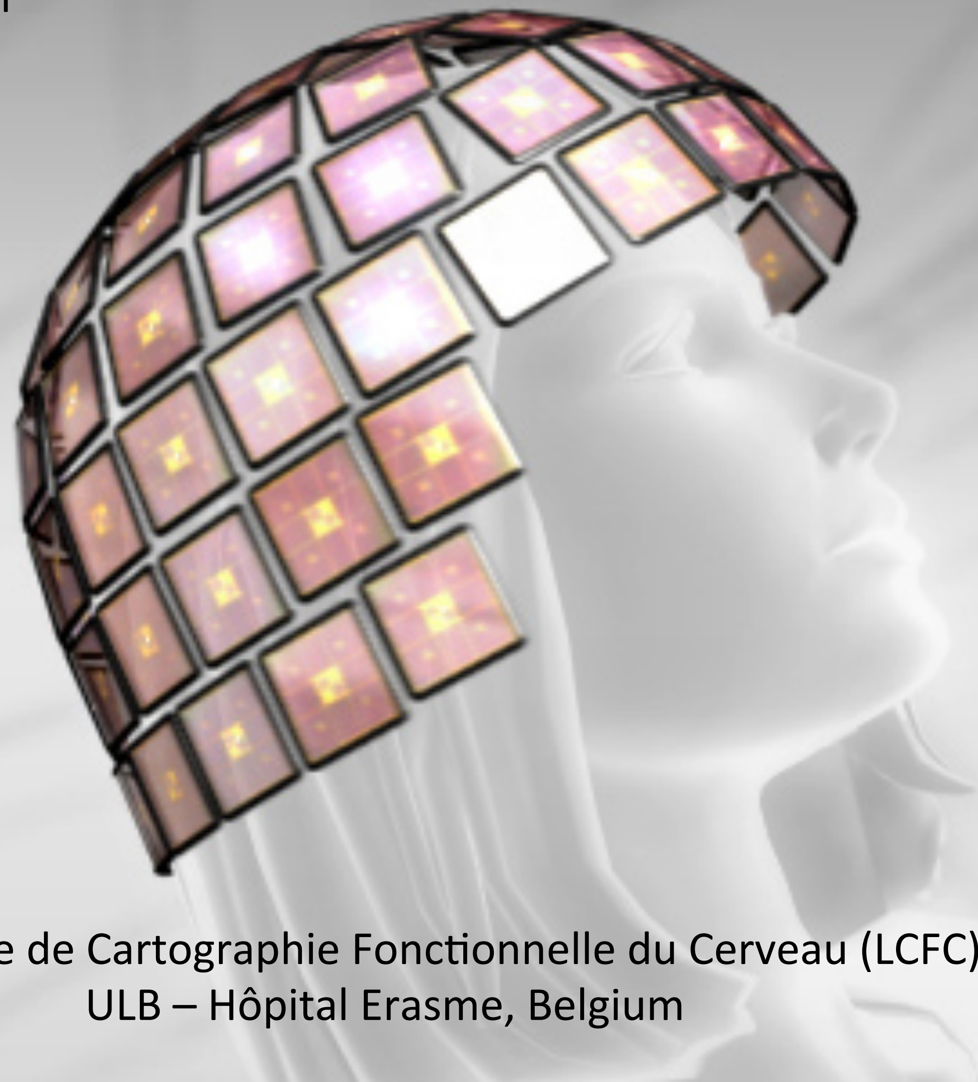
MEG & the Study of Cognitive Processes
the Brussels Experience

Chaudfontaine, Belgium
March 8, 2012



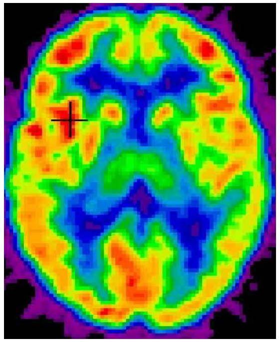
Mathieu Bourguignon
Serge Goldman
Vincent Wens

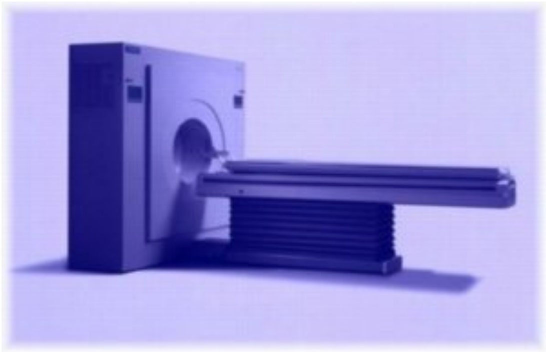
Laboratoire de Cartographie Fonctionnelle du Cerveau (LCFC)
ULB – Hôpital Erasme, Belgium

