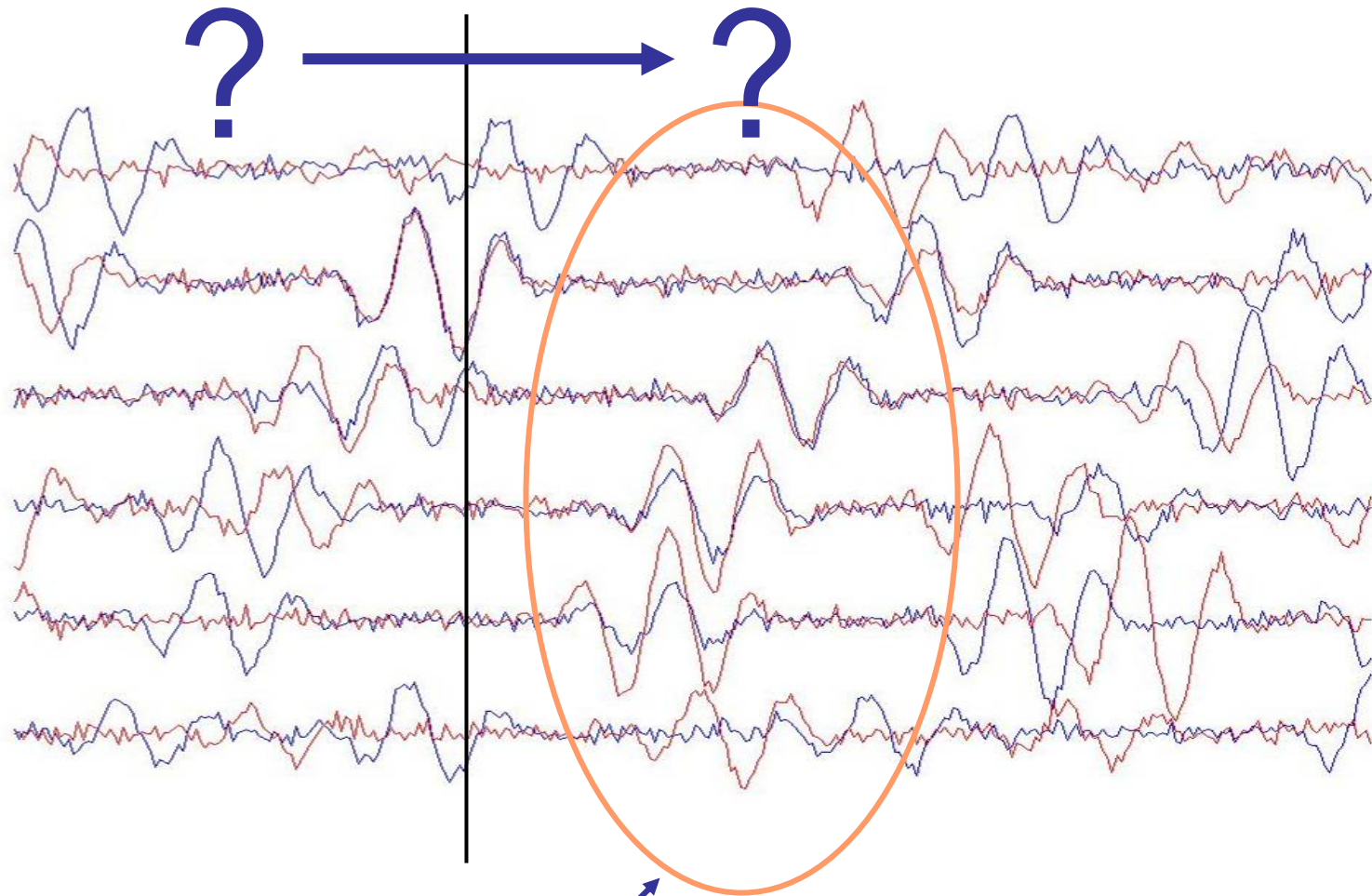
A contradiction in terms?

Event-Related Coherence (ERC)

- Significant consistency of local phase **difference** between two concurrent physiological waveforms.



