Multi-modal imaging: EEG-fMRI

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Outline

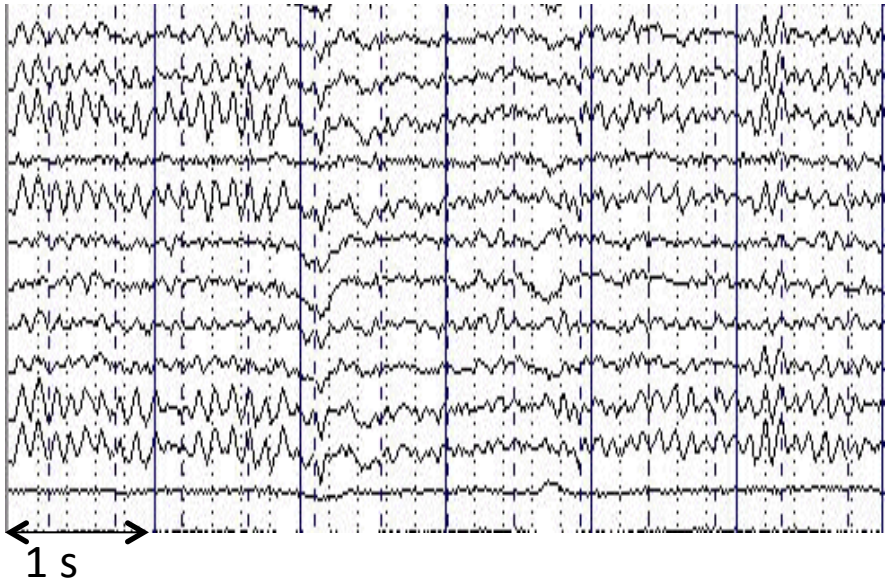
- What
- Why
- How
- When
- Examples

WHAT?

simultaneous EEG and fMRI

EEG (electroencephalography):

Synchronous activity of population of neurons primarily reflects postsynaptic potentials



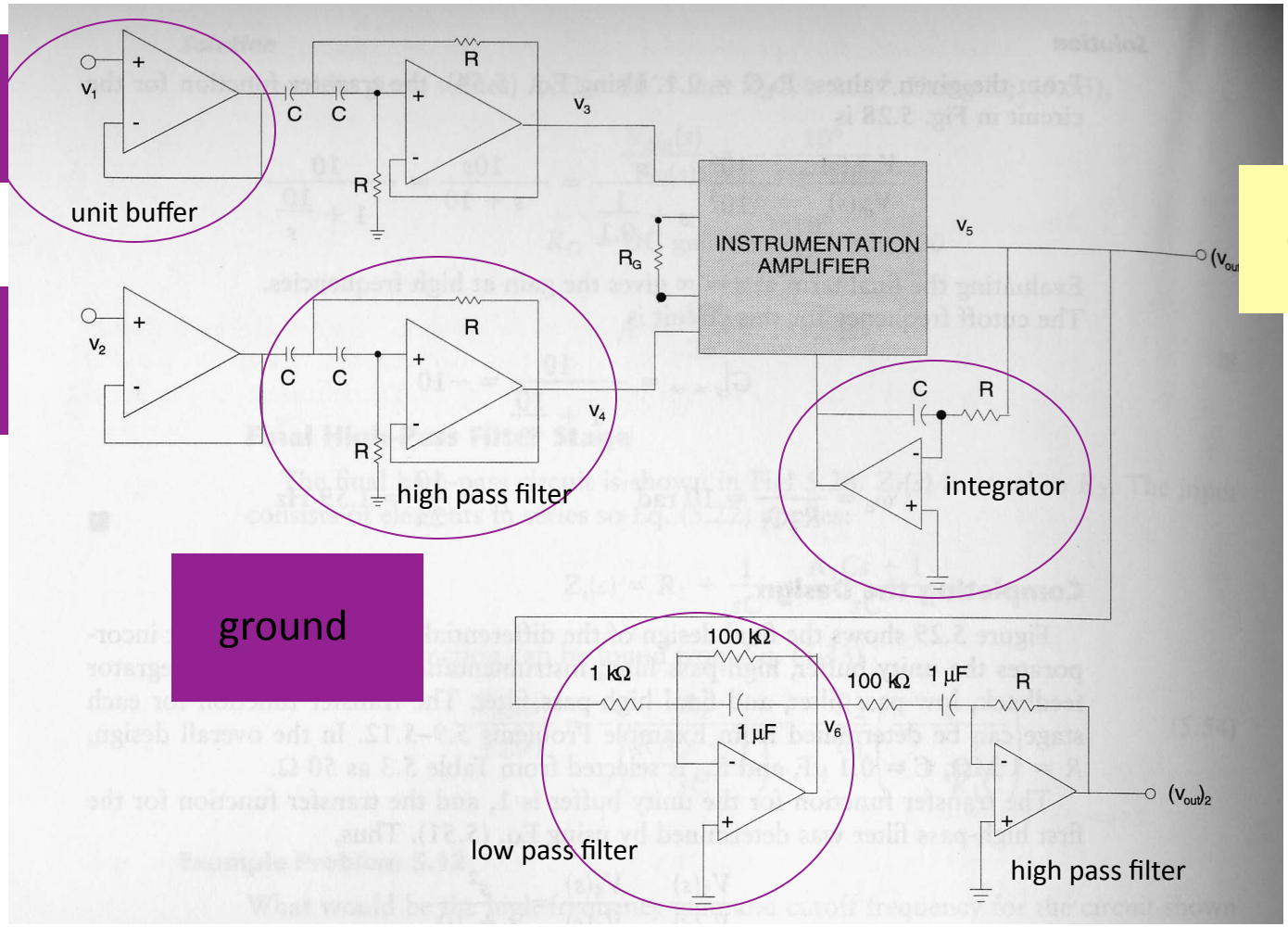
Instrumentation

reference

signal

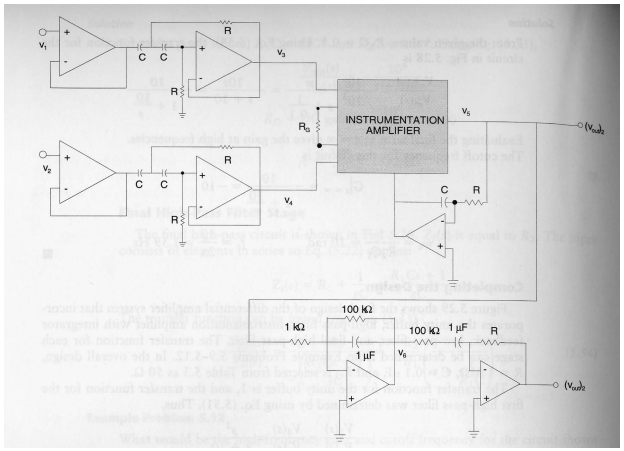
ground

output

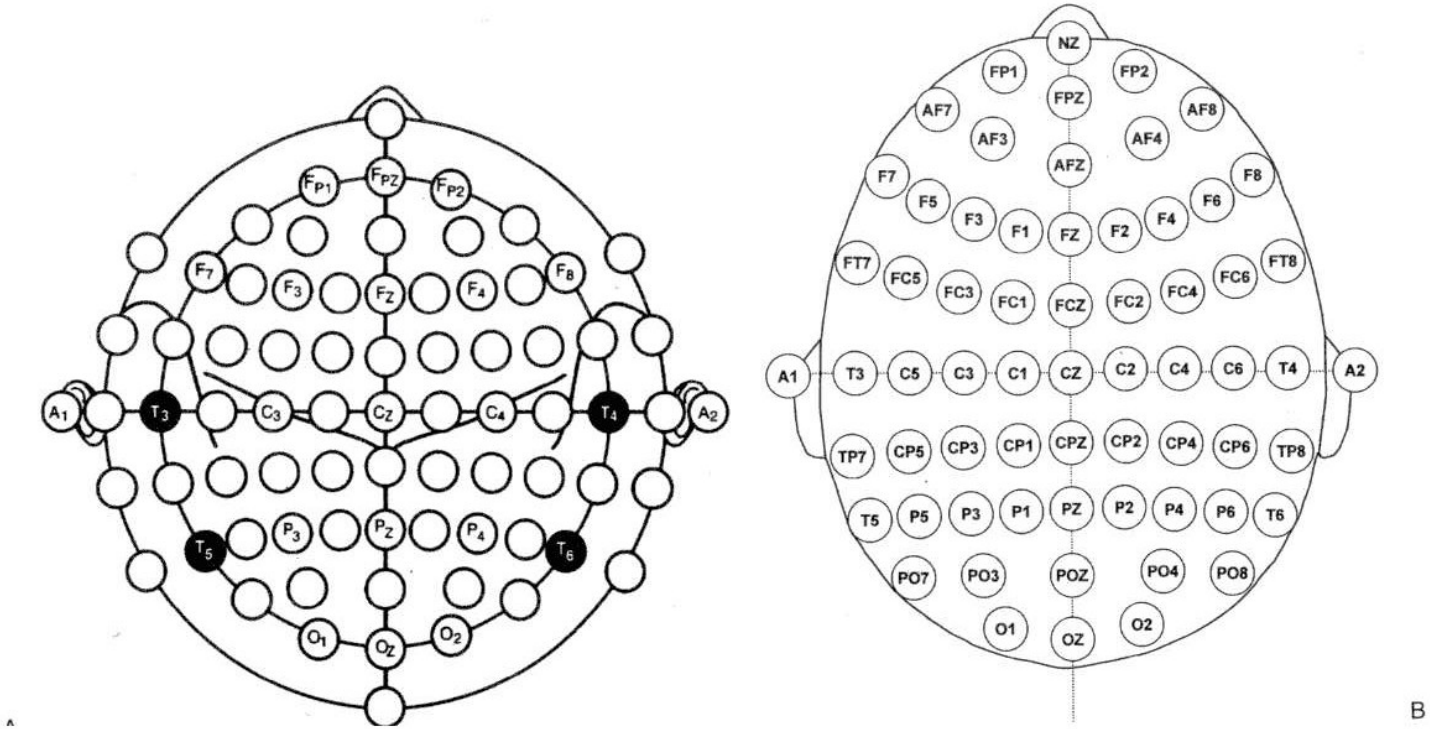


Instrumentation

- Referential
  - (S_i vs. Ref; S_k vs. Ref)
- Bipolar
  - (S_i vs.. S_k)
- Reference:
  - Single
  - Linked
  - Average reference



montage



International 10-20 System of Electrode Placement

F - Frontal lobe T - Temporal lobe

C - Central lobe P - Parietal lobe

O - Occipital lobe

"Z" refers to an electrode placed on the mid-line.

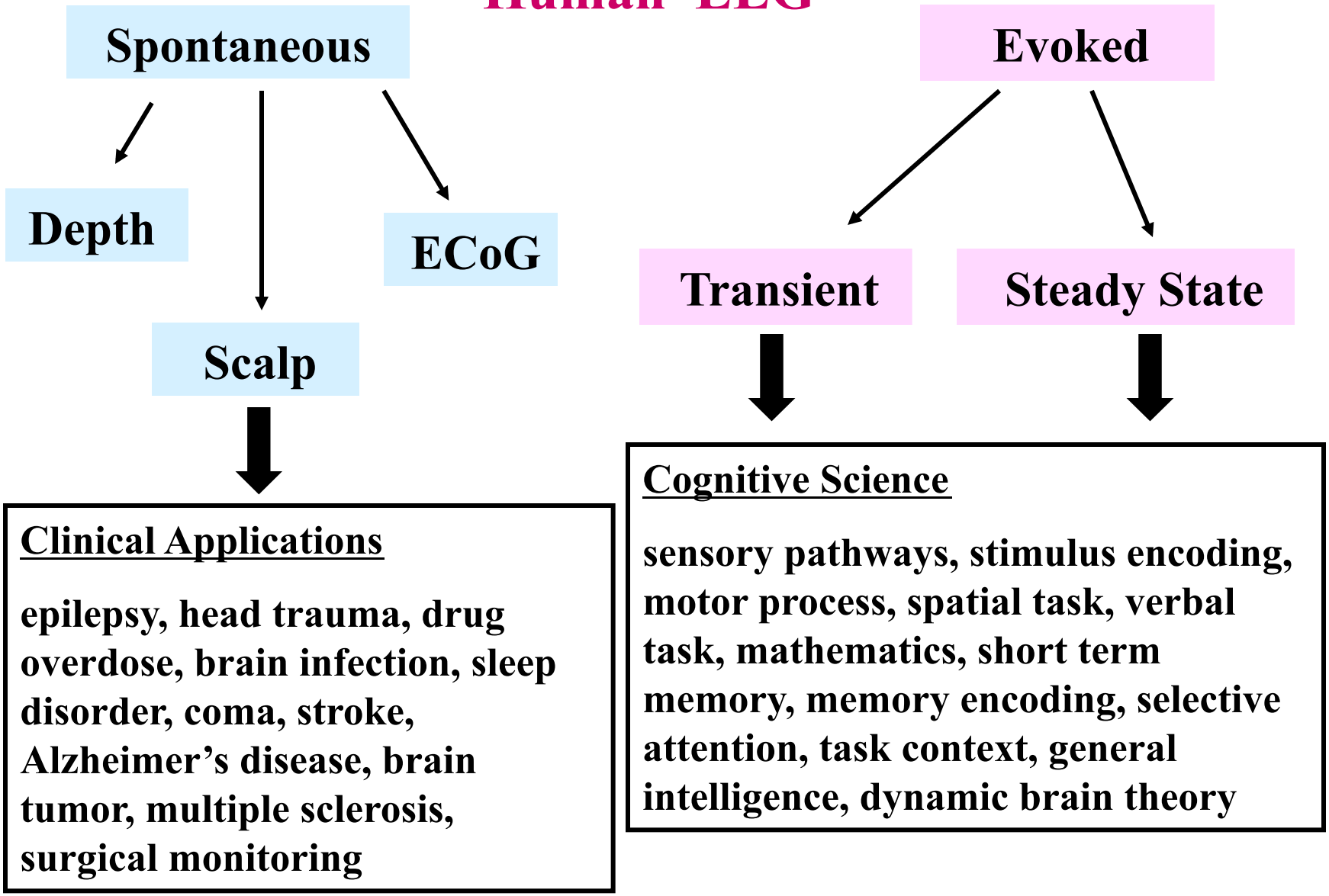
Data processing

- Time domain
  - Event Related Potentials (ERPs)
    - pre-processing:
      - detrend - filtering
      - epoch
      - baseline correction
      - ocular artifact reduction
      - (common grounded, artifact rejection)
      - time-locked averaging