Functional brain imaging and neurophysiological relevance of MEG

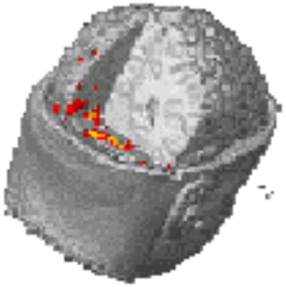
Available modalities

PET/SPECT

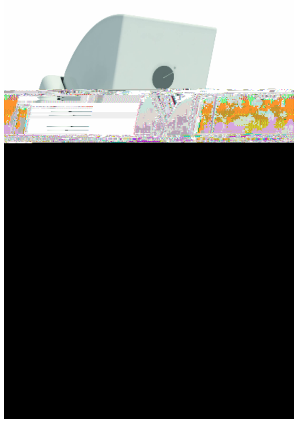




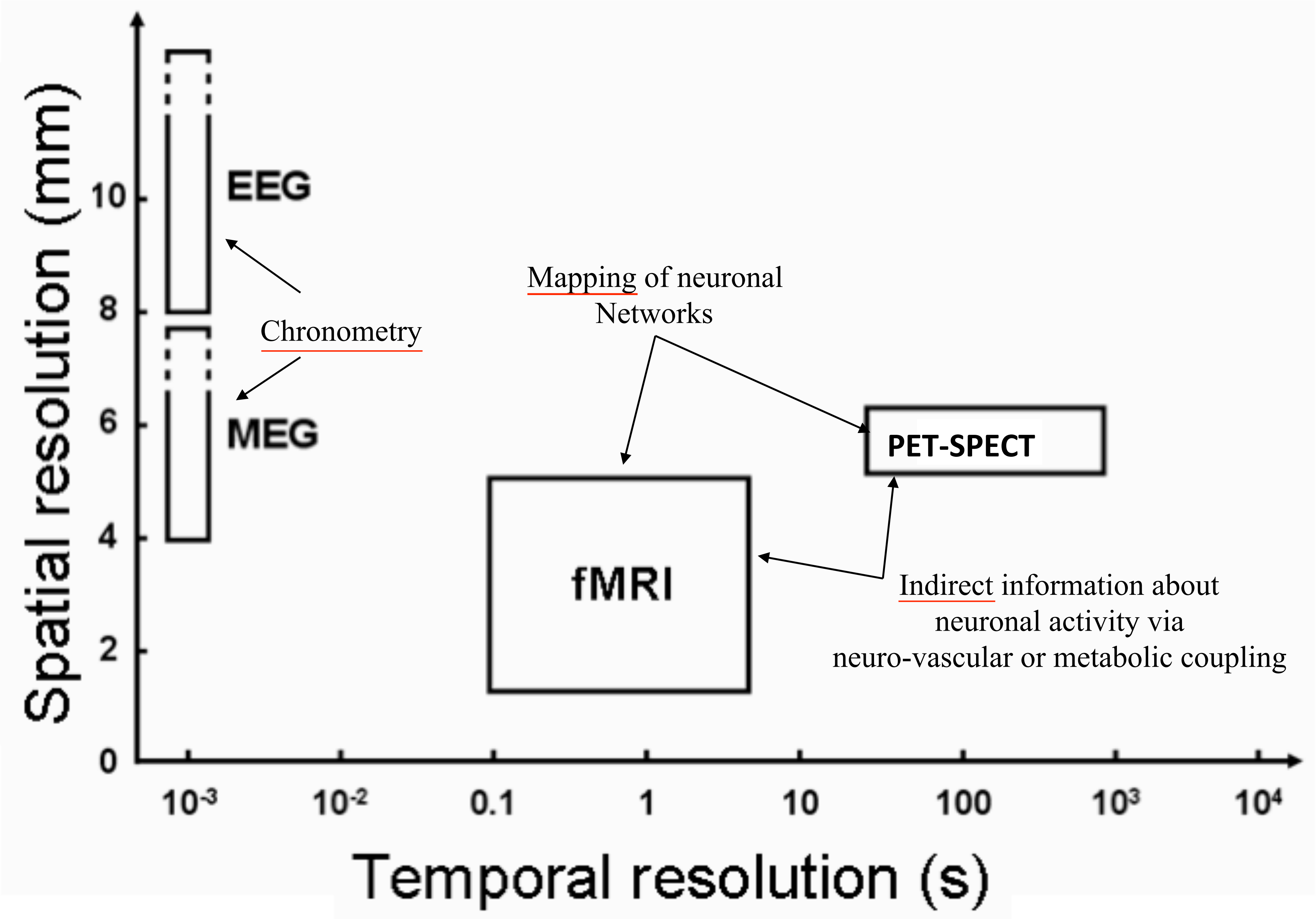
fMRI



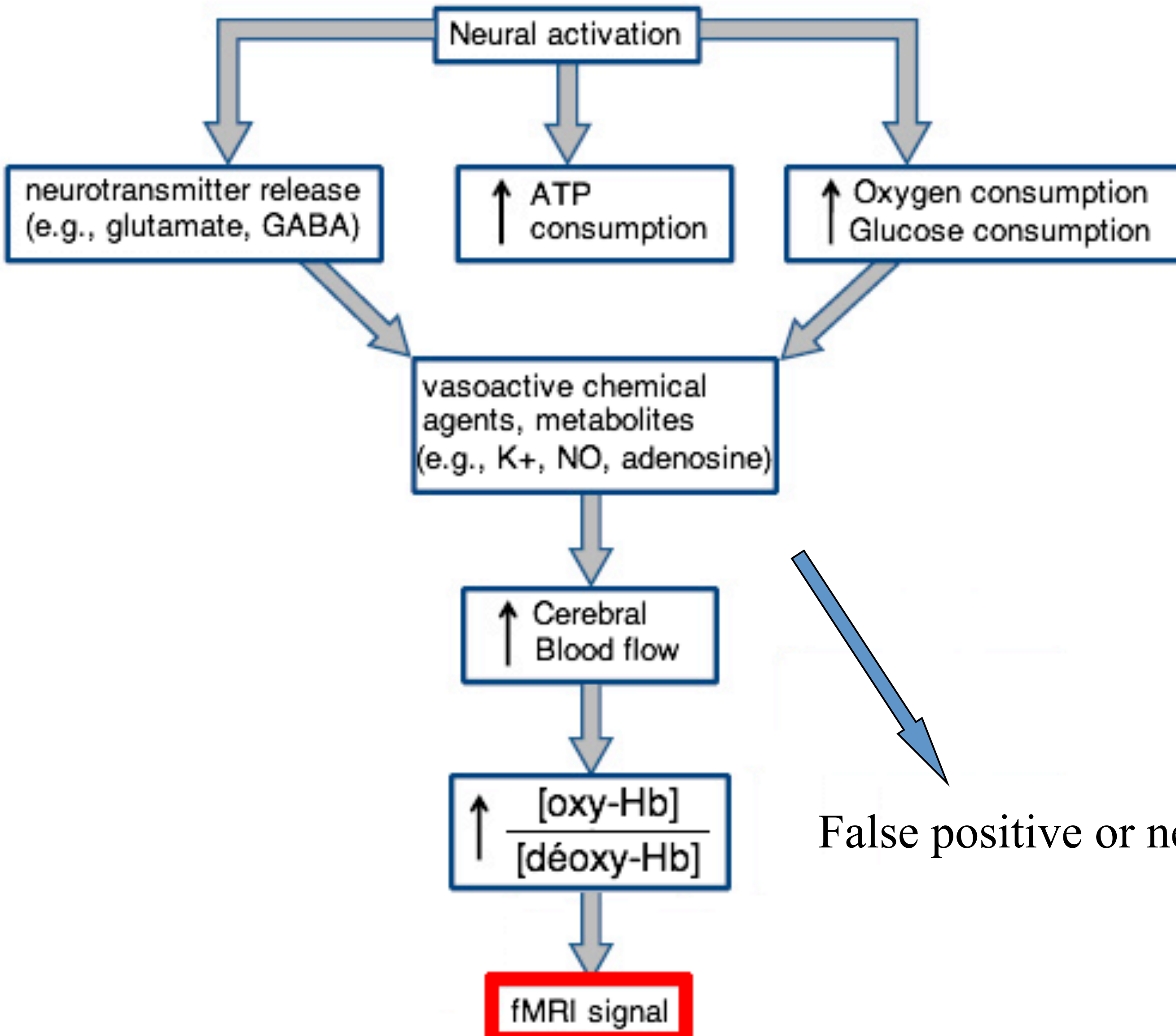
M-EEG

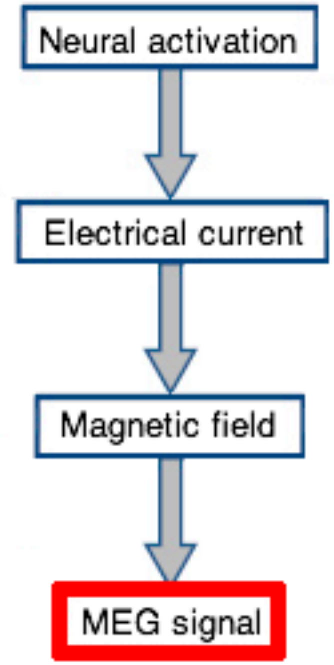


Available modalities



Available modalities





False positive or negative activation(s)

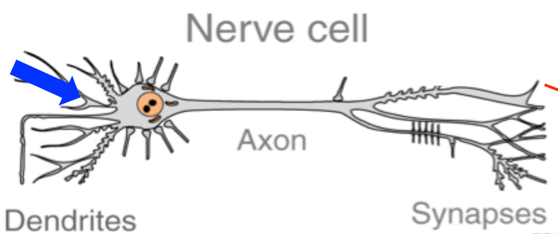
ALTERATIONS IN THE BOLD FMRI SIGNAL WITH AGEING AND DISEASE: A CHALLENGE FOR NEUROIMAGING