TWO SIMULATED THETA PROCESSES



Event-related Coherence

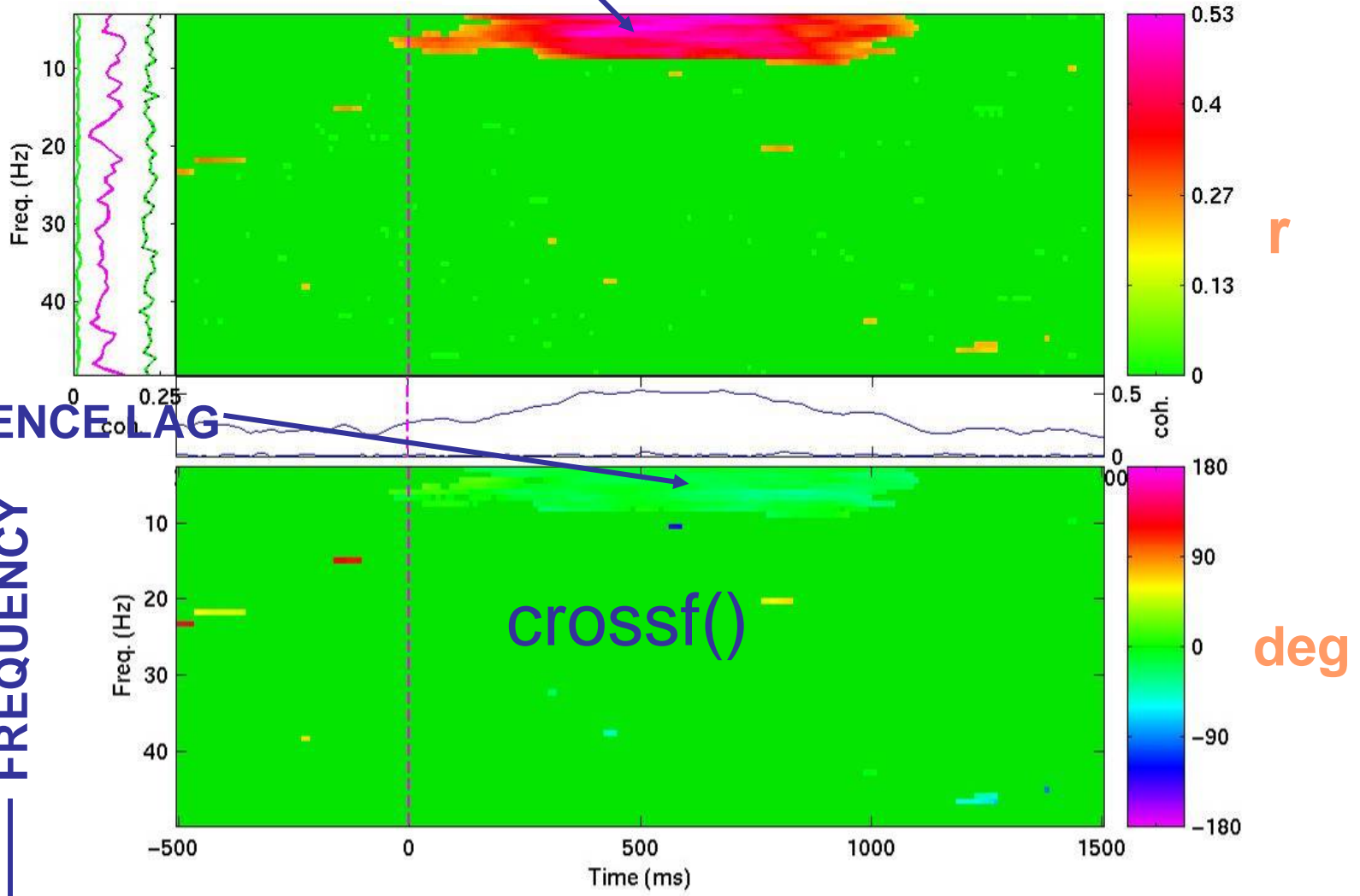
EVENT-RELATED COHERENCE

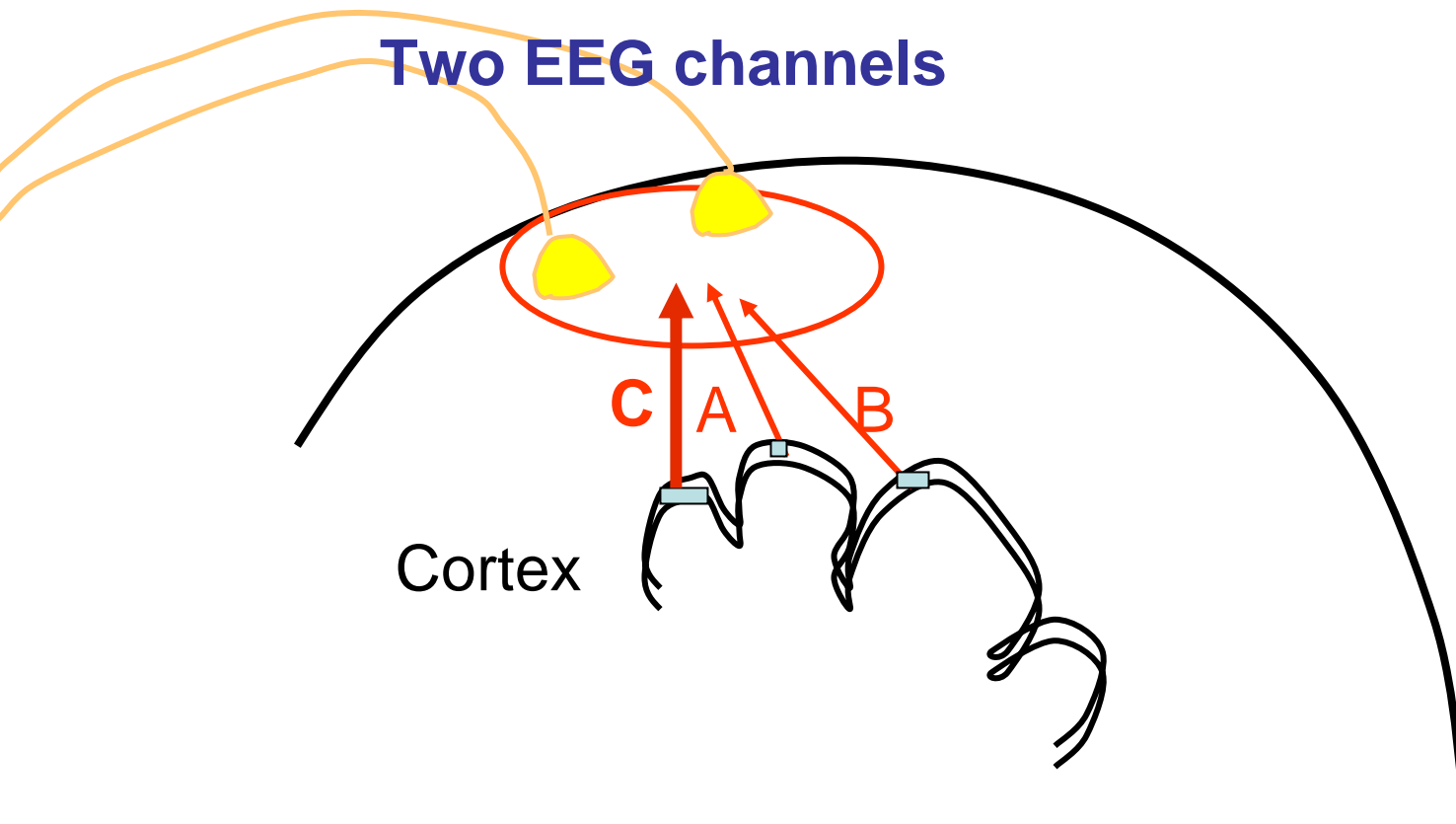
ERC

COHERENCE LAG

FREQUENCY

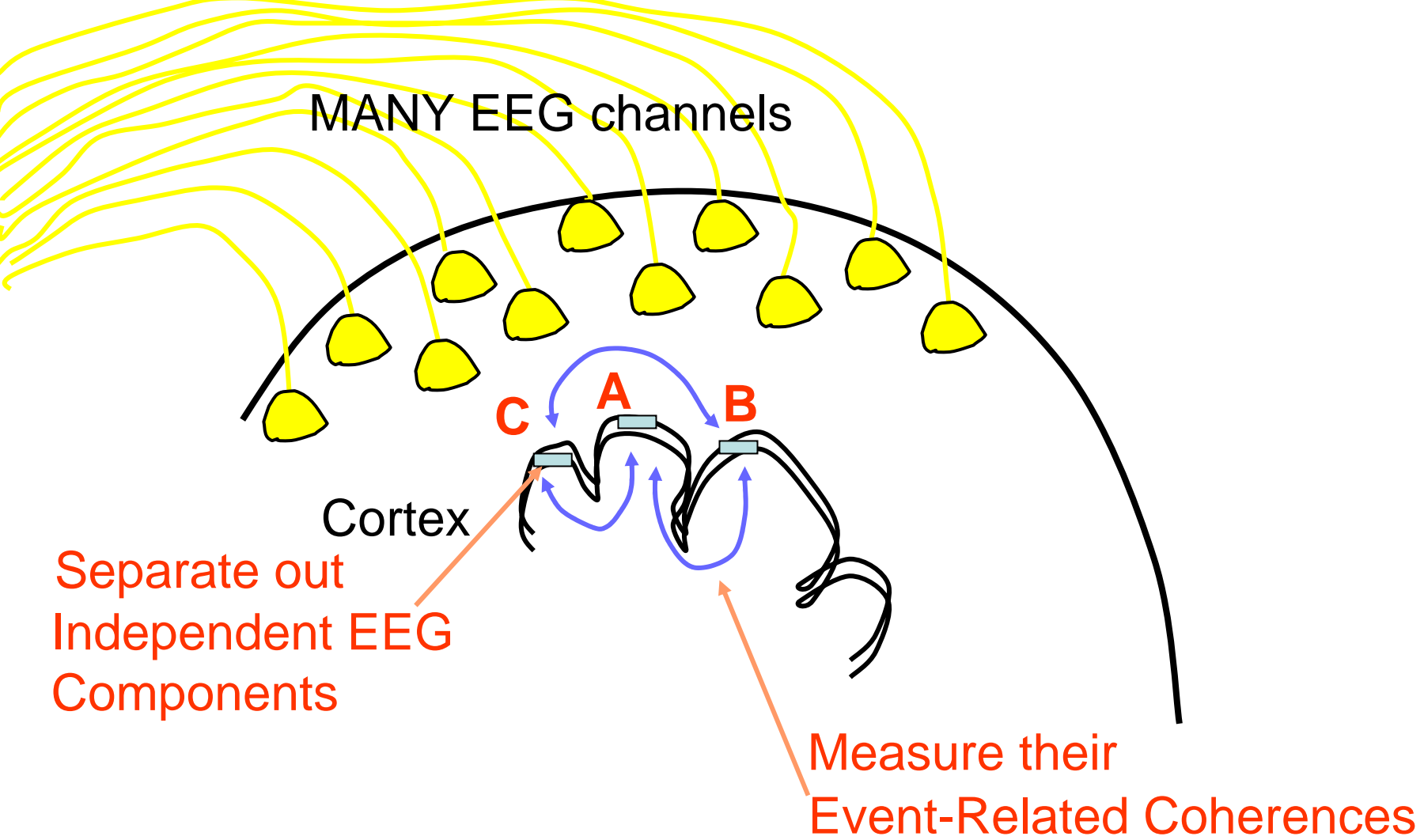
TIME





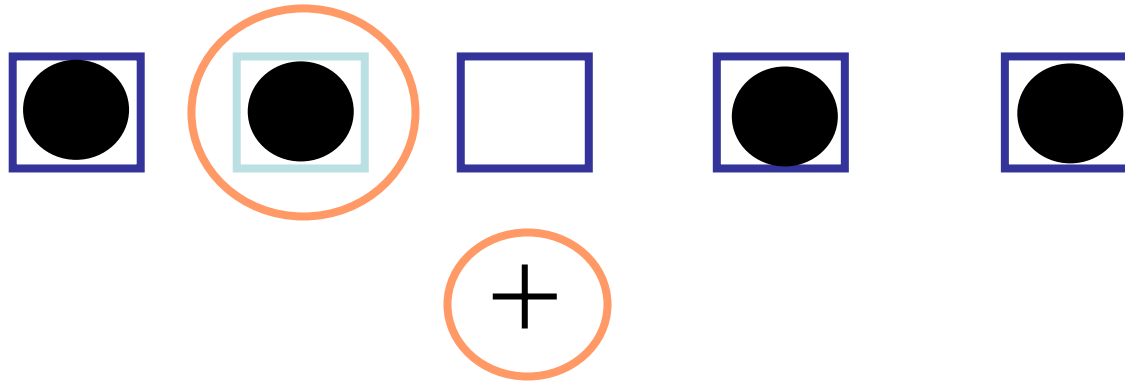
Coherence ↑

Scalp channel coherence → source confounds!



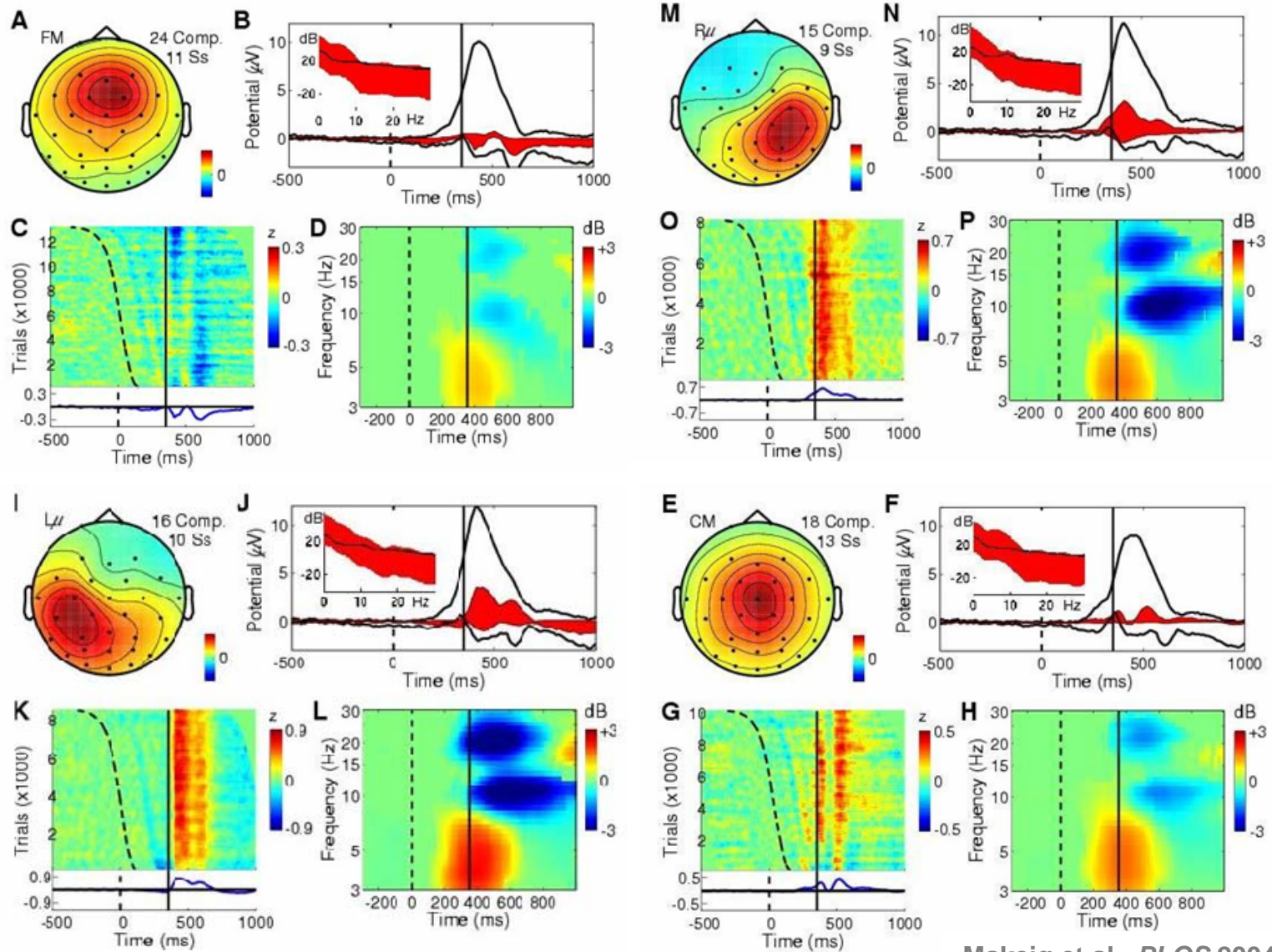
ICA Component coherence → source dynamics!