Data processing

- Frequency domain
  - Power at different bands
  - Power spectra density (FFT)
  - Cross-spectra (correlation among different electrodes)
    - Coherence (similar to cross-correlation in time domain)
  - phase shift between electrodes
  - event related desynchronization

Human EEG



PL Nunez, EEG, *Encyclopedia of the Brain*, 2003

WHY

Neuroimaging

BRAIN ACTIVITY
f(x,t)

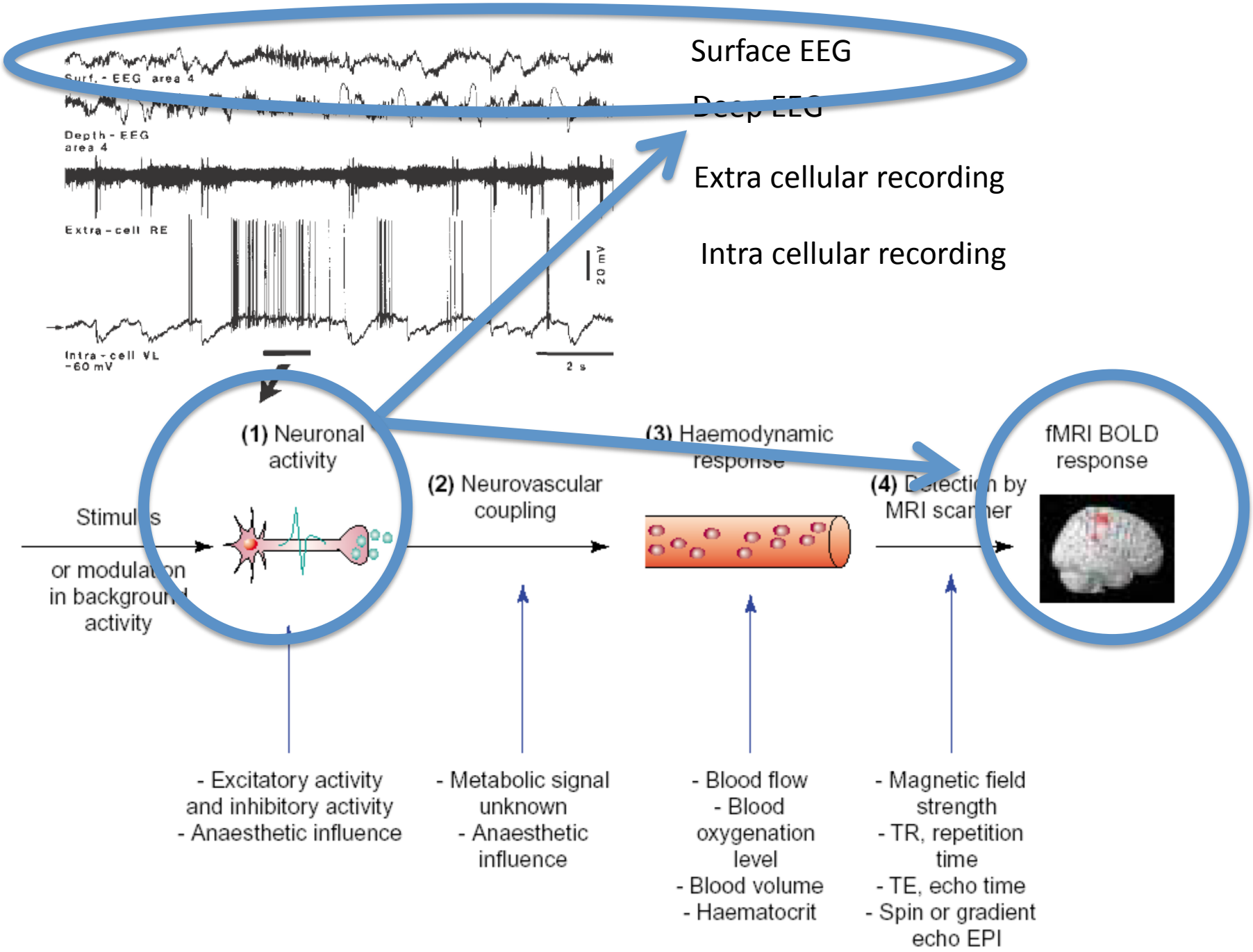
Metabolic/ vascular responses
g[f(x,t)]

PET, MRS
h{g[f(x,t)]}

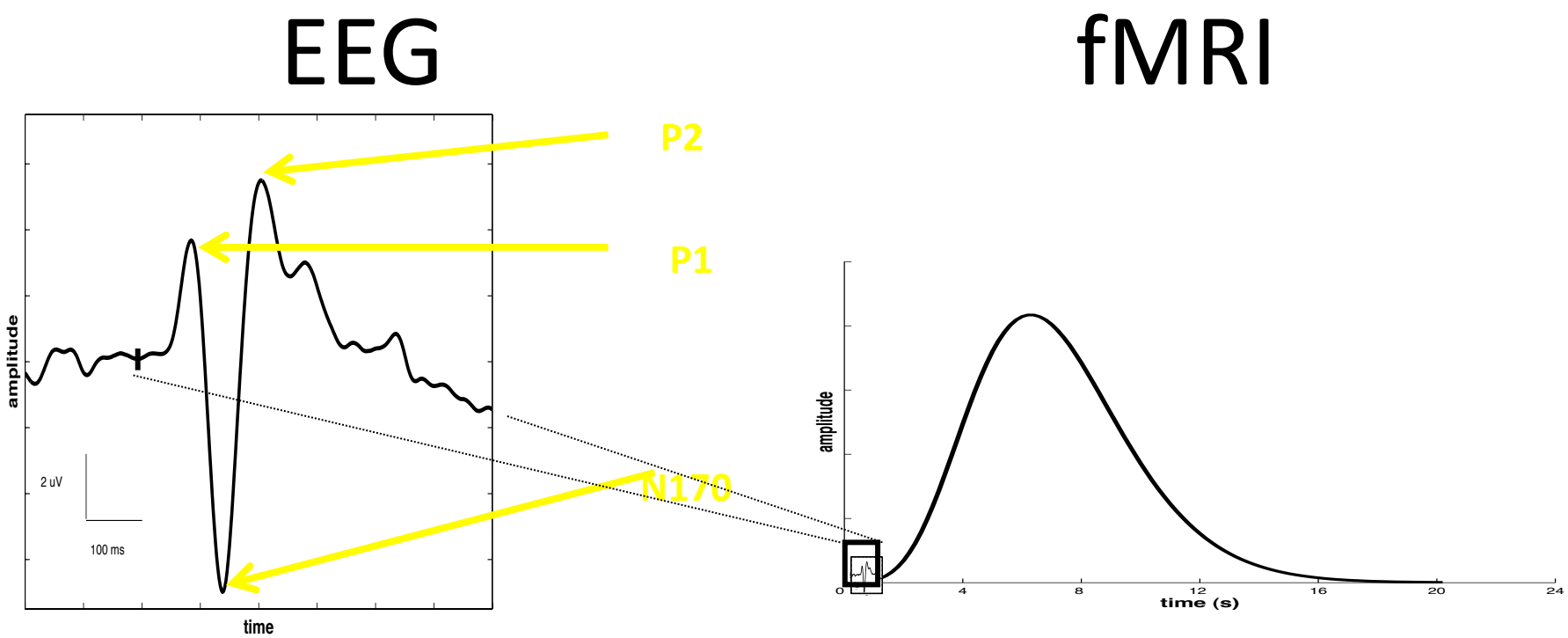
fMRI
k{g[f(x,t)]}
Good spatial resolution
Poor time resolution

electrical EEG, MEG
m[f(x,t)]
Good time resolution
Poor spatial resolution

NIRS
l{g[f(x,t)]}



TRENDS in Neurosciences

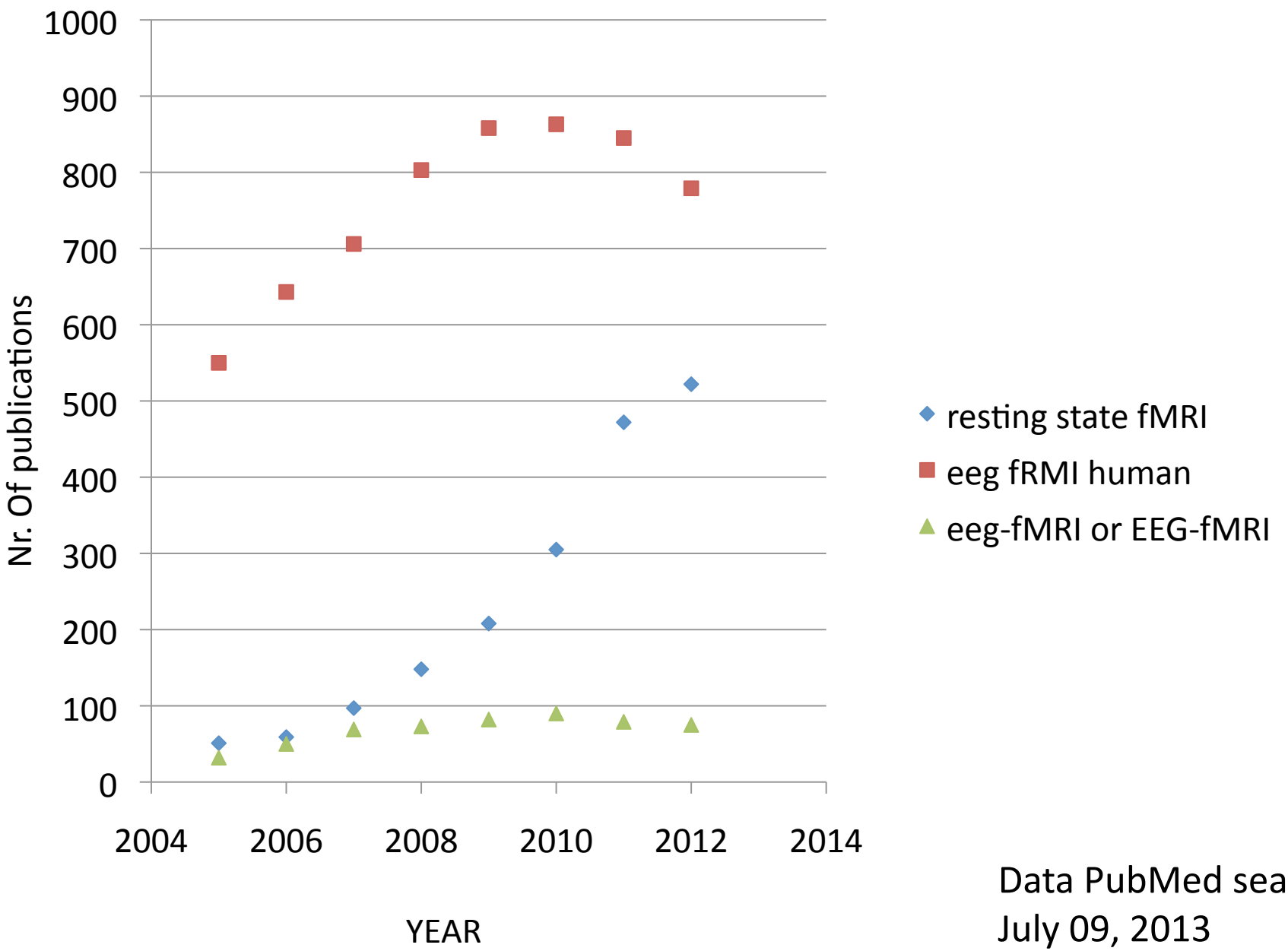


EEG is the *gold standard* for sleep classification and studies, epilepsy, some cognitive tasks, etc

- EEG/MEG measure in milliseconds
    - But origin unknown
- fMRI in seconds
    - But has excellent localization
- PET in minutes
    - Ligands for neuroreceptors
- Drug/treatment effect in hours/days

AND WE WANT IT ALL!

Dimensionality problem

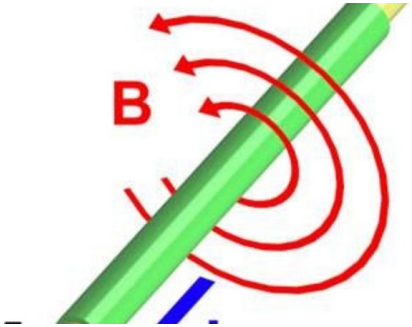


Data PubMed search
July 09, 2013

HOW

Technical Issues

Electromagnetism 101



Maxwell's Laws.