Mark D'Esposito, Leon Deouell and Adam Gazzaley

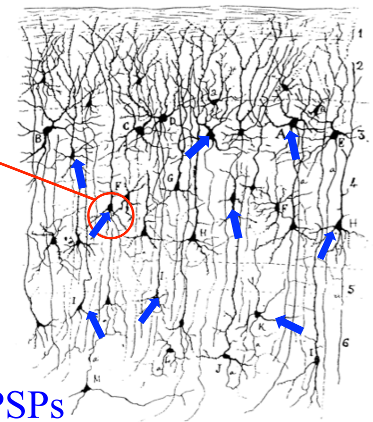
Functional MRI (fMRI) has rapidly emerged as a powerful tool for studying brain function, despite the fact that it measures neuronal activity indirectly, through the blood-oxygen-level-dependent (BOLD) signal. The BOLD signal depends on neurovascular coupling — the processes by which neural activity influences the haemodynamic properties of the surrounding vasculature. Although the exact mechanisms that underlie neurovascular coupling are not completely understood, there is empirical evidence that these mechanisms might be altered in normal ageing and disease. So, interpretation of BOLD fMRI studies of individuals with different ages or pathology might be more challenging than is commonly acknowledged.

Electro-magnetic measurements

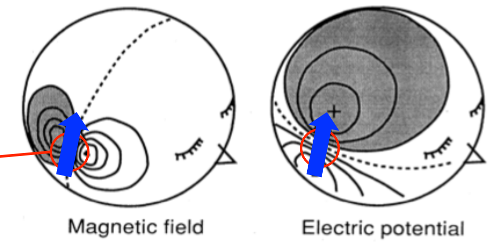
Direct measure of electro-physiological activity of neuronal populations



Post-synaptic potential (PSP)



Sum of synchronous PSPs

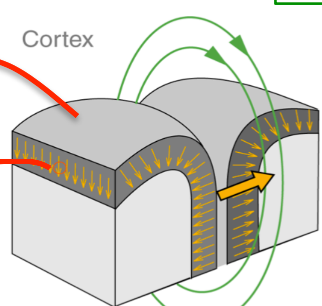


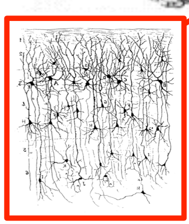
Macroscopic current dipole

[Hamalainen et al. Rev.Mod.Phys. 1993]