Visual Selective Attention Task



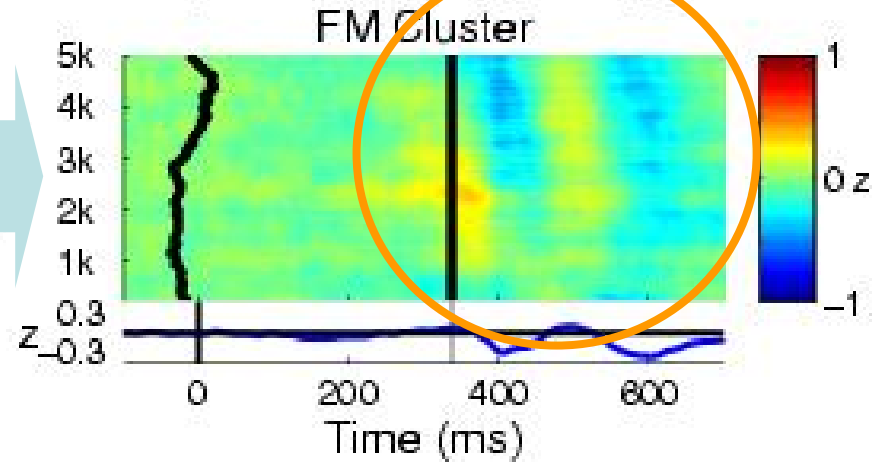
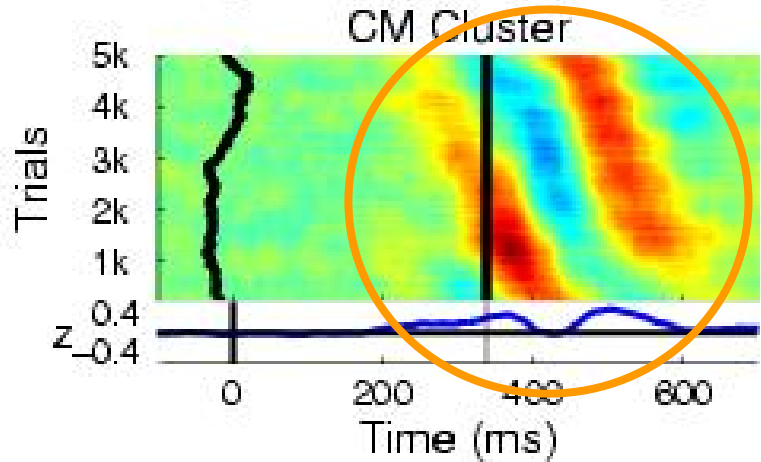
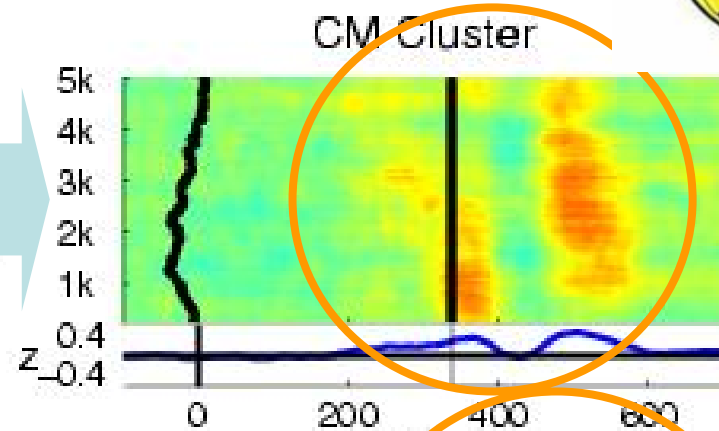
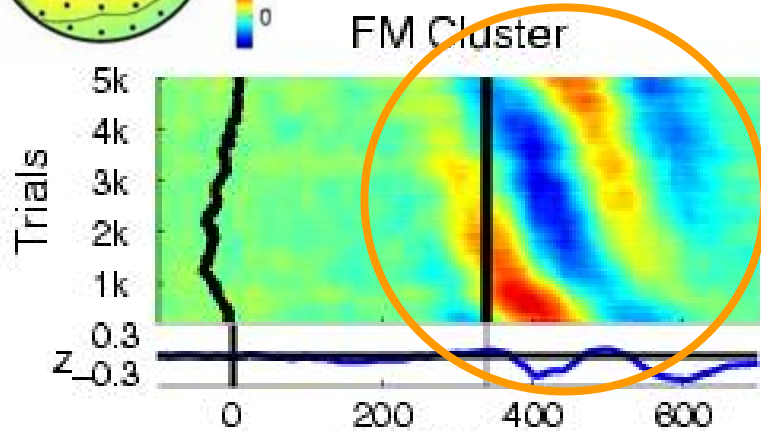
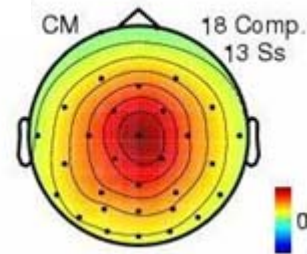
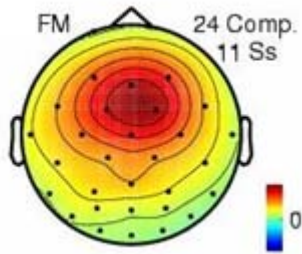
15 subjects

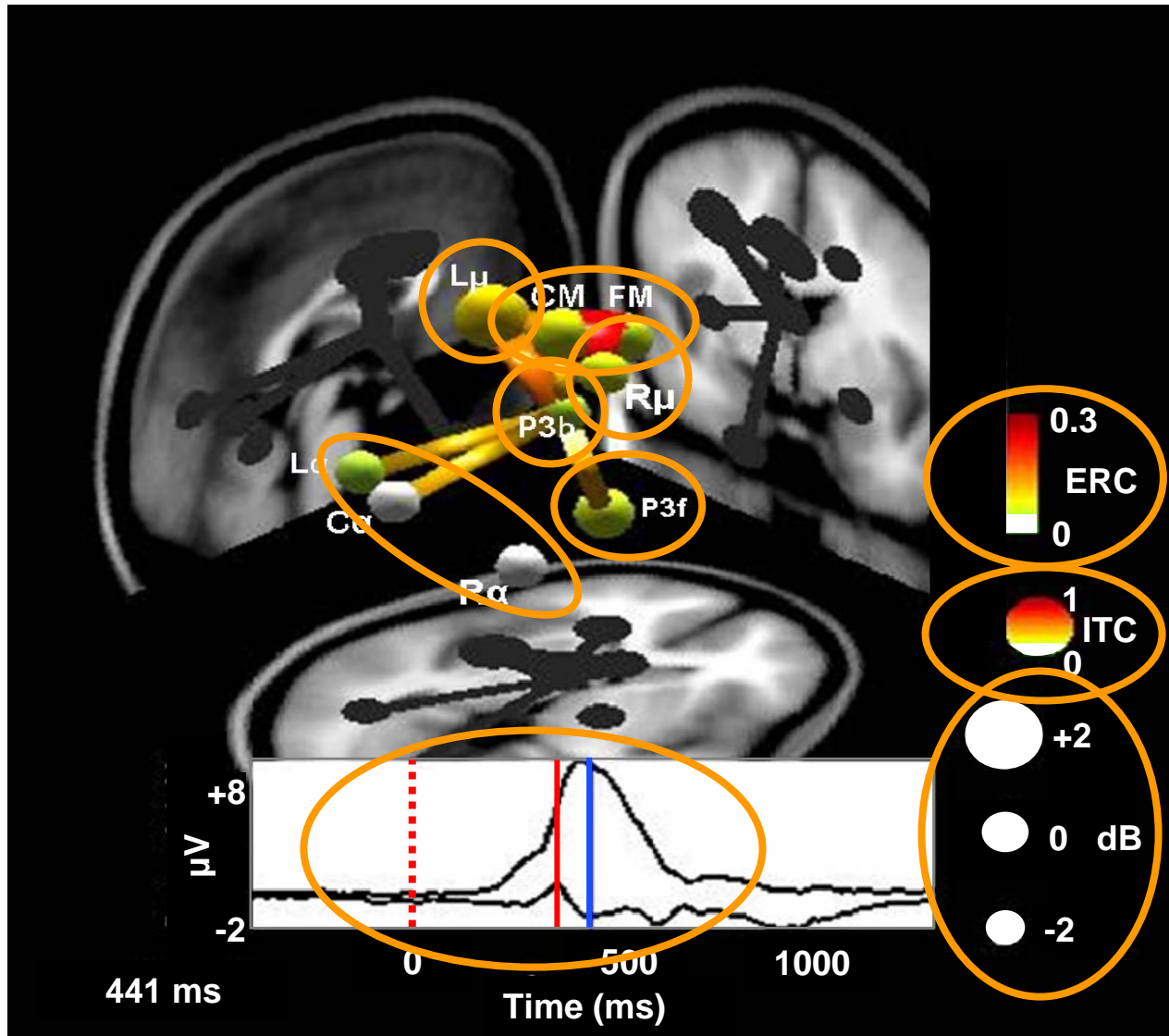
Four component clusters with brief theta bursts event-locked to the speeded button press



Makeig et al., *PLOS* 2004

Partial Phase Coherence of FM and CM Clusters





I realized that ...!