- A changing magnetic field produces an electric field

BIG PROBLEM

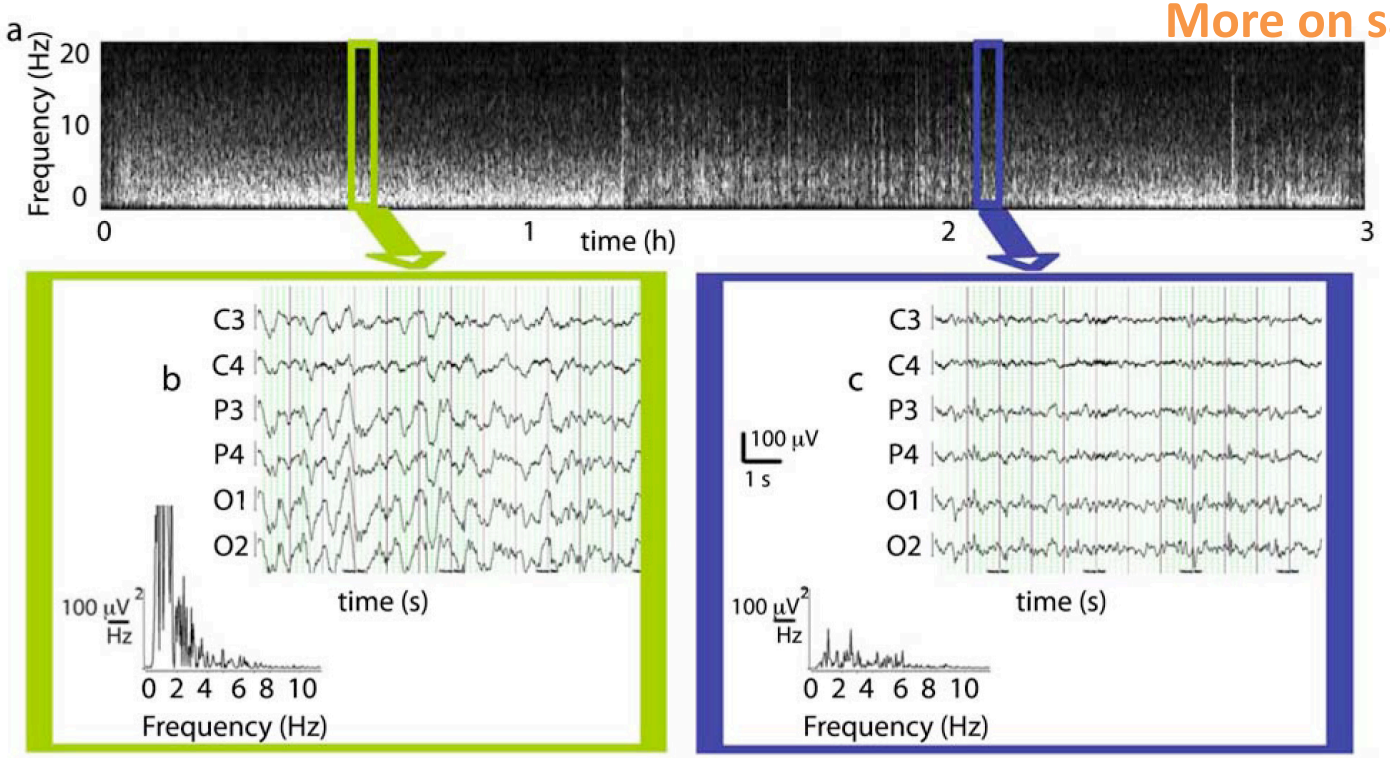
- A changing electric field or current produces a magnetic field.

Luckily, the magnetic field change
Form the EEG does not affect the image quality!

THE GOOD NEWS

- MRI compatible EEG equipment
  - Safe for the scanner
  - Safe for the subject

More on safety later

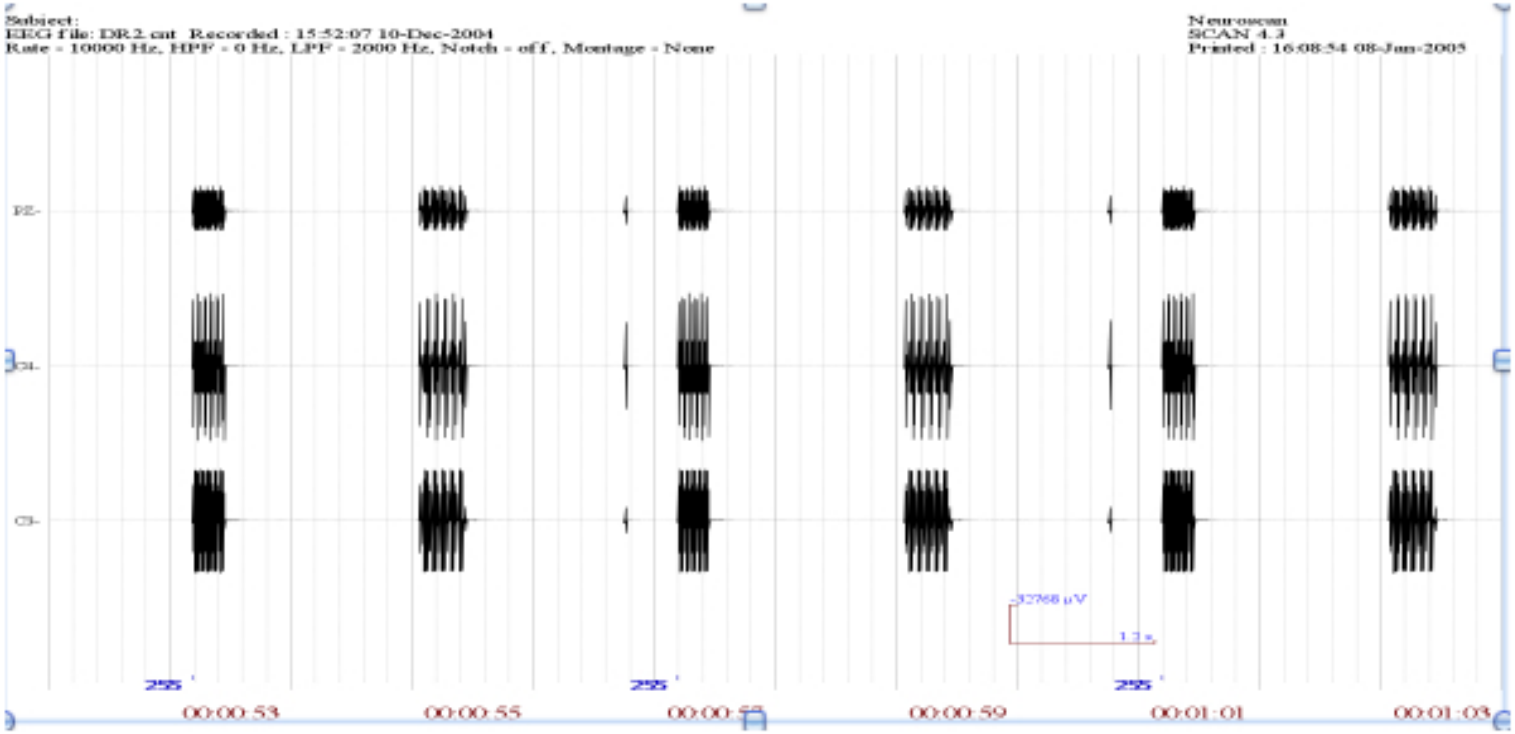


THE not so good NEWS

- **MRI is noisy**
  - Electrical noise → MRI and EEG were not meant for each other …

Remember Maxwell's Law?

Simultaneous EEG-fMRI
- Technical issues



Sources of artifacts:

- gradients
- physiological noise: ballistocardiogram

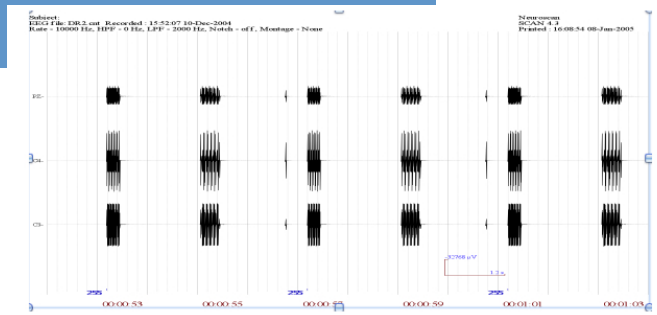
Gradient artifact

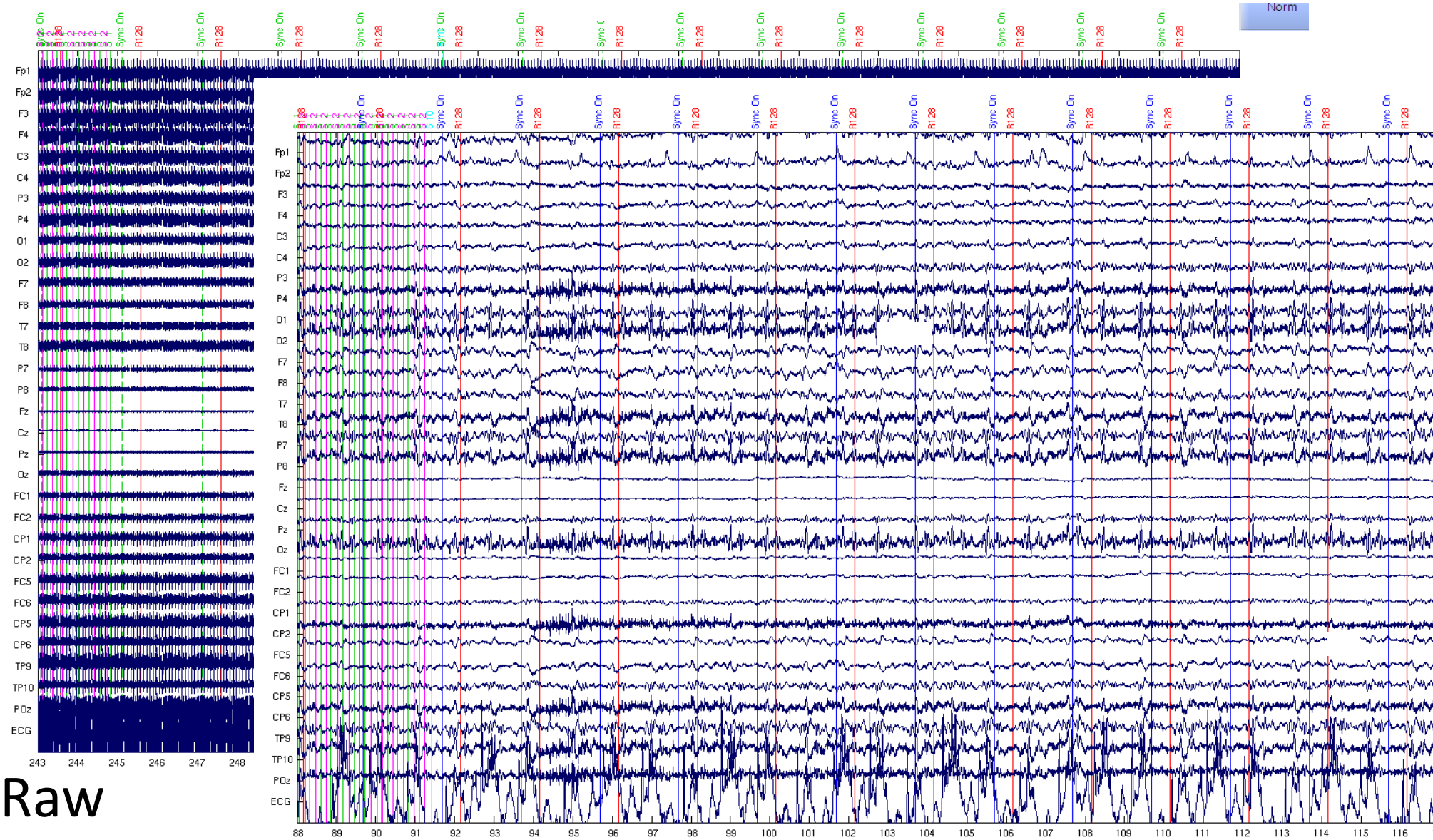
- Sample EEG at 5000 kHz
- Slice TR at a frequency that is not of interest
- Low Pass Filter at 250Hz
- High Pass Filter DC or 0.01Hz
- Volume marker

- Artifact removal (Matching filter)
  - **Create a template of the artifact**
  - **Subtract average artifact**
  - If proper timing

    and no movement works great!