Magneto-encephalography

Electro-encephalography

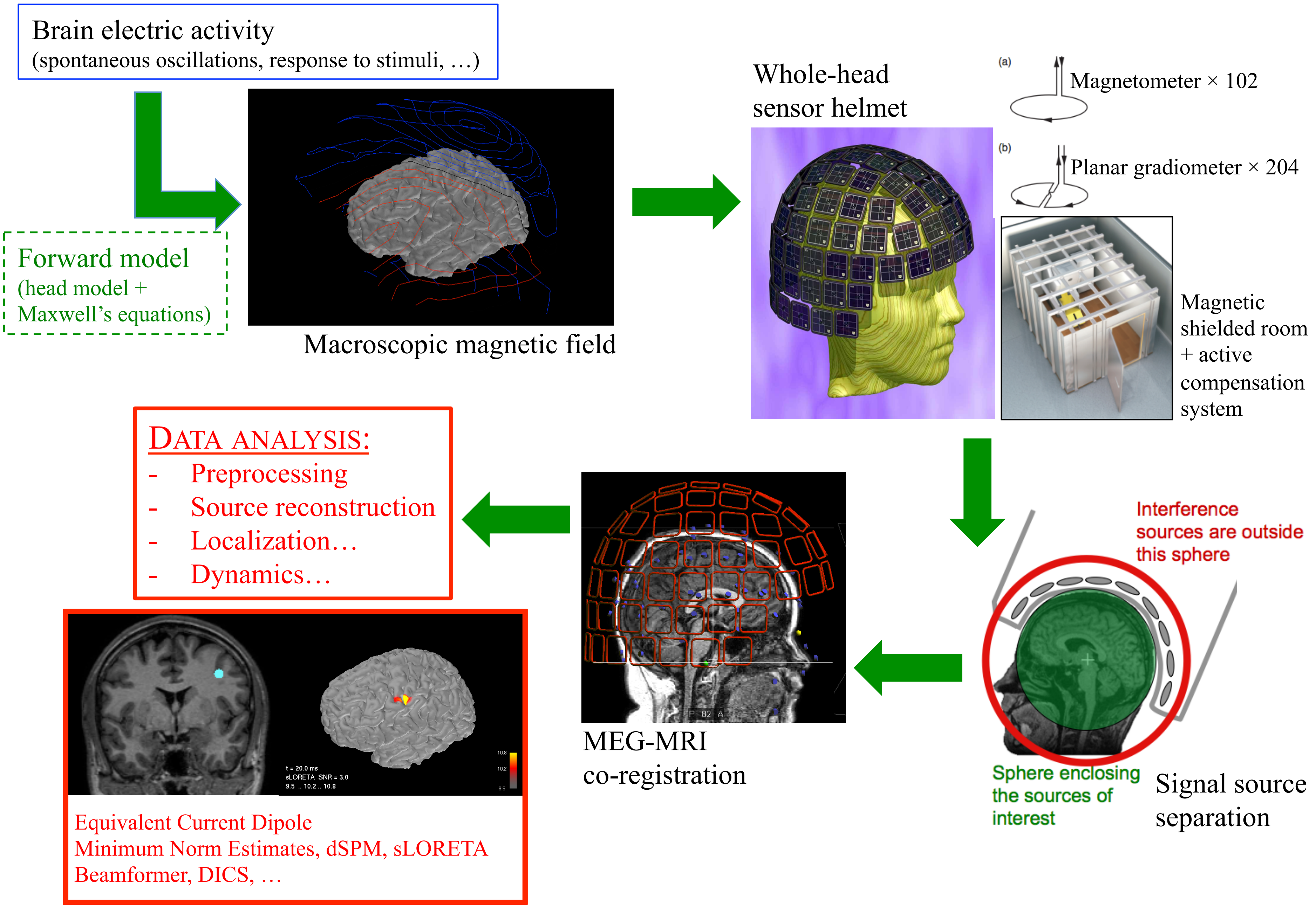




Detectable magnetic fields mainly generated by tangential dipoles.

MEG records the variation of fissural cortical activity

MEG


Brain electric activity
(spontaneous oscillations, response to stimuli, …)
Forward model
(head model + Maxwell's equations)
Macroscopic magnetic field
Whole-head sensor helmet
(a)
Magnetometer × 102
(b)
Planar gradiometer × 204
Magnetic shielded room + active compensation system
Interference sources are outside this sphere
Sphere enclosing the sources of interest
Signal source separation
MEG-MRI co-registration
P 82 A
DATA ANALYSIS:
- Preprocessing
- Source reconstruction
- Localization…
- Dynamics…
t = 20.0 ms
sLORETA SNR = 3.0
9.5 .. 10.2 .. 10.8
Equivalent Current Dipole
Minimum Norm Estimates, dSPM, sLORETA
Beamformer, DICS, …