It struck me that ...!

I wondered whether ... ?

All of a sudden ...!!

The feeling hit me that ...!

I looked to see if ...??

I noticed that ...!

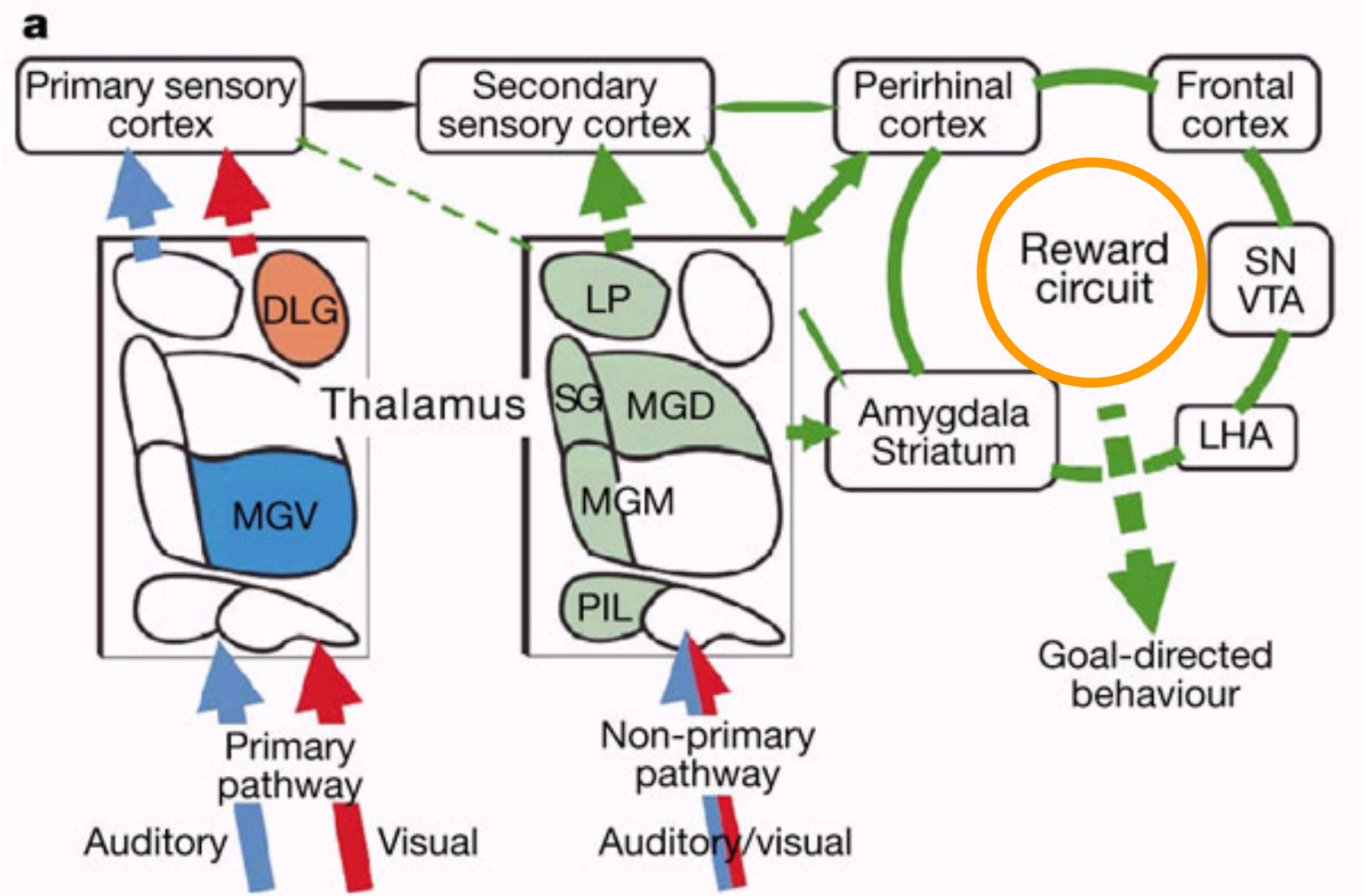
I looked again at ...?

I decided that ...!

It occurred to me that ...

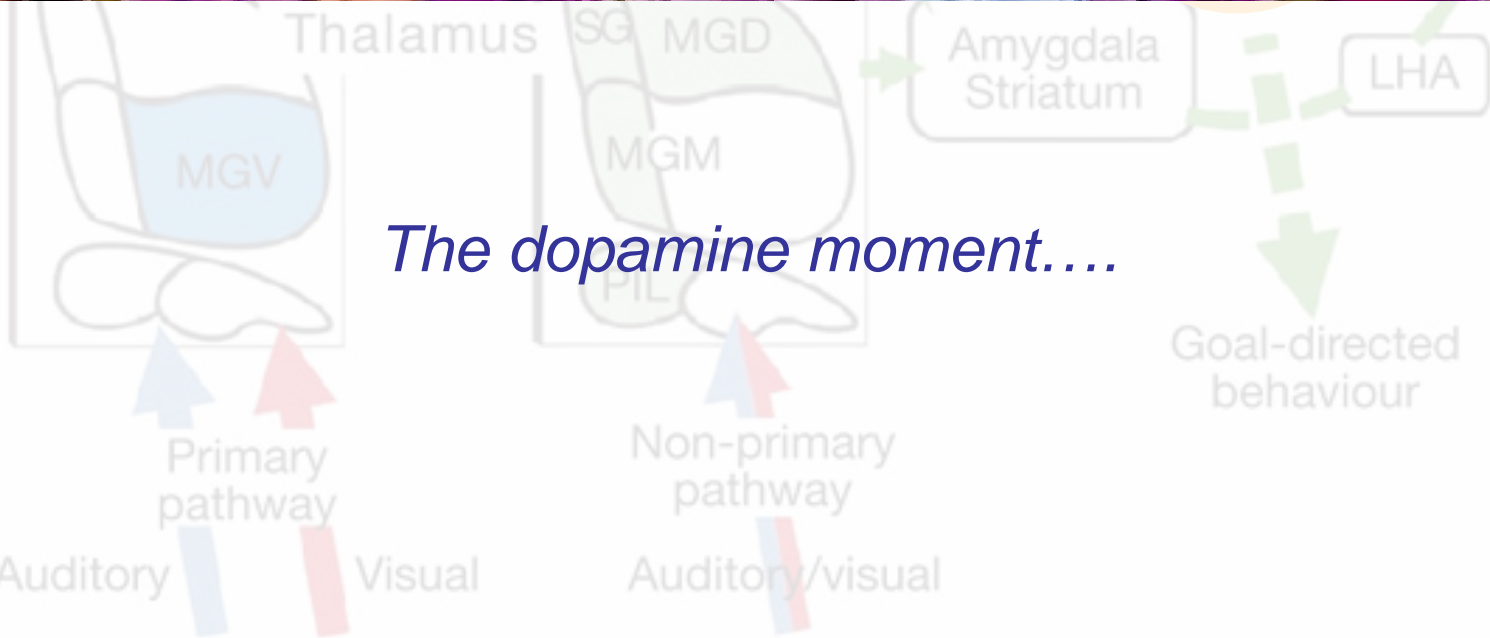
I imagined ...?

I searched my memory for ...???



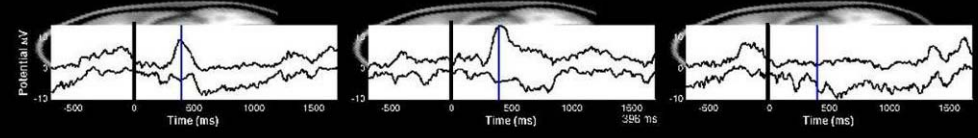
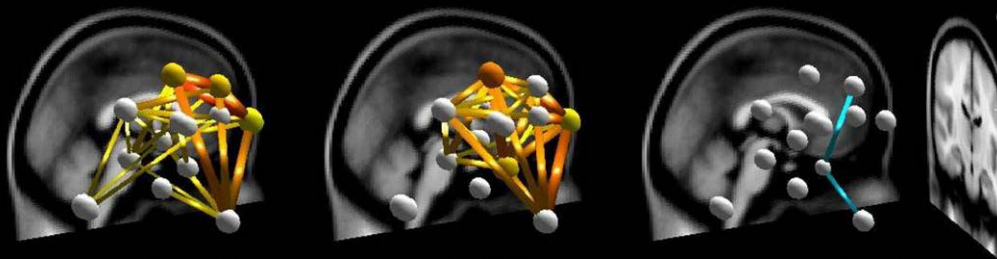
a

Primary sensory Secondary Frontal



The dopamine moment....