  – **Some improvements by** Synchronizing clock of EEG acquisition to scanner





Raw

Gradient artifact corrected

Courtesy Dr Jen Evans

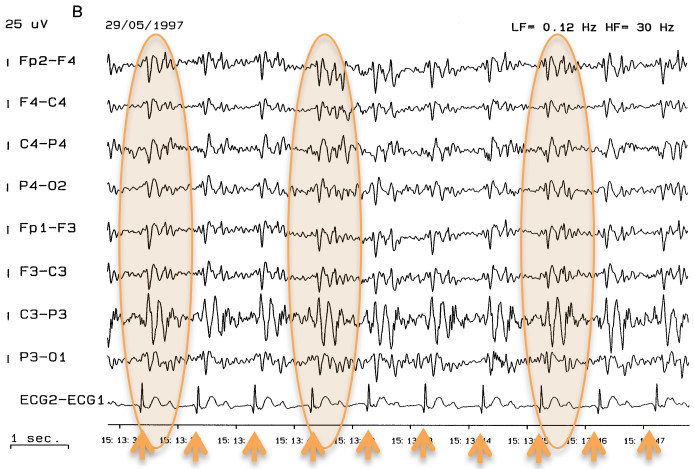
ballistocardiogram

Matching filter (BV Analyzer) (Allen et al, 2000):

Detect R

Create a template

Subtract (allows for amplitude adjustment)



Single Value Decomposition (Neuroscan)

Run classification

Remove components

Reconstruct time series

Optimal base set (EEGLAB Niazy, 2005)

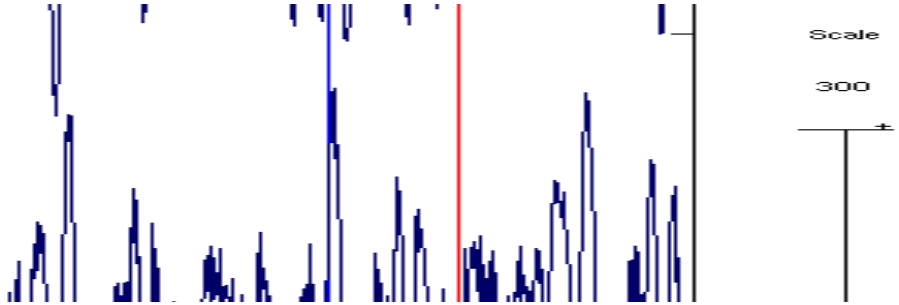
PCA to create bases

Fitting (adaptive algorithm)

Subtraction

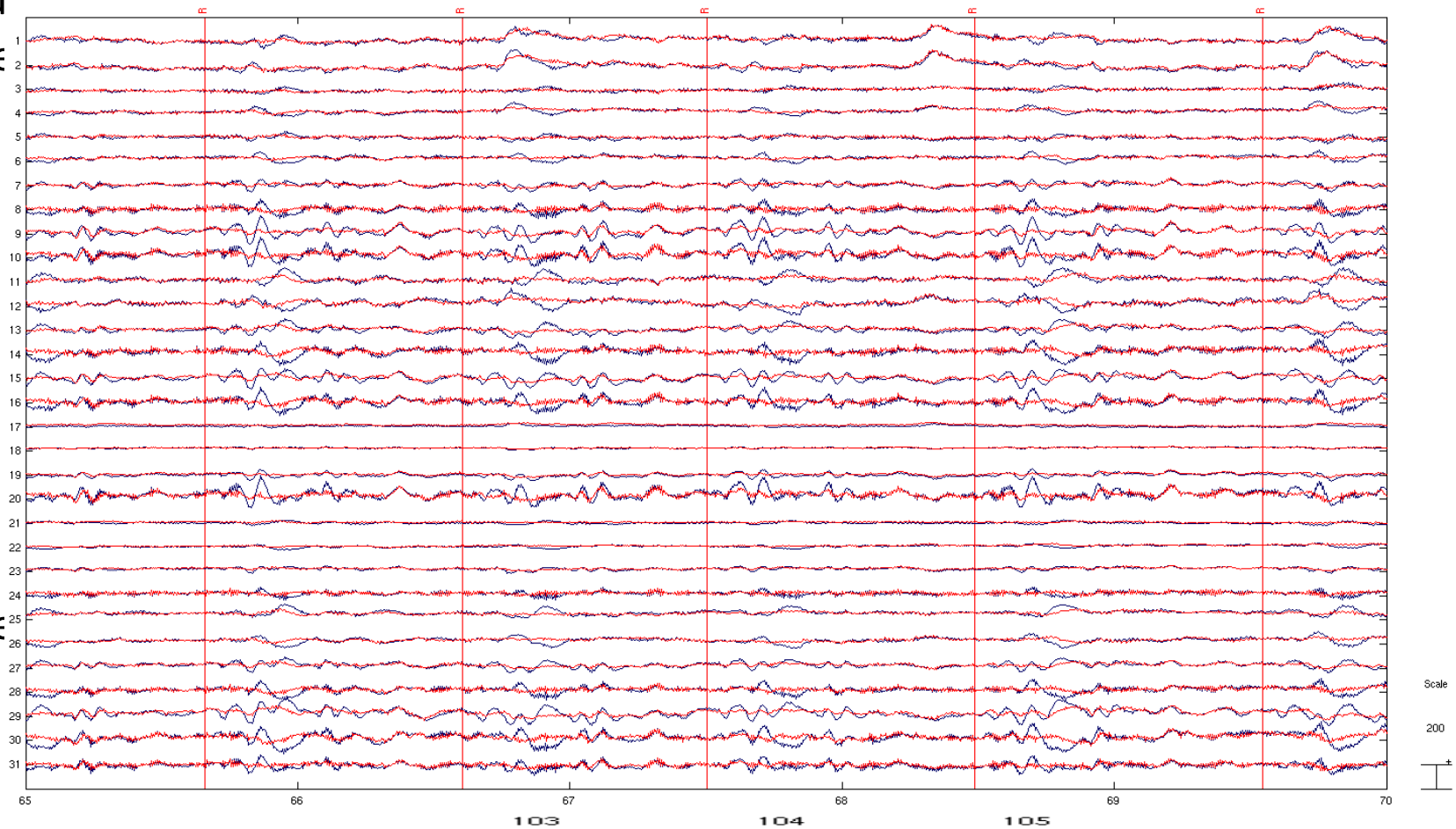
Combinations

i.e → Liu, 2012 use ICA, SVD & mutual information (based on Peng, IEEE 2005)



Grad

corre



Card

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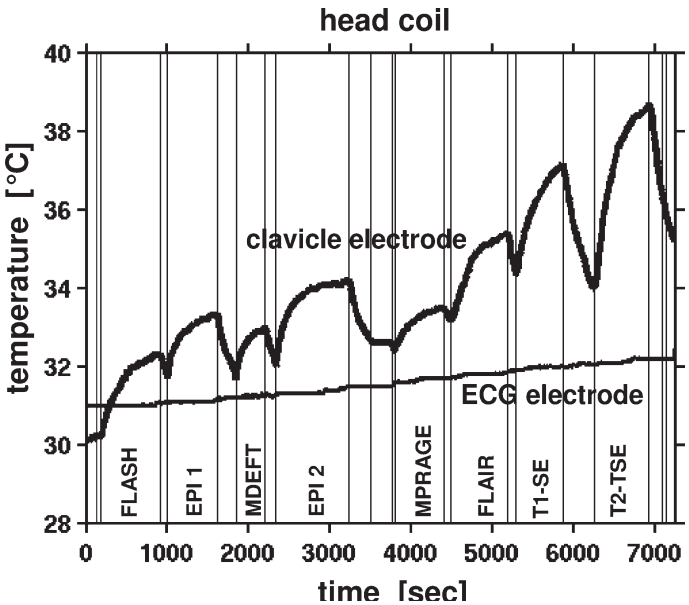
Courtesy Dr Jen Evans

SAFETY considerations



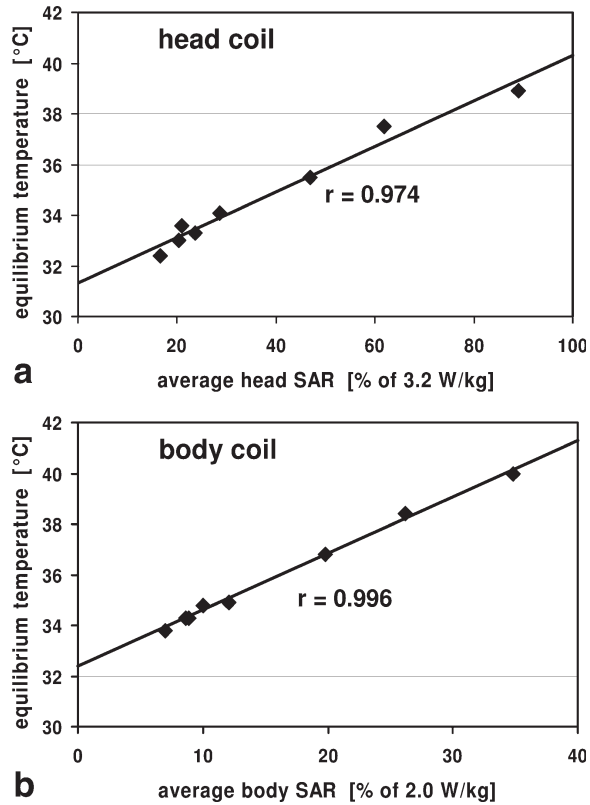
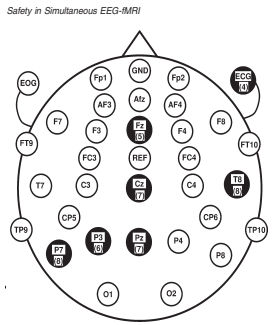


Figure 5. Relation between scanner-calculated average head (**a**) and body (**b**) SAR and fitted equilibrium temperatures for subject m90, clavicle electrode (a) and subject m85, T8 electrode (b) when using the head (a) and body (b) coil, respectively. The least-squares linear fit (solid line) shows a clear linear increase of the equilibrium temperature with average head (a) and body (b) SAR.



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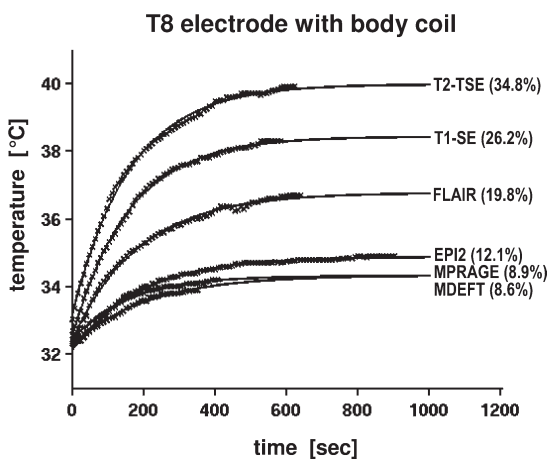
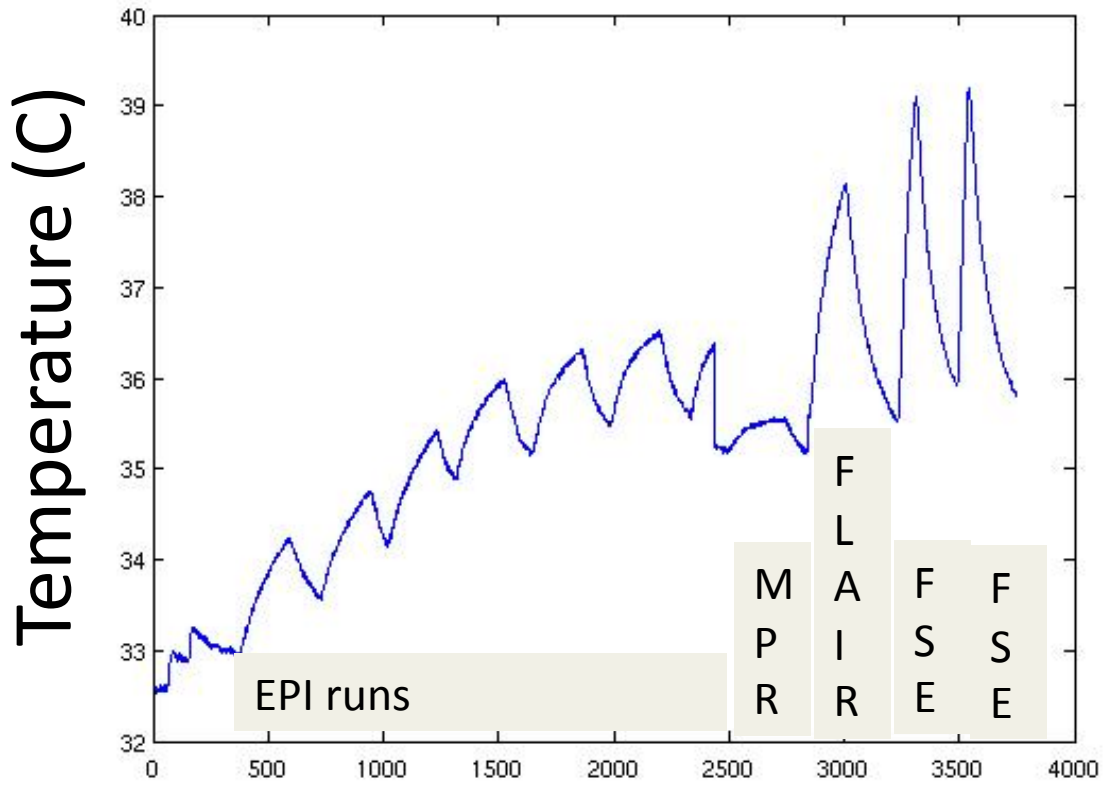