MEG & EEG

MEG	EEG

- Temporal resolution ~ 1 ms
- Direct measure of macroscopic electric brain activity
- Good realistic forward models (BEM, …)
- Source reconstruction methods not unique
    - ECD, MNE, Beamformer, …
	- Temporal resolution ~ 1 ms
	- Direct measure of macroscopic electric brain activity
	- Good realistic forward models (BEM, …)
	- Source reconstruction methods not unique
	    - ECD, MNE, Beamformer, …

- MEG signal *less deformed by in-homogeneities in head conductivity*, cleaner signal - *Better* source reconstruction and localization - High-density helmet *easy to use*	- EEG signal *strongly deformed by in-homogeneities in head conductivity* - In particular, traumatic brain injuries affect EEG signal - *Less precise* source reconstruction and localization - High-density EEG *difficult to use*

- Mainly sensitive to *tangential* dipoles
    - limited to fissural activity
- MEG helmet *not attached* to subject's head
    - need quiet subjects
    - HPI coils and movement compensation algorithm
- *Sensible* to *external magnetic perturbations*
    - SSS preprocessing absolutely necessary
- *Magnetic materials* lead to strong *artifacts*
    - radio-opaque wires, tracheotomy, nasogastric tubes, …
    - Difficulties for post-surgical and DOCs patients
    - Need to develop MEG-compatible devices!
	- Sensitive to *both tangential and radial* dipoles
	    - *not* limited to fissural activity
	- EEG electrodes attached to subject's head
	- *Less sensible* to *background electric perturbations*
	- *Less affected* by such materials

Both modalities have their advantages and inconveniences. They should be viewed as *complementary* methods.

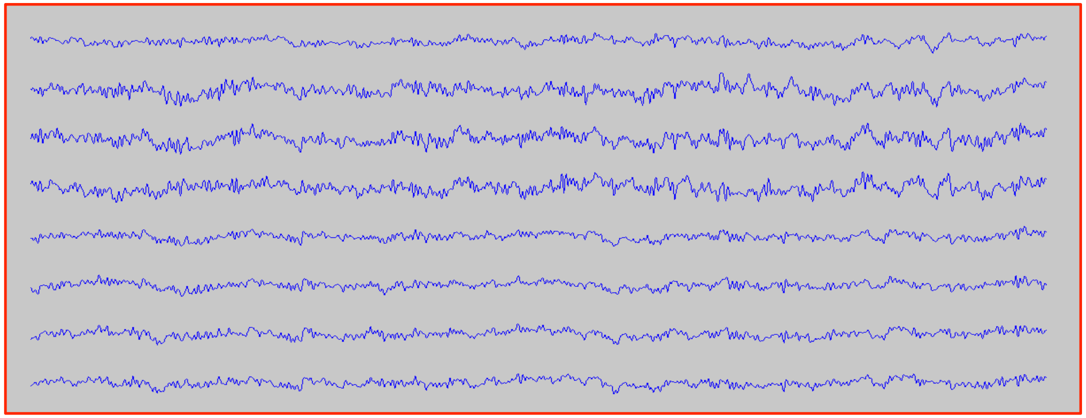
MEG data analysis and disorders of consciousness

Resting state and connectivity

Simplest type of experimental set-up:
subject at rest (not engaged in task or subject to specific stimuli)
for 5 minutes, with eyes closed or open

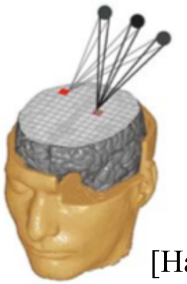
Particularly suited to DOC patients

SPONTANEOUS BRAIN ACTIVITY or BRAIN NOISE



This activity is not just random noise!

The brain is a *dynamical system* composed of a large number of "simple" constituents (neurons) *interacting* through synaptic connections.

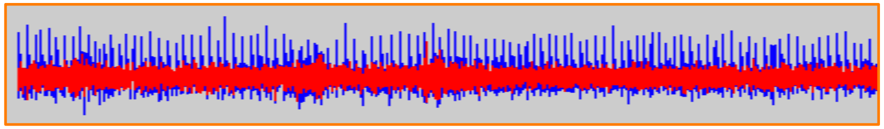


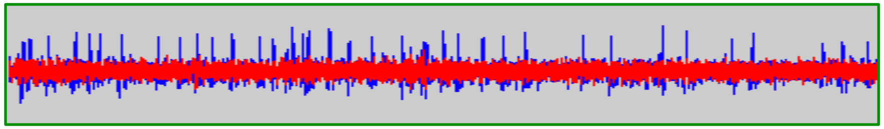
[Hansen et al. 2011]

A method to study this activity is to perform *cortico-cortical functional connectivity analyses*: evaluate dependency measures between sensors or reconstructed current dipoles.