Subj 1

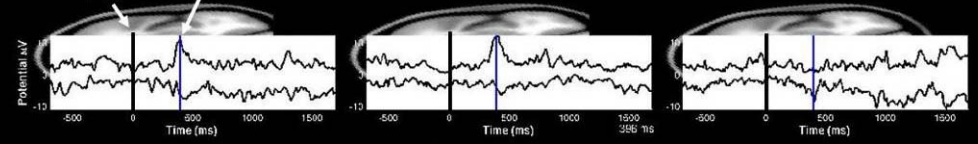
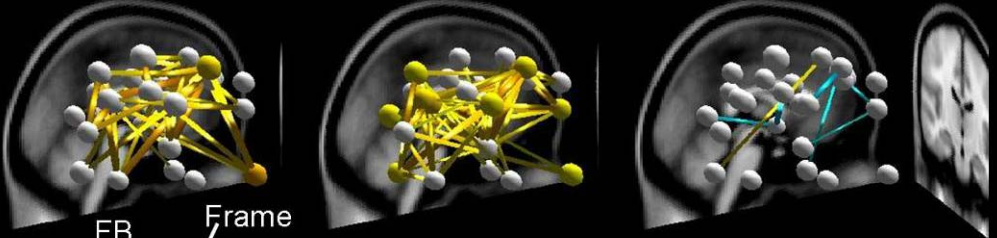


Bonus

Wrong

Difference

Subj 2

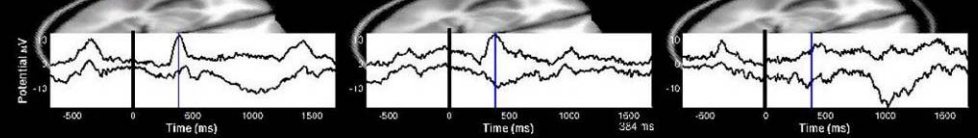
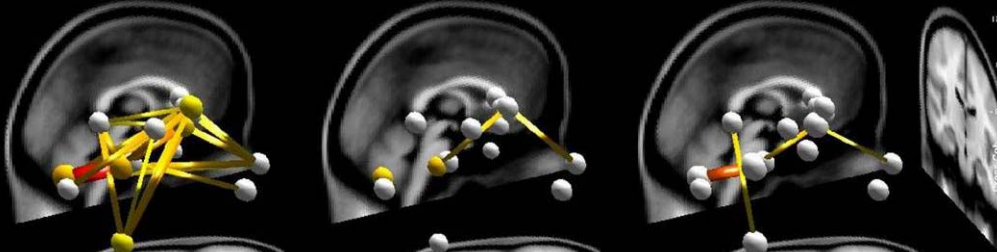


Bonus

Wrong

Difference

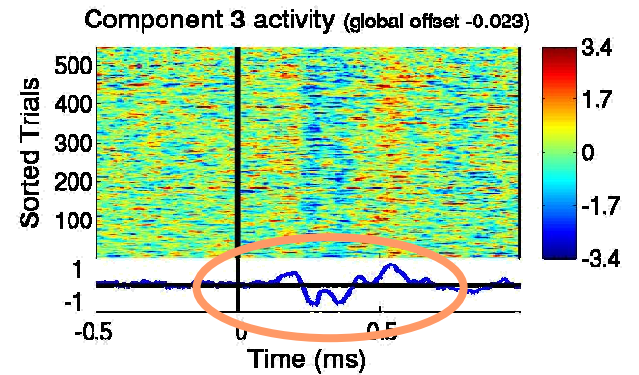
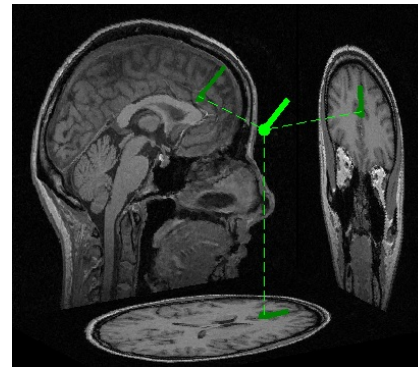
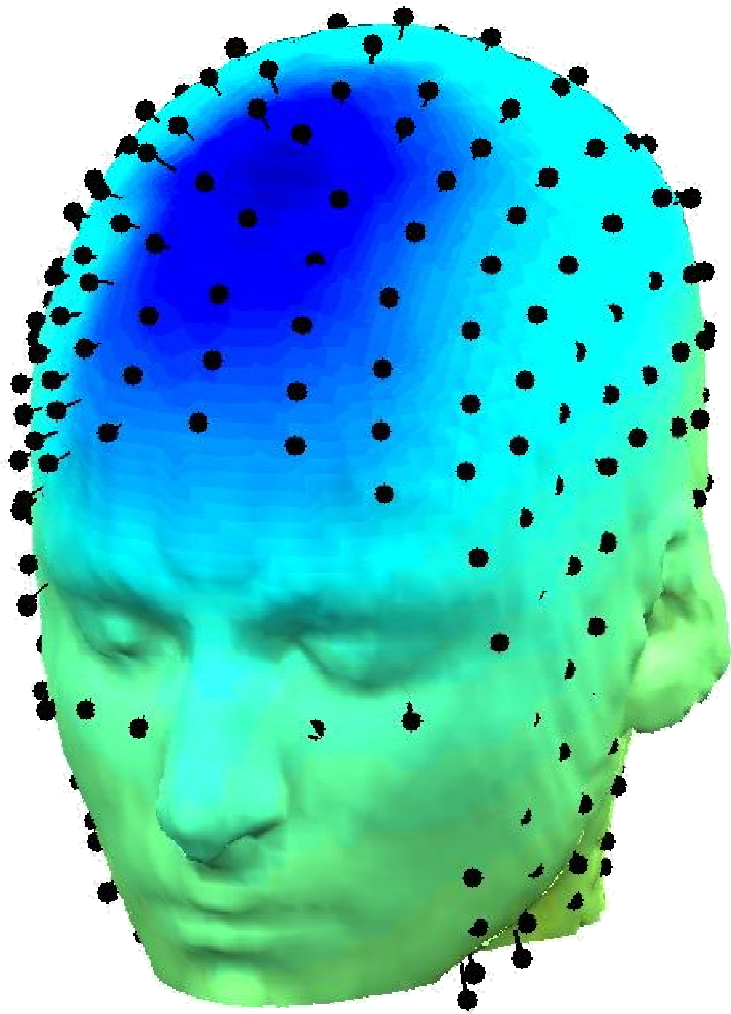
Subj 3



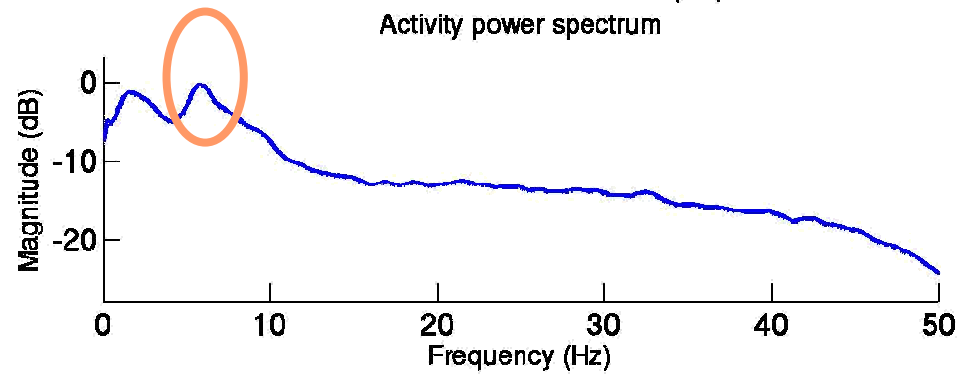
Trial-to-trial variability

Vive la difference!