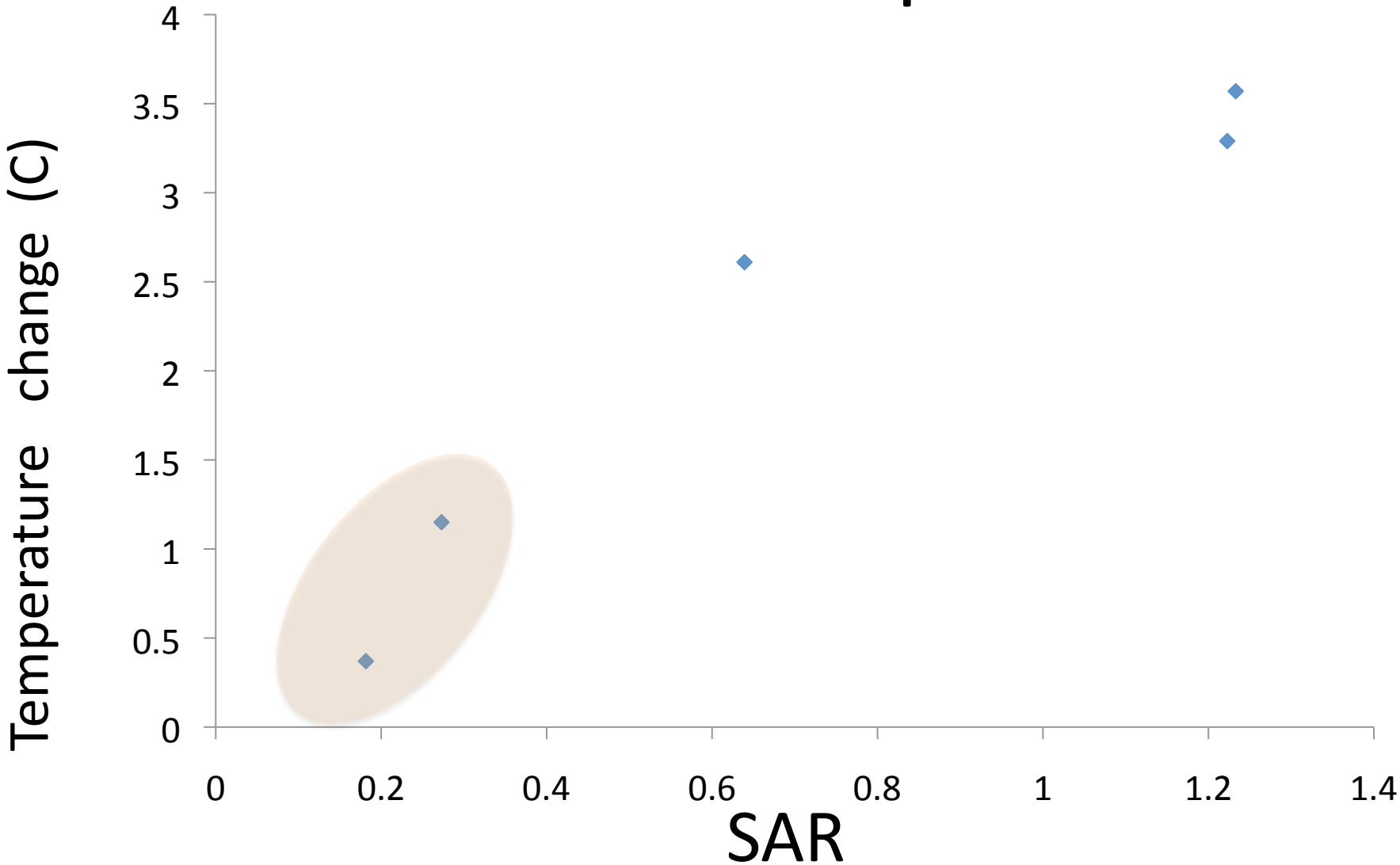
Simultaneous Electroencephalography-Functional MRI at 3 T: An Analysis of Safety Risks Imposed by Performing Anatomical Reference Scans With the EEG Equipment in Place

Ulrike Nöth, Laufs, Stoermer, and Deichmann JMRI 2012

Temperature on EMG electrodes



Be aware of the sequence



Specific Absorption Rate (or the energy deposited in the body by the radio frequency transmission)

SAFETY considerations

- Sequences
  - EPIs (ok to run an MPRAGE for localization)
    - be aware of high res short TR EPIs (pay attention to SAR)

- Set up
  - Cables straight and in the center.
    - Avoid loops
  - Equipment as far back from iso-center as possible
    - (far front for EMG)
    - All scanners are **not** equal; gradients and coils affect electrodes' temperature

WHEN

When is it important to measure simultaneously?

- state dependent analysis
  - Alertness,
  - STATE VS TRAIT
- Physiological markers defined by EEG
  - seizures

Type of studies

- Correlations of EEG and fMRI
  - In time domain
  - In frequency domain
    - Dimensionality reduction
- Multivariate methods
  - ICA
- Informing one with the other
  - Sorting data and perform analysis in one modality

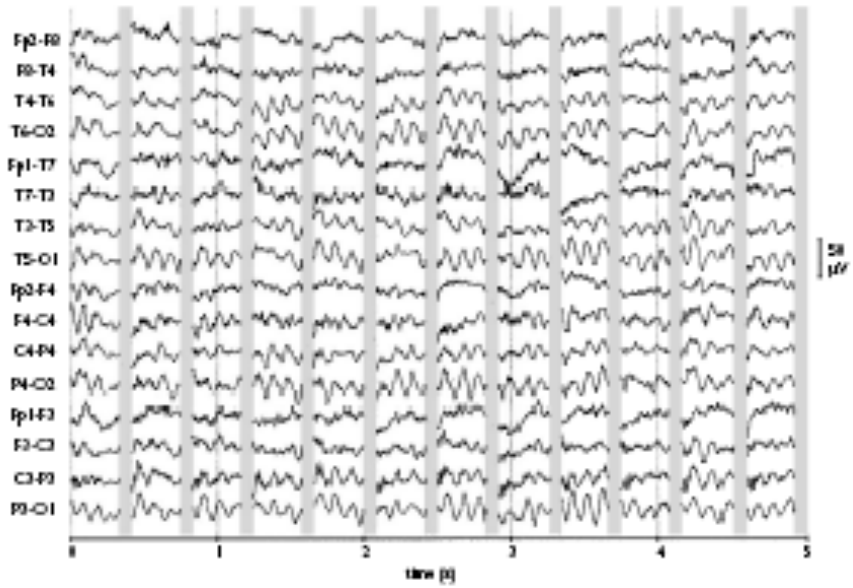
Summary

- Electrical measurements have:
  - Good temporal resolution
  - Poor spatial resolution

    (when measure non invasively)
- Origin of the signal can be obtained using source localization models
- Electrical and hemodynamic response are related
- Simultaneous EEG-fMRI requires special equipment
- SAFETY PROCEDURES
- Dimensionality reduction

EXAMPLES

Correlations in the frequency domain



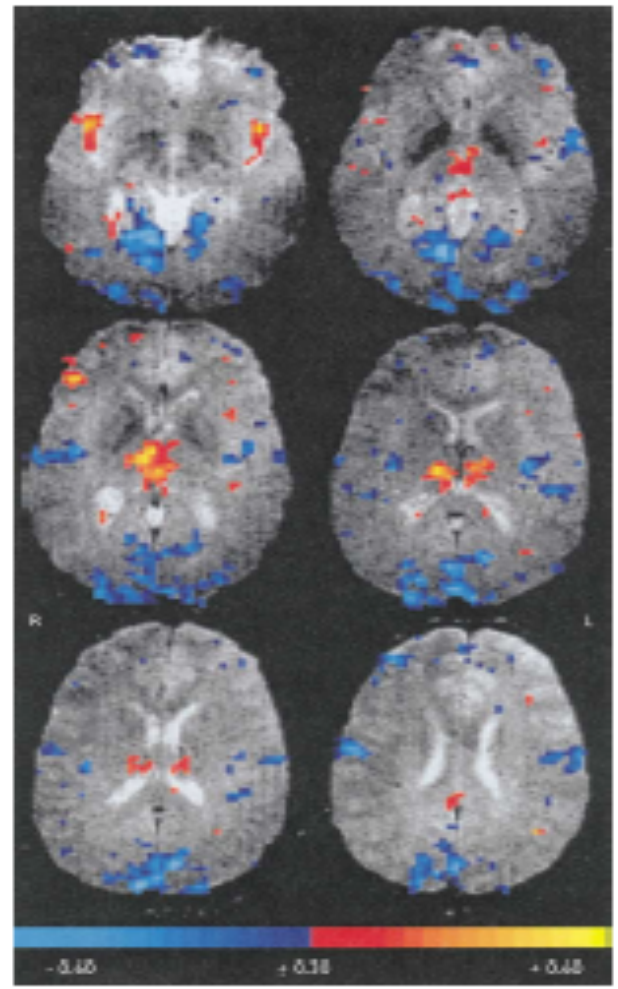
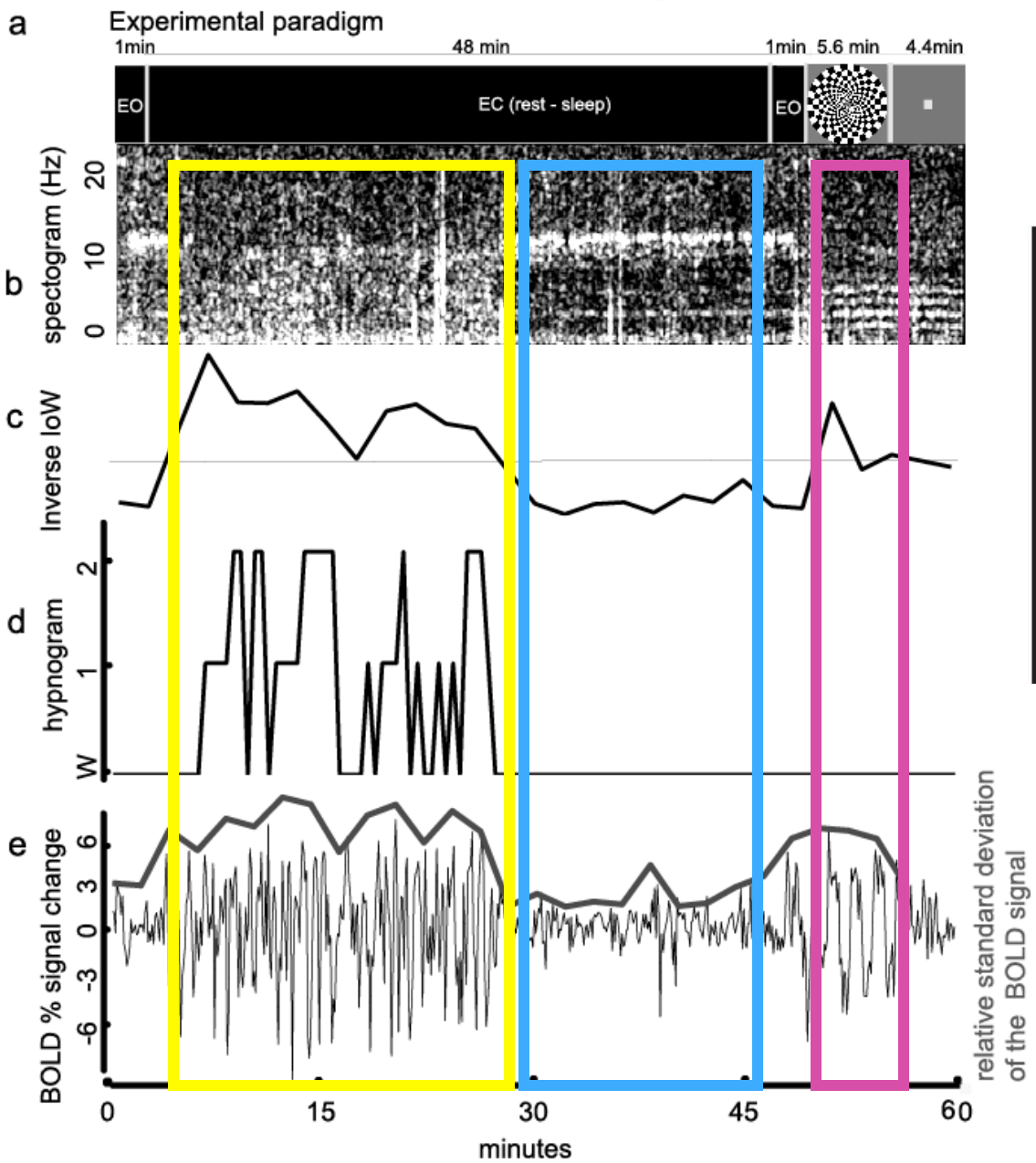


Fig. 2. Regions where MR signal increased (red-yellow) and decreased (blue–cyan) with elevations in alpha power for a representative single subject. The bottom bar shows the Pearson correlation value between signal intensity and alpha power modulation.