In general, resting state needs careful preprocessing and rejection of artifacts.

E.g. ICA for detection of artifacts due to heart beating and eye blinks



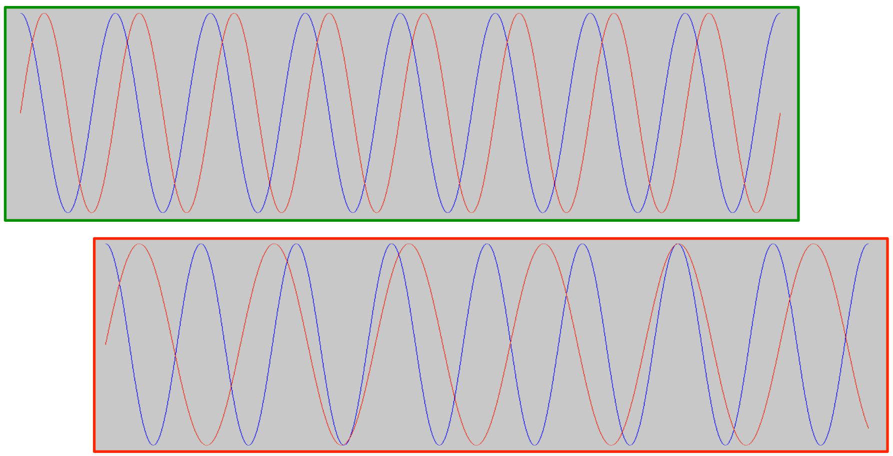
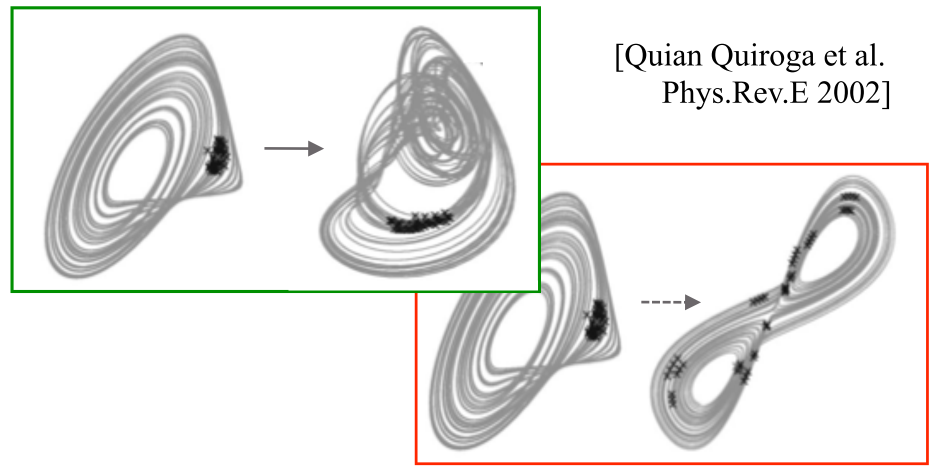


Resting state and connectivity

An example of robust index assessing functional connectivity is *synchronization*.

Synchronization is one of the major mechanisms leading to the *emergence of ordered dynamics* in many complex biological systems…

Examples of synchronization measures

Phase synchronization	*Generalized synchronization*
	 [Quian Quiroga et al. Phys.Rev.E 2002]
Linear or narrow-band oscillations (Fourier transform, coherence, phase-locking value, …)	Non-linear dynamical systems (attractor reconstruction, metric continuity, synchronization likelihood, …)

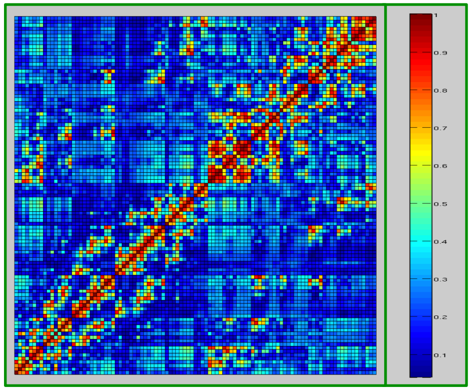
Many other measures of functional connectivity exist. Their choice depends on the questions and hypothesis under investigation.