Frontal Midline Theta Process



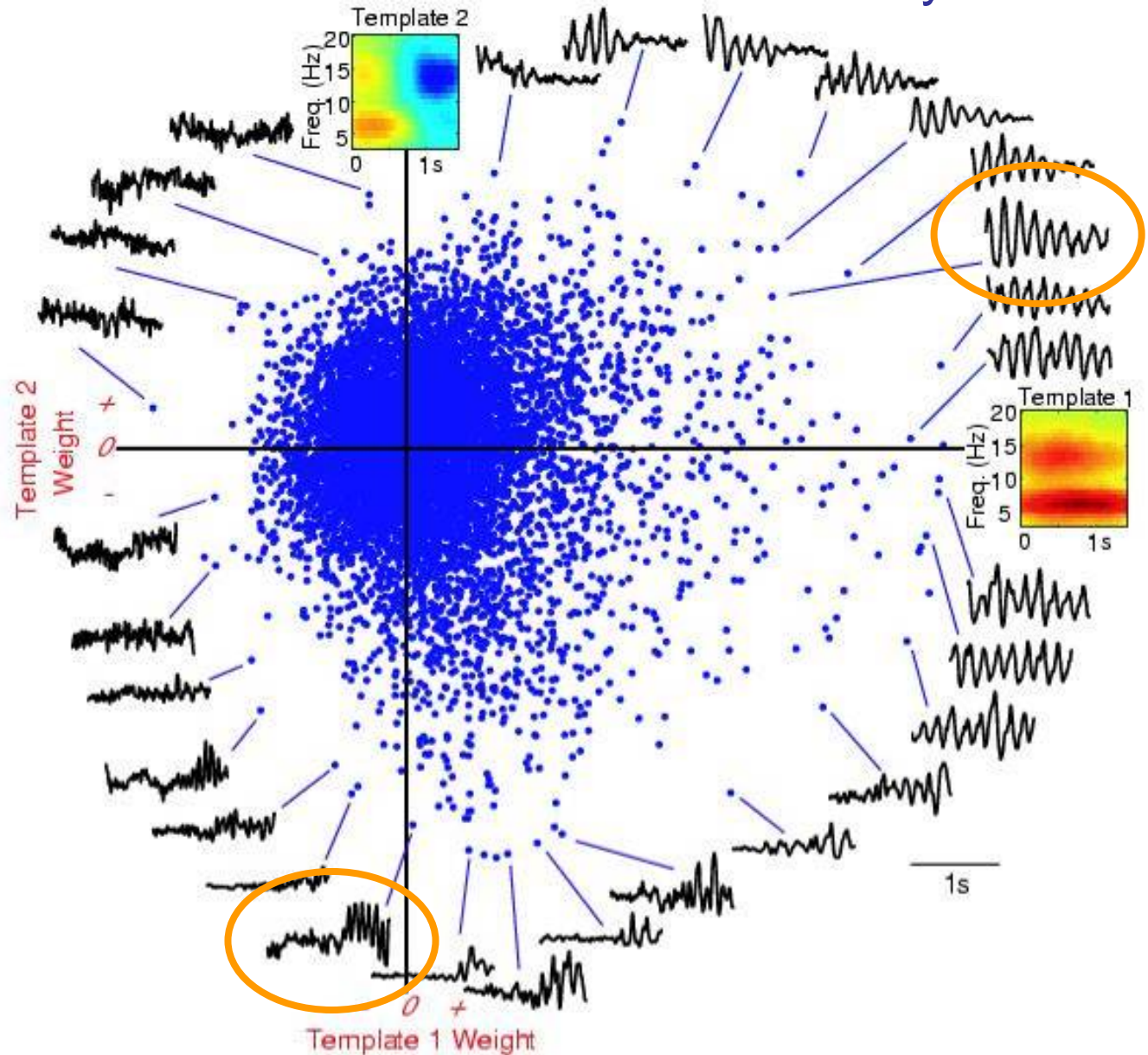
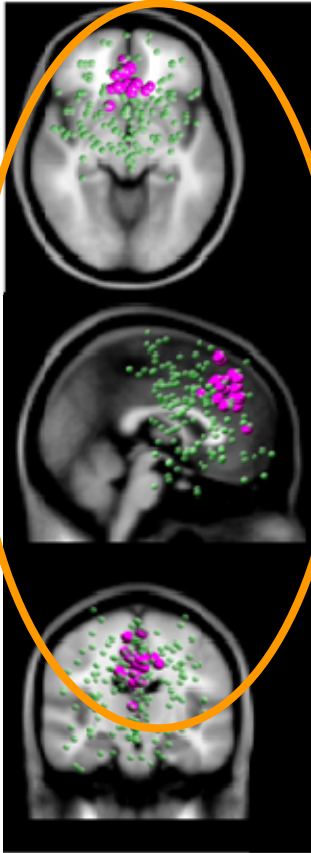
Activity power spectrum

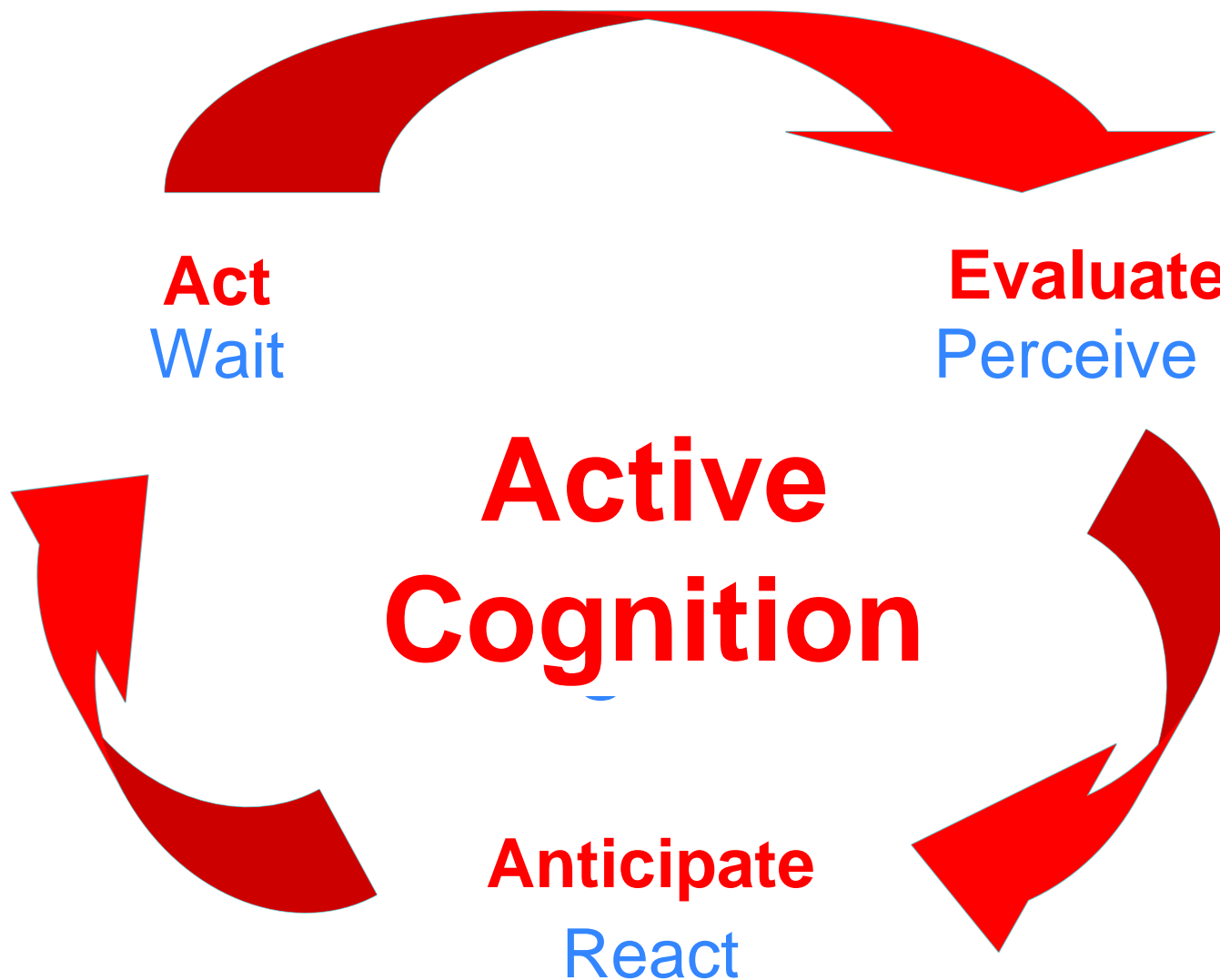




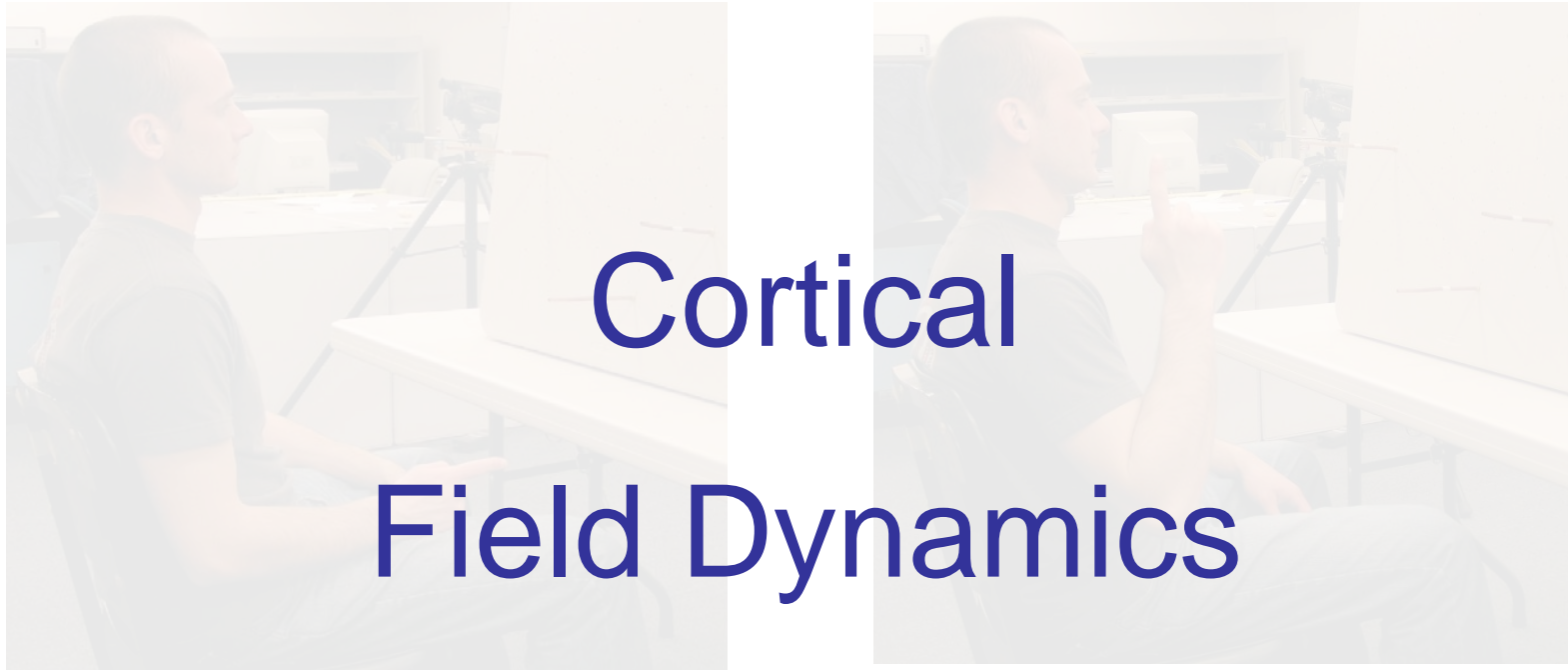
Multiple trial modes from an component cluster – trials time-locked to letter onsets in a memory task