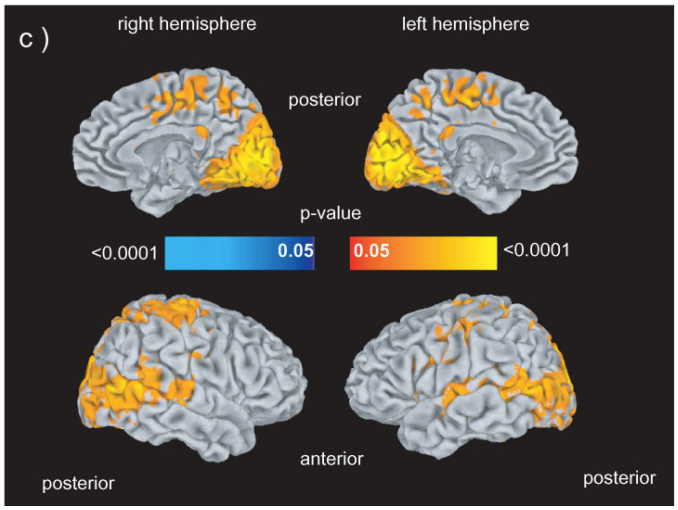
How did we include EEG information in the MRI analysis?

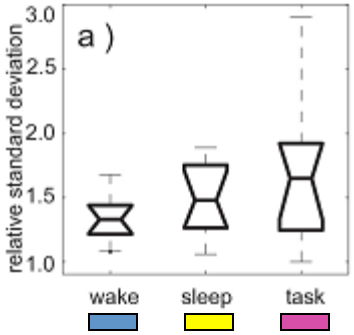
- Direct integration of EEG and fMRI data
- Inform the fMRI analysis
  - Divide fMRI based on EEG parameters
  - Use EEG “events” as regressors for fMRI

DAYTIME 1 hour PARADIGM



Horovitz et al
HBM, 2008



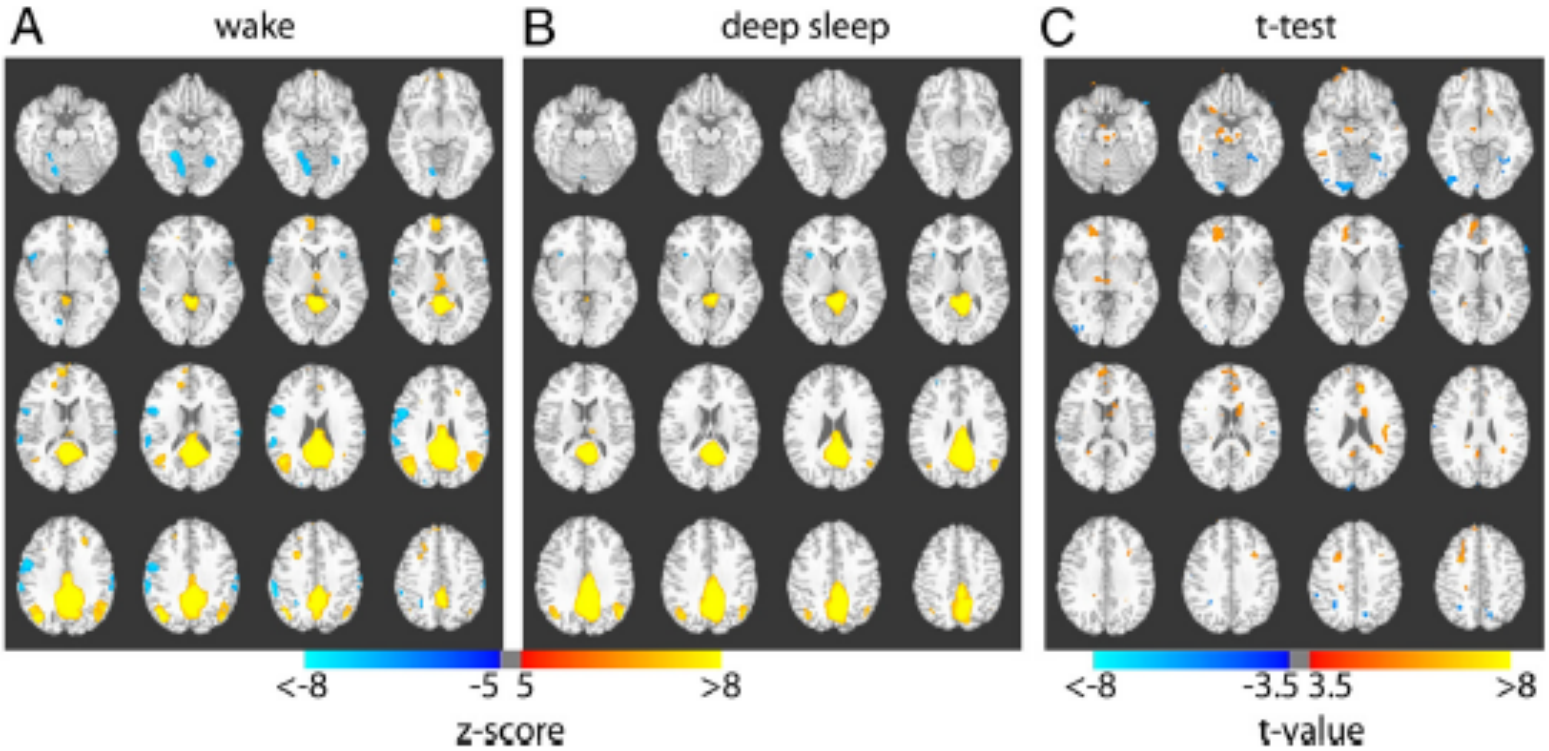


Changes in the level of consciousness

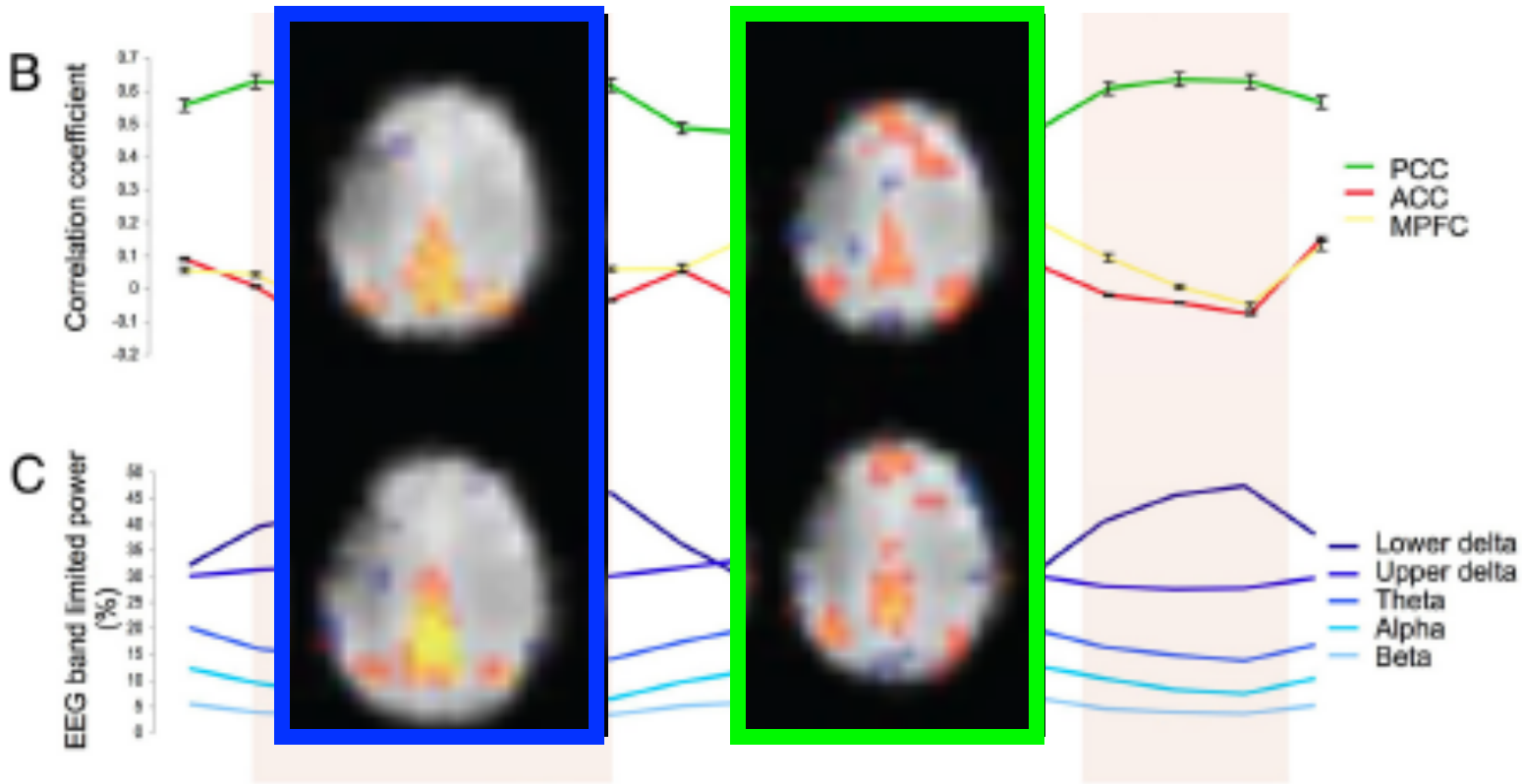
Decoupling of the brain's default mode network during deep sleep

Silvina G. Horovitz[a,b,1], Allen R. Braun[c], Walter S. Carr[d], Dante Picchioni[e], Thomas J. Balkin[e], Masaki Fukunaga[b], and Jeff H. Duyn[b]

11276–11281 | PNAS | July 7, 2009 | vol. 106 | no. 27



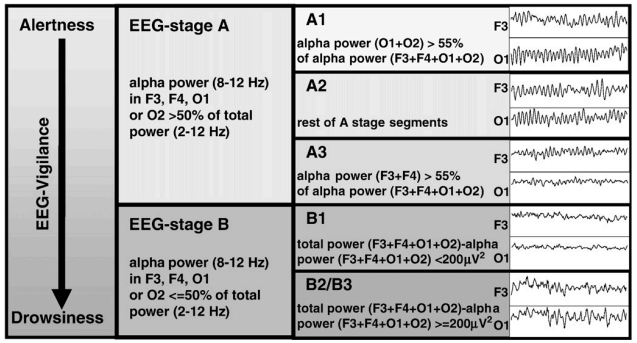
Changes in connectivity over time

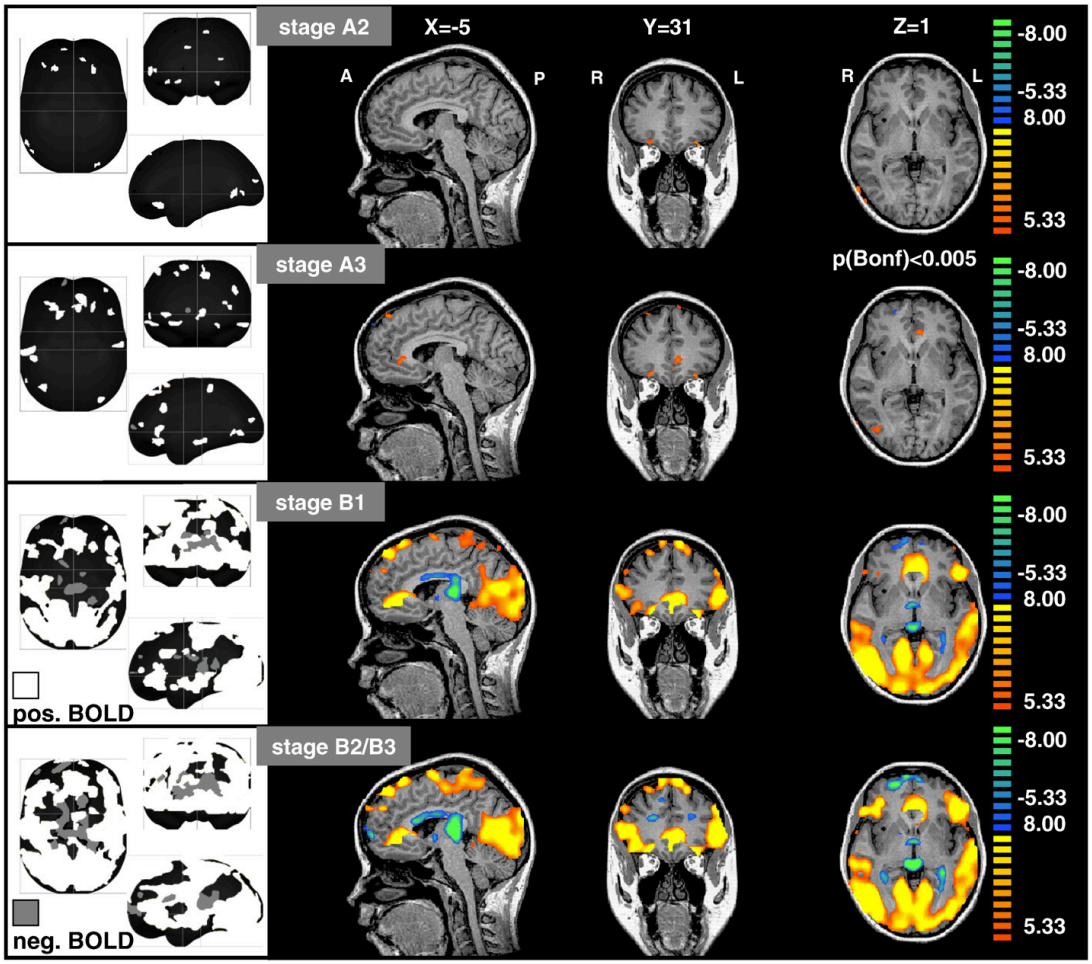


Horovitz et al.

EEG-vigilance and BOLD effect during simultaneous EEG/fMRI measurement

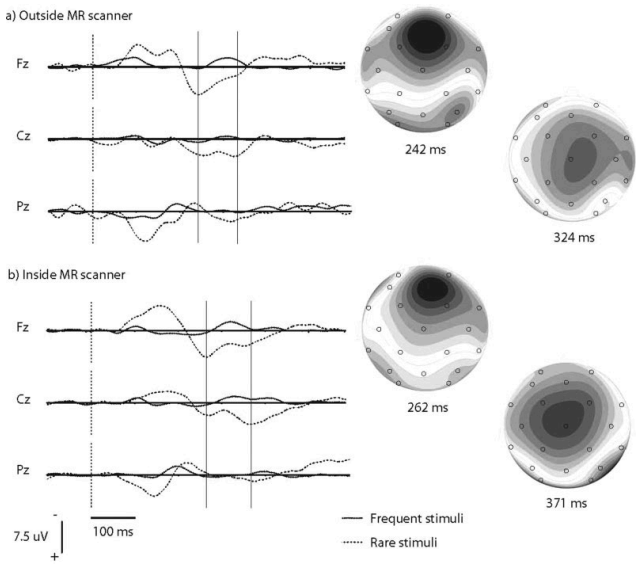
S. Olbrich et al. / NeuroImage 45 (2009) 319–

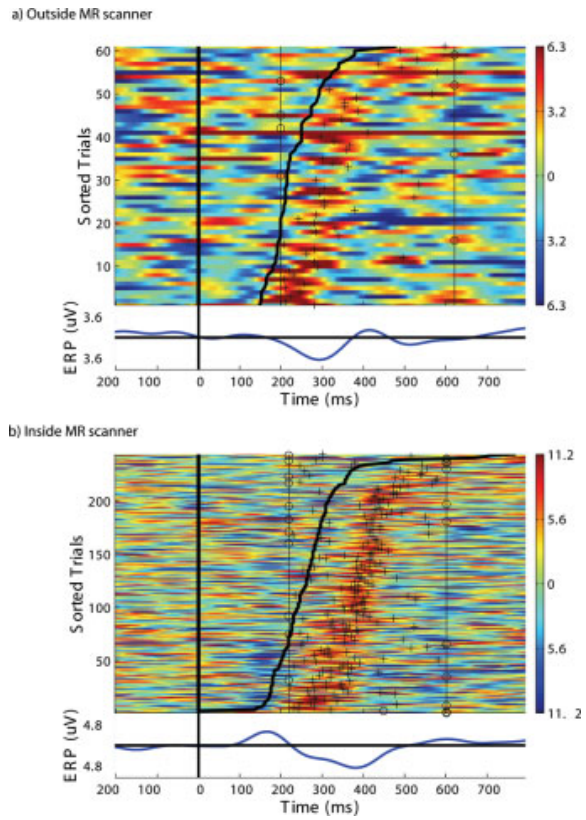




Single-Trial Analysis of Oddball Event-Related Potentials in Simultaneous EEG-fMRI

Be´nar et al. Human Brain Mapping 28:602–613 (2007)





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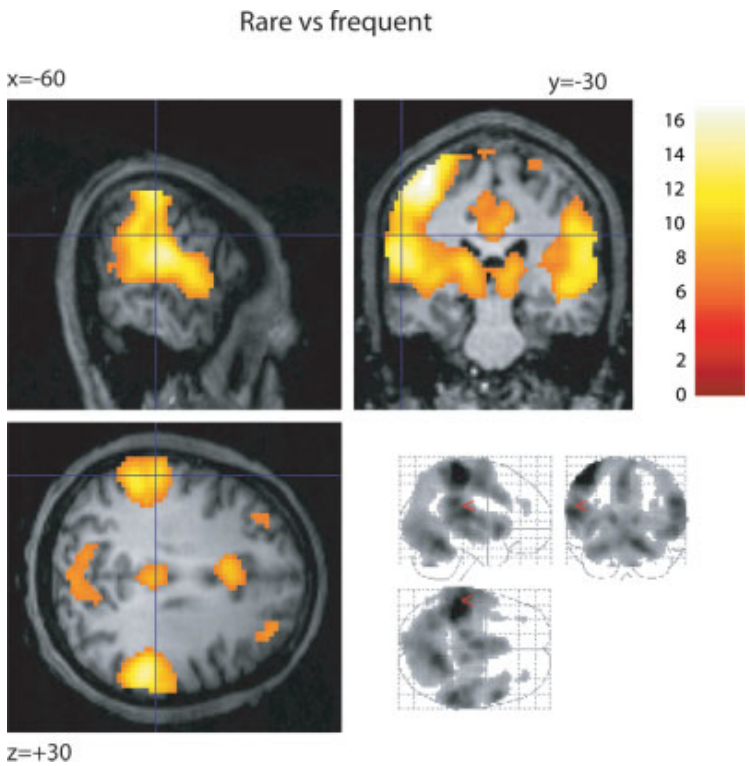
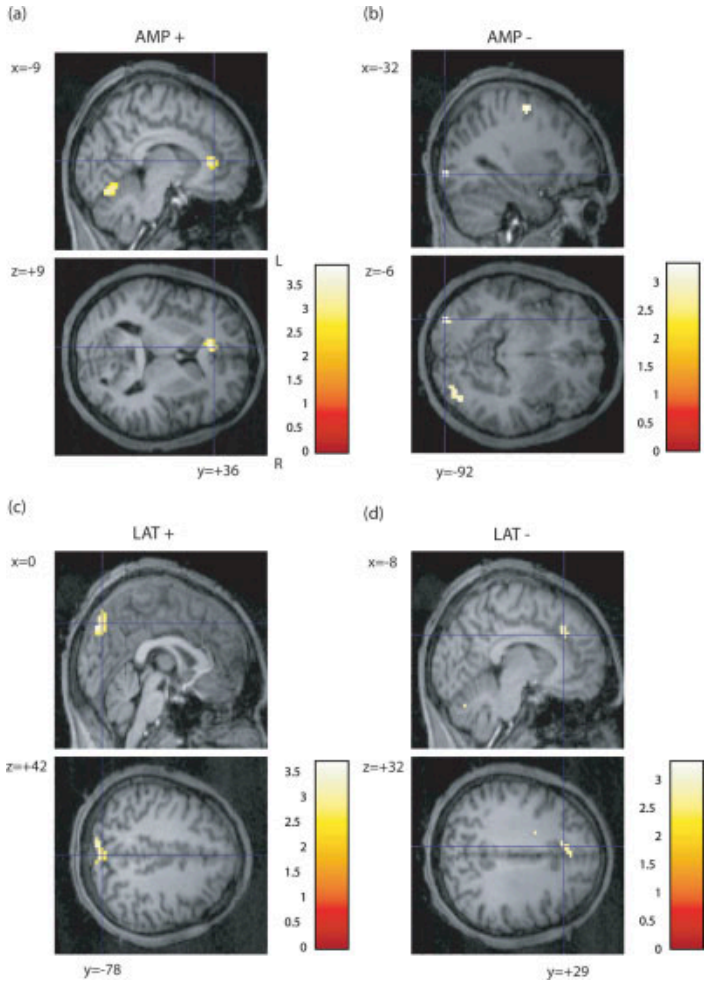


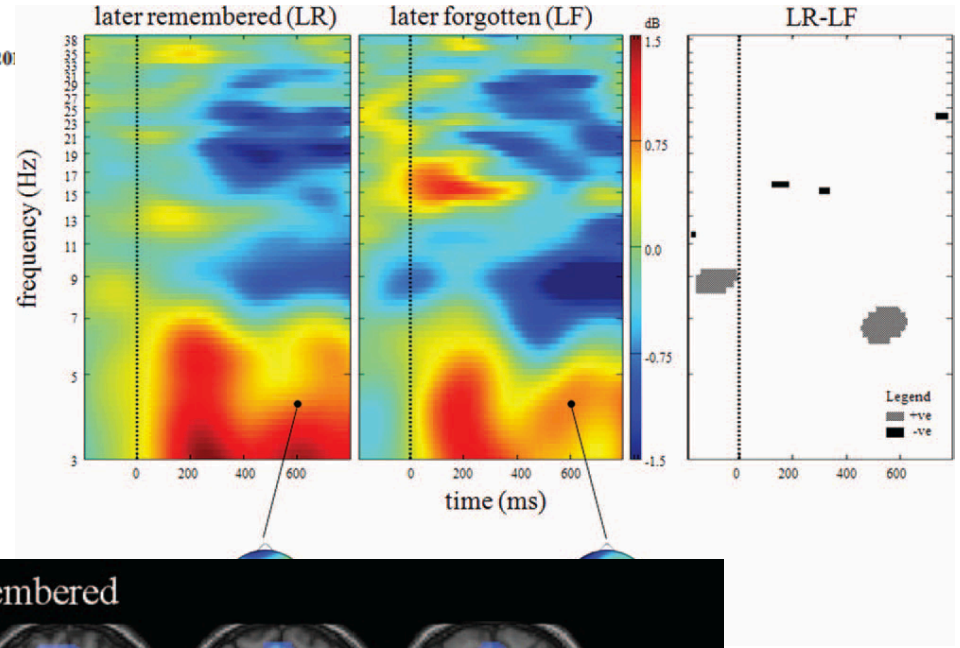


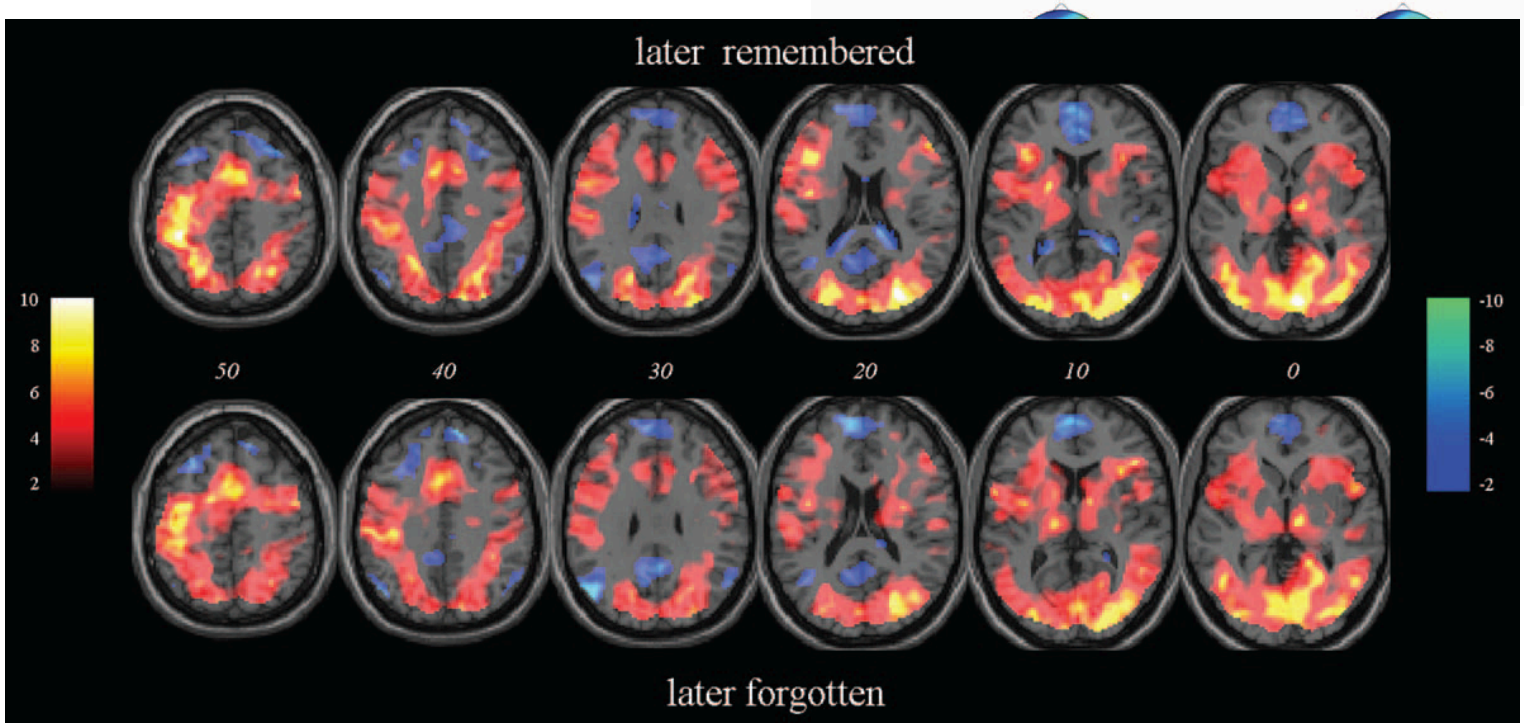
Variations in single trial

• Human Brain Mapping 000:000–000 (20

Theta Power During Encoding Predicts Subsequent-Memory Performance and Default Mode Network Deactivation

Thomas P. White,[1,3] Marije Jansen,[1] Kathrin Doege,[1] Karen J. Mullinger,[2] S. Bert Park,[1] Elizabeth B. Liddle,[1] Penny A. Gowland,[2] Susan T. Francis,[2] Richard Bowtell,[2] and Peter. F. Liddle[1]*