FM0 Cluster





Reach Task

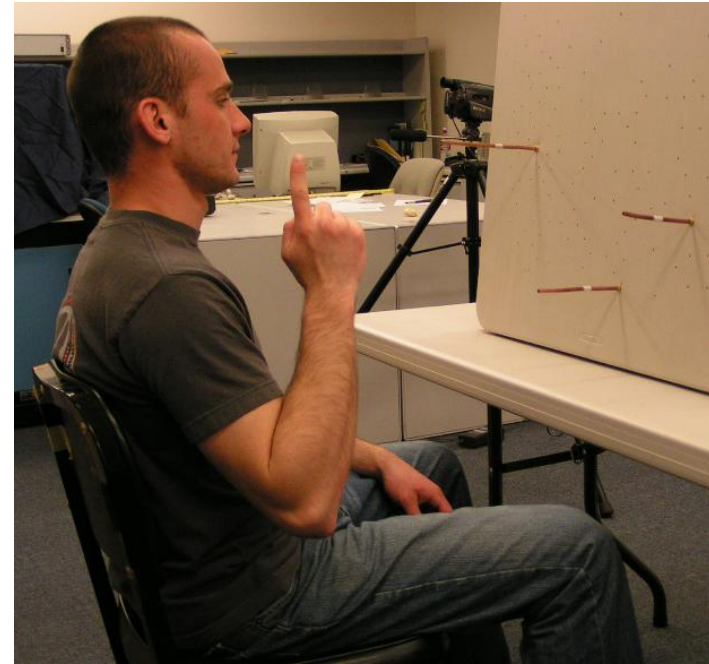
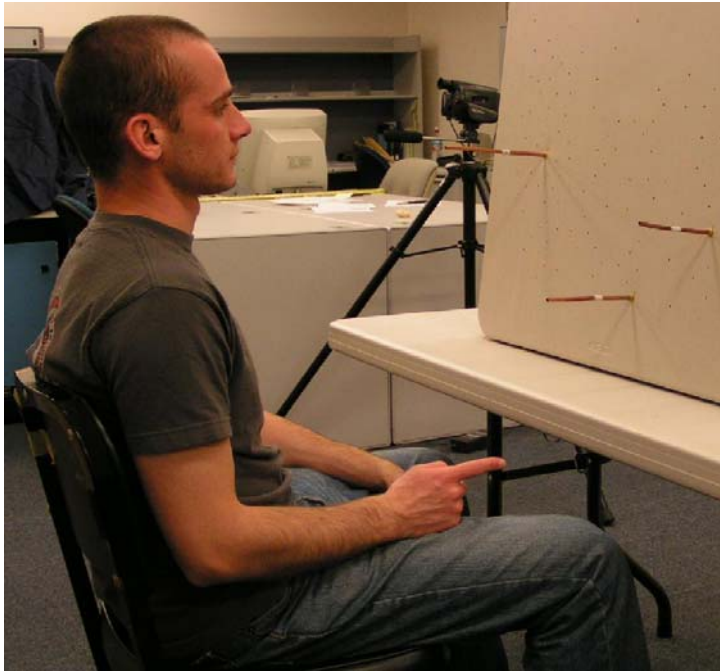


Cortical Field Dynamics

of Active Cognition

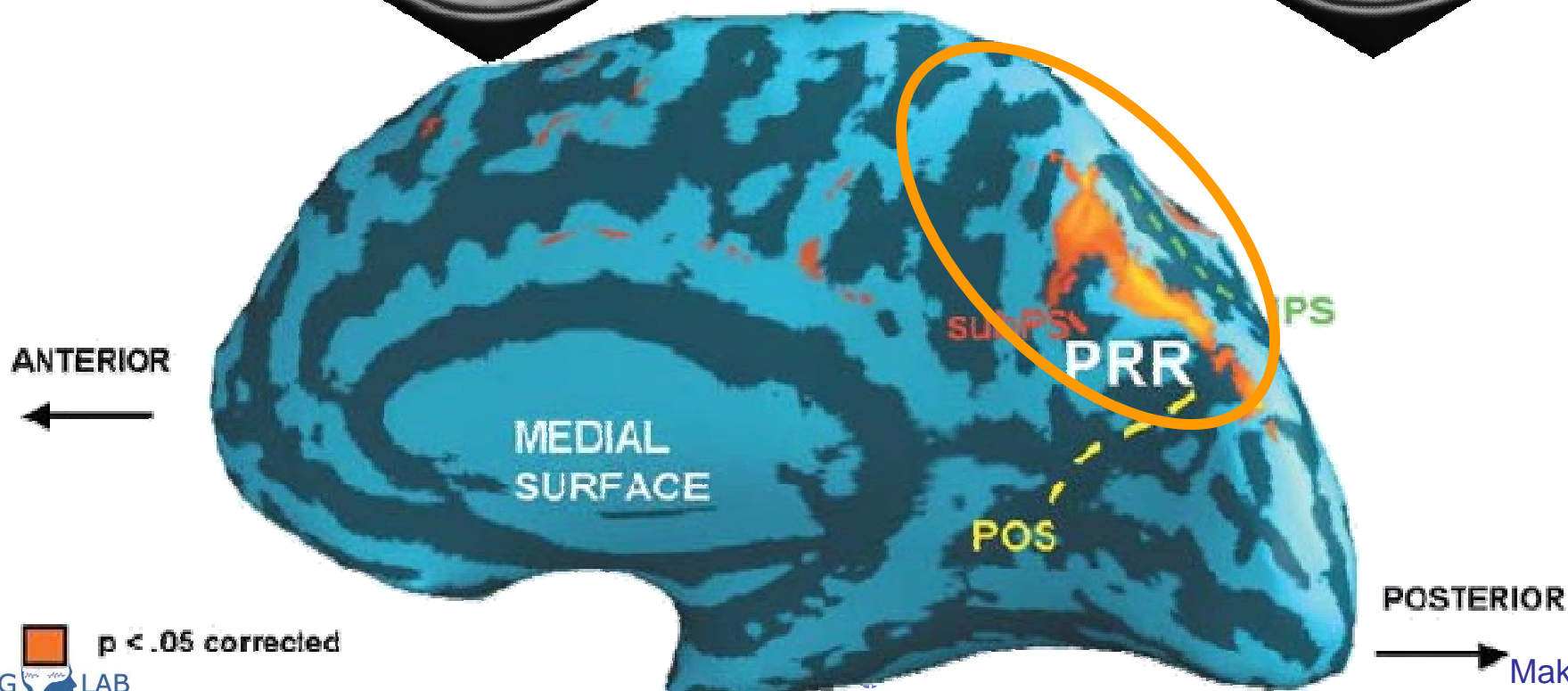
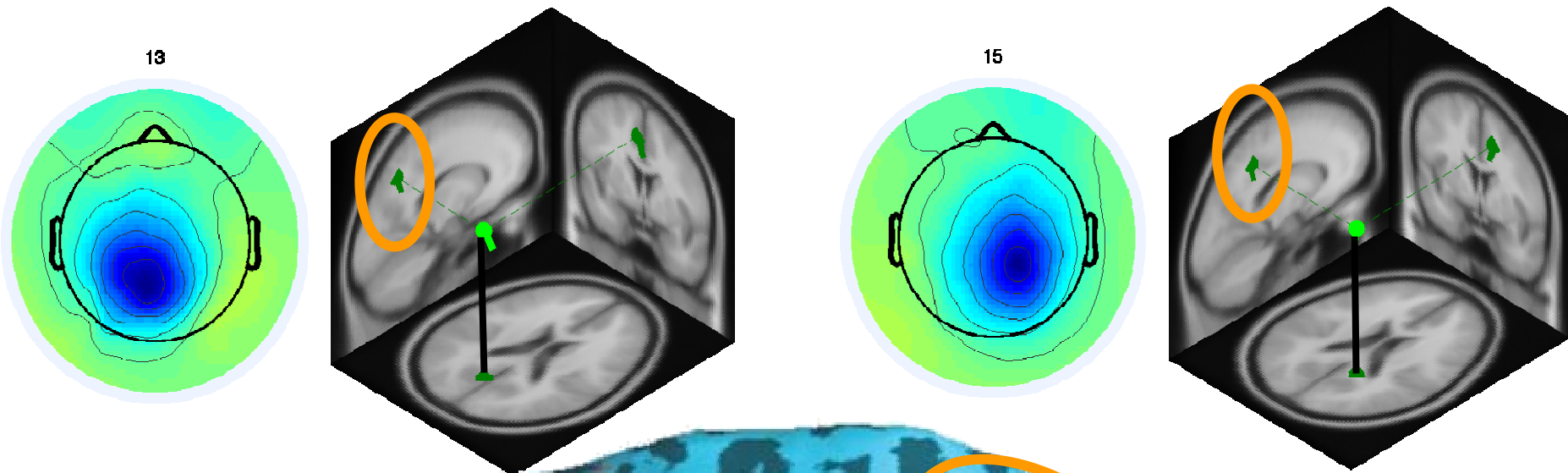
- Subject sits in chair facing a pegboard
- Twelve LEDs positioned on board (3x4x1m)
- One LED is lit at a time (in random order)
- Subject reaches to touch LED with stiff right index finger, then returns to rest
- Two resting conditions (hand in lap, hand upright)
- Touches rarely successful w/o visual guidance
- 256-channel active electrode EEG (@ 256 Hz)
- 4-channel infrared joint tracking (60 Hz)
- EEG and position tracking sync'd in the EEG record

Reach Task



- Subject sits **in the dark** facing a pegboard
- Three LEDs protrude from board (L | M | R)
- One LED is lit at a time (in random order)
- Subject reaches to touch LED with stiff right index finger, then returns to rest
- Two resting conditions (hand in lap, hand upright)
- Touches rarely successful w/o visual guidance
- 256-channel active electrode EEG (@ 256 Hz)
- 4-channel infrared joint tracking (60 Hz)
- EEG and position tracking sync'd in the EEG record

Symmetrically Located ICs In/Near the 'Parietal Reach Region'

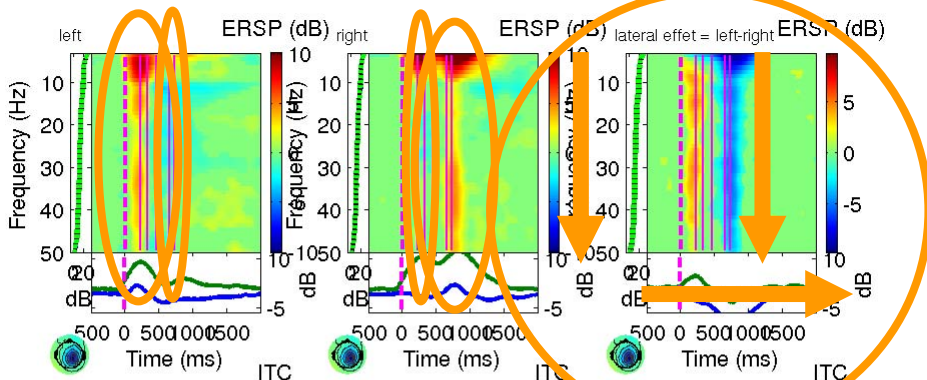


EEG LAB 2006

$p < .05$ corrected

Event-Related Brain Dynamics, Connelly, Andersen, Goodale, 2003

Makeig, Poizner et al.