◆ Human Brain Mapping 000:000–000 (2012) ◆

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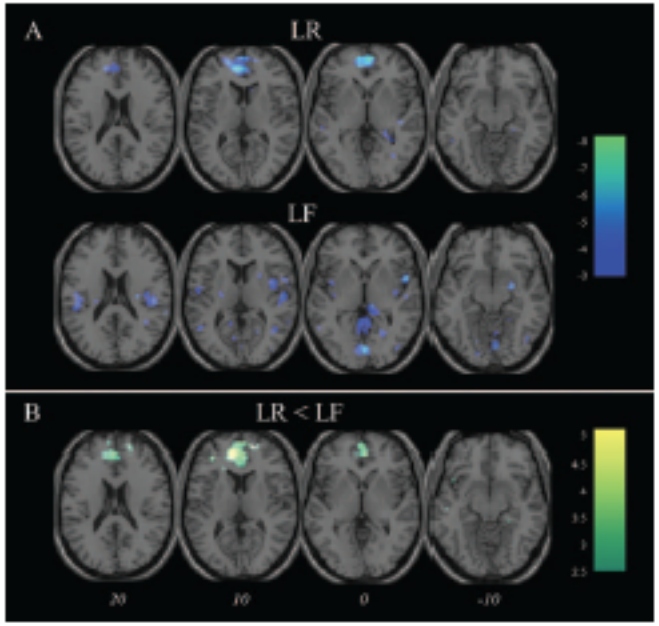

Figure 4.
Theta negatively predicts frontomedial blood oxygenation level
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d (LR; top) and
regions exhib-
r LR compared
rd T1-weighted
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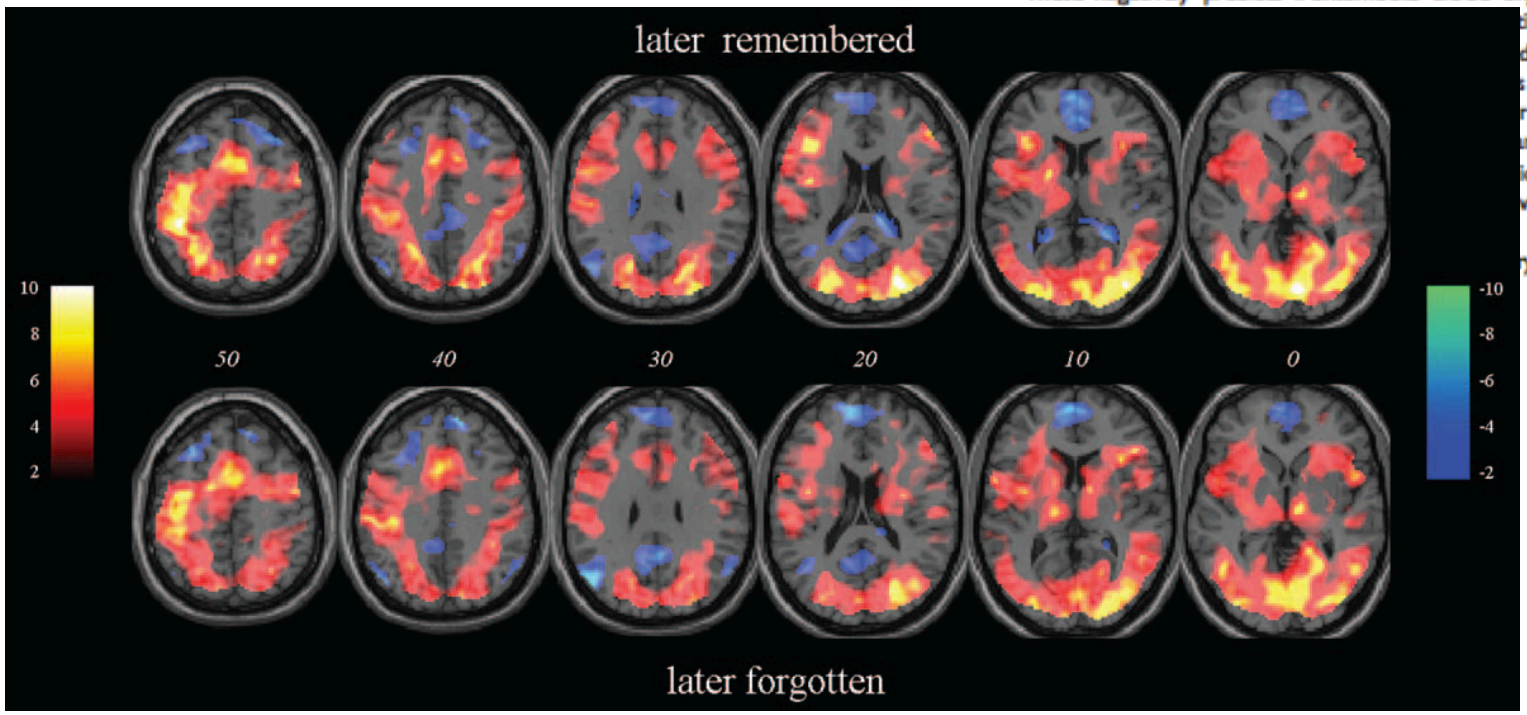
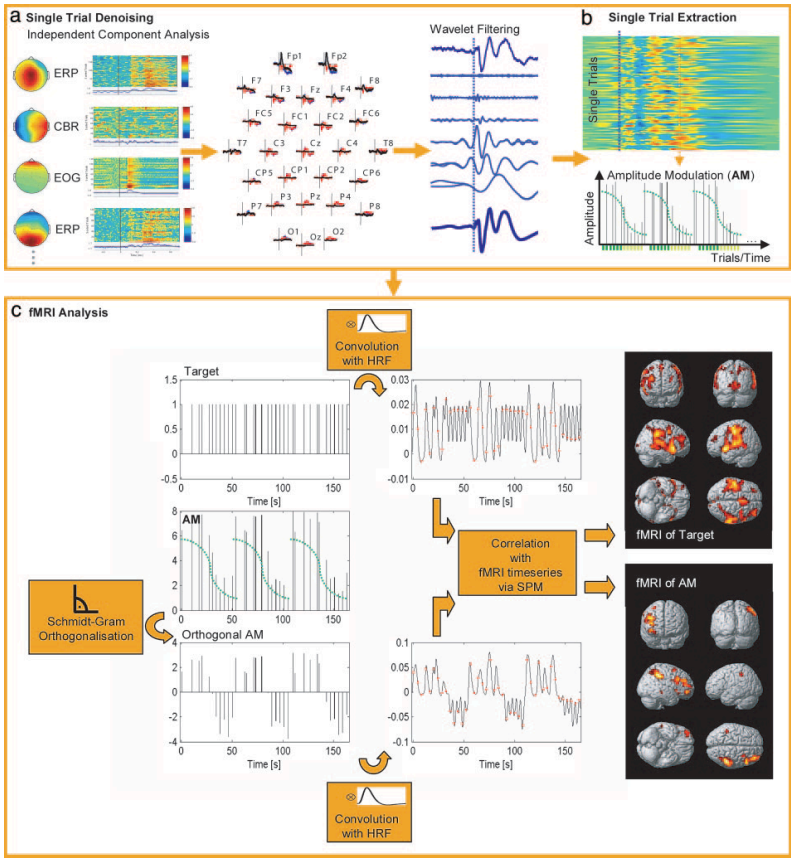


Assessing the spatiotemporal evolution of neuronal activation with single-trial event-related potentials and functional MRI

Tom Eichele*†‡

PNAS " **December 6, 2005 " vol. 102 " no. 49**



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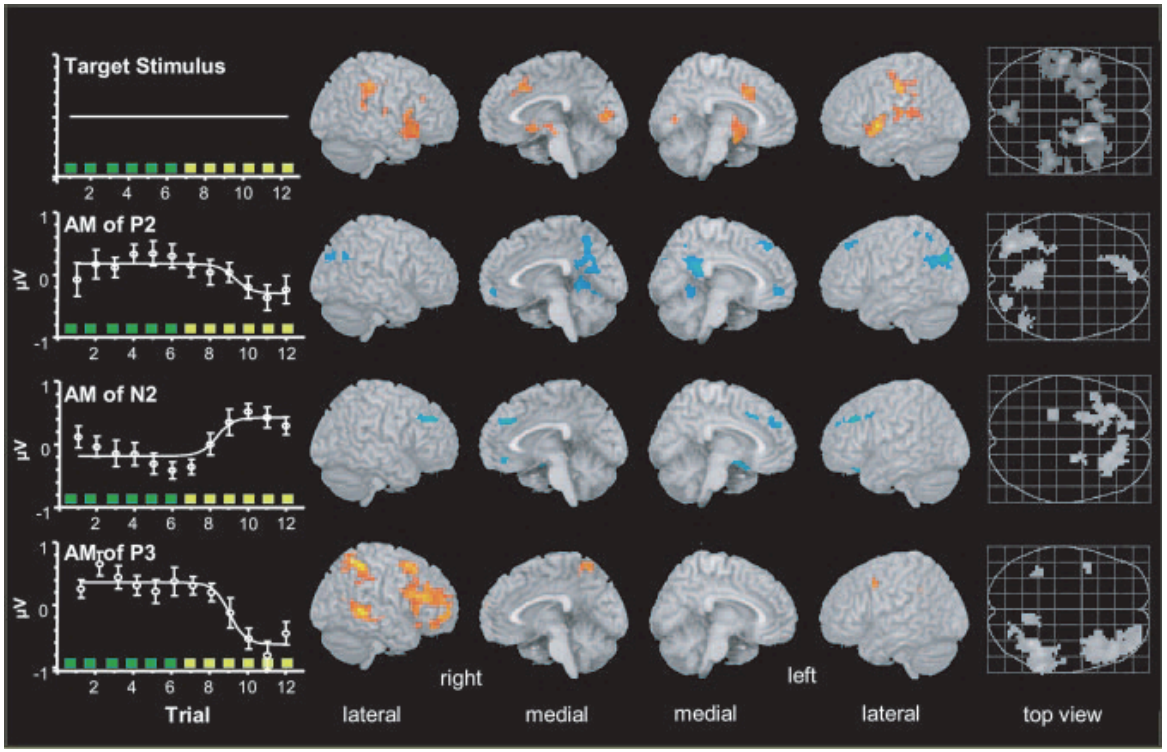
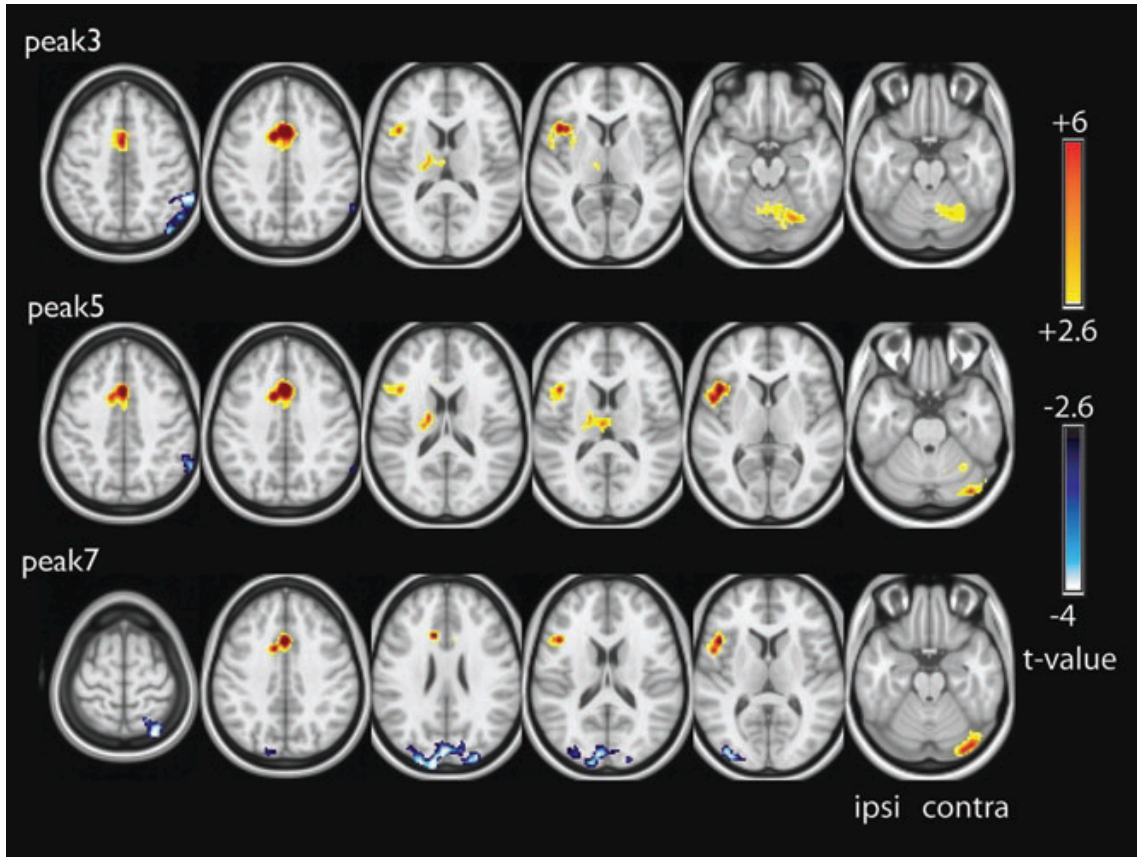


Widespread epileptic networks in focal epilepsies—EEG-fMRI study

Firas Fahoum, Renaud Lopes, Francesca Pittau, Franc¸ois Dubeau, and Jean Gotman

Epilepsia, **(*):1–10, 2012