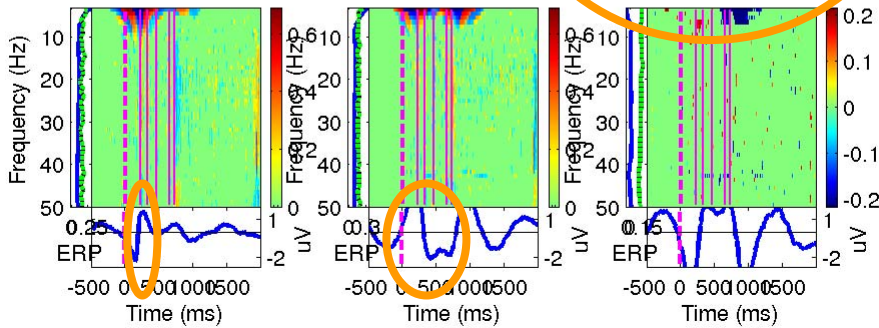
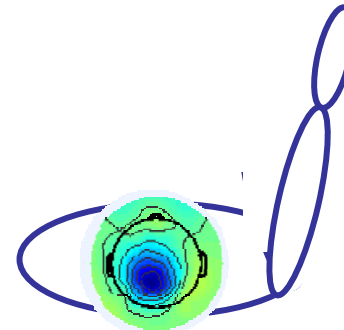
“Parietal Reach Region” Spectral Activities

Implications:

- spat. separation
- temp. precision
- freq. precision

Caveats:

- N = 1? (so far)
- PRR?



In **left** PRR, onsets of movements to the right (AND offsets to the left!) produce a gamma burst ...

While on leftward movements, the early ERP is absent.

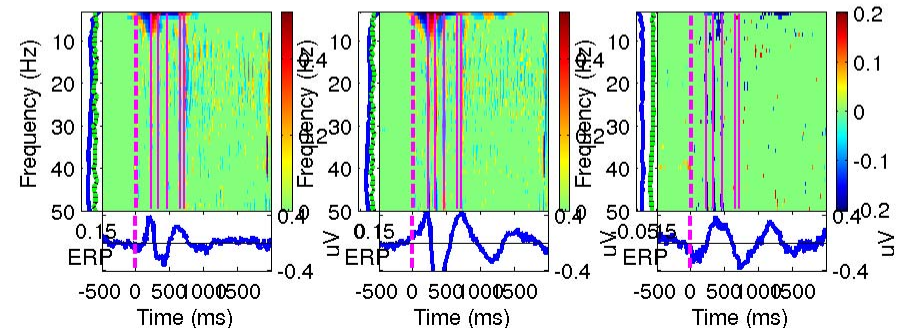
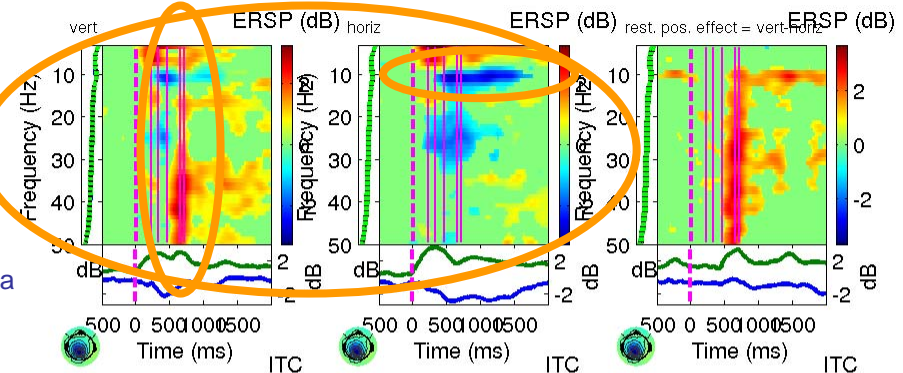
In **right** PRR, onsets of movements to the left (AND offsets to the right!) produce a gamma burst ...

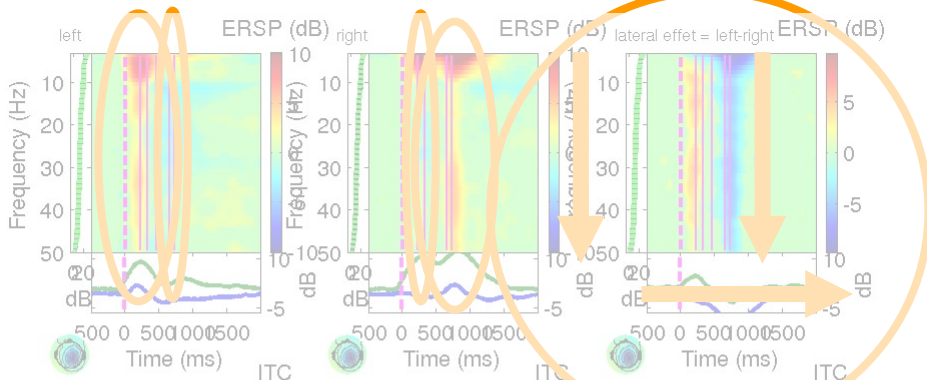
While on rightward movements, ERP polarity reverses.

In **right** PRR, vertical and horizontal movement onsets produce similar activities,

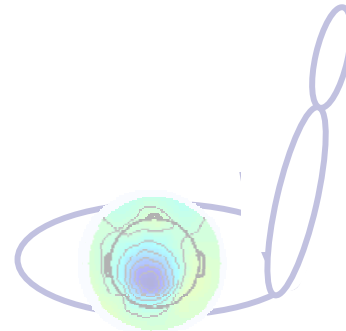
But in **left** PRR, ONLY offsets of **vertical** movements produce gamma ...

While offsets of horizontal movements produce stronger alpha blocking





“Parietal Reach Region” Spectral Activities



- Computations:**
- ~~spat?~~ (spatial)
 - ~~temp.~~ precision
 - freq. precision

Ambulatory Brain Imaging!?

In **left** PRR, onsets of movements to the right (AND offsets to the left!) produce a gamma burst...

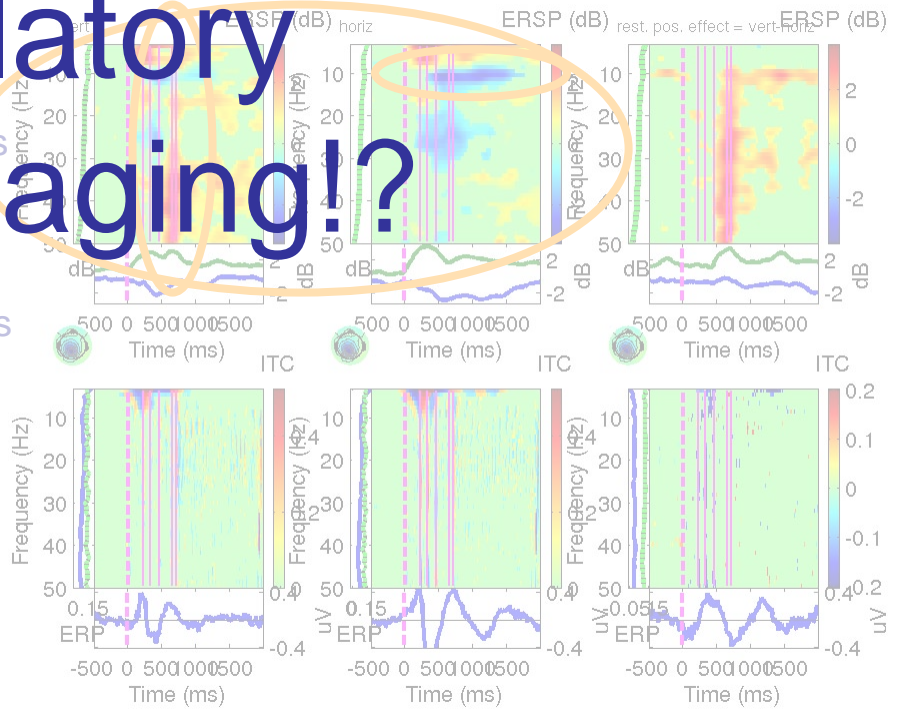
While on leftward movements, the early ERP is absent.

In **right** PRR, onsets of movements to the left (AND offsets to the right!) produce a gamma burst ...

While on rightward movements, ERP polarity reverses.

In **right** PRR, vertical and horizontal movement onsets produce similar activities,

But in **left** PRR, ONLY offsets of **vertical** movements produce gamma ...



While offsets of horizontal movements produce stronger

A New Beginning