Other examples: *temporal correlation*, *mutual information*, *Granger causality*, …

Resting state and connectivity

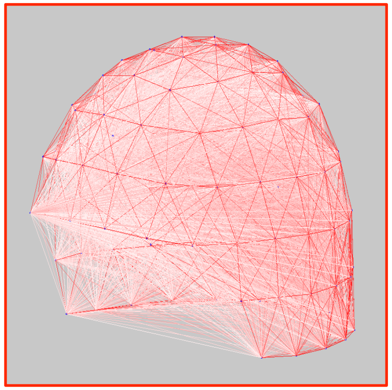
Evaluation of pairwise functional connectivity determines a connectivity matrix representing a complex network.

cortico-cortical



sensor-space coherence (α)

Statistical graph theory offers tools to study the structure of such network and characterize its functional architecture.



sensor-space weighted graph

clustering coef.= 0.32
path length = 2.98
small-worldness = 0.11

Graph indices can be used to observe changes due to brain disorders…

Full cortico-cortical connectivity analyses in source-space heavier and more difficult.
The use of priors can help (seed-based connectivity maps, …).

Resting state and connectivity

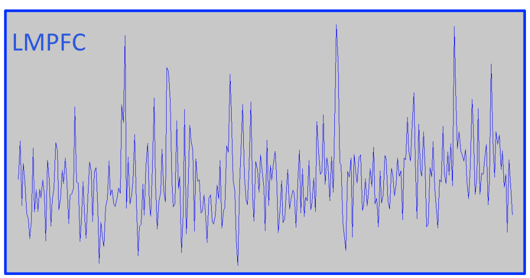
Consistent resting state networks have been discovered and studied in fMRI.

They can also be uncovered in MEG, showing their electrophysiological relevance.

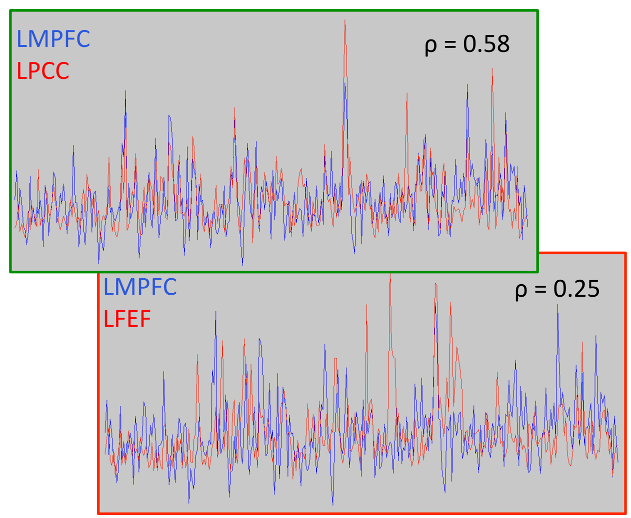
[de Pasquale et al. PNAS 2010; Brookes et al. PNAS 2011]

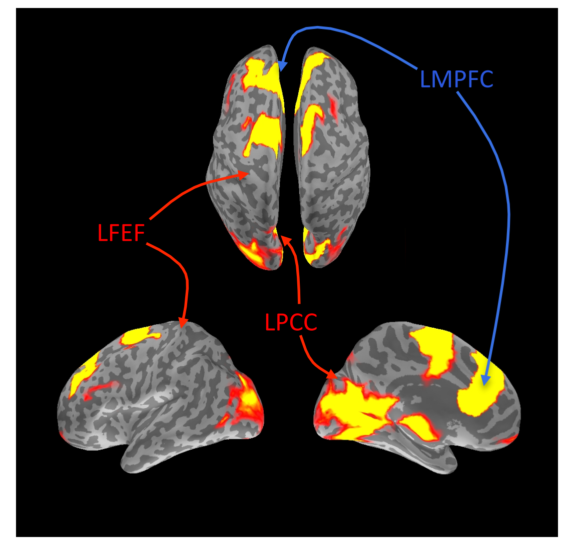
Example of methodology

Slow fluctuations of sources power time course	Seed-based connectivity: temporal correlation	Correlation map



α-band, MNE, rms (1sec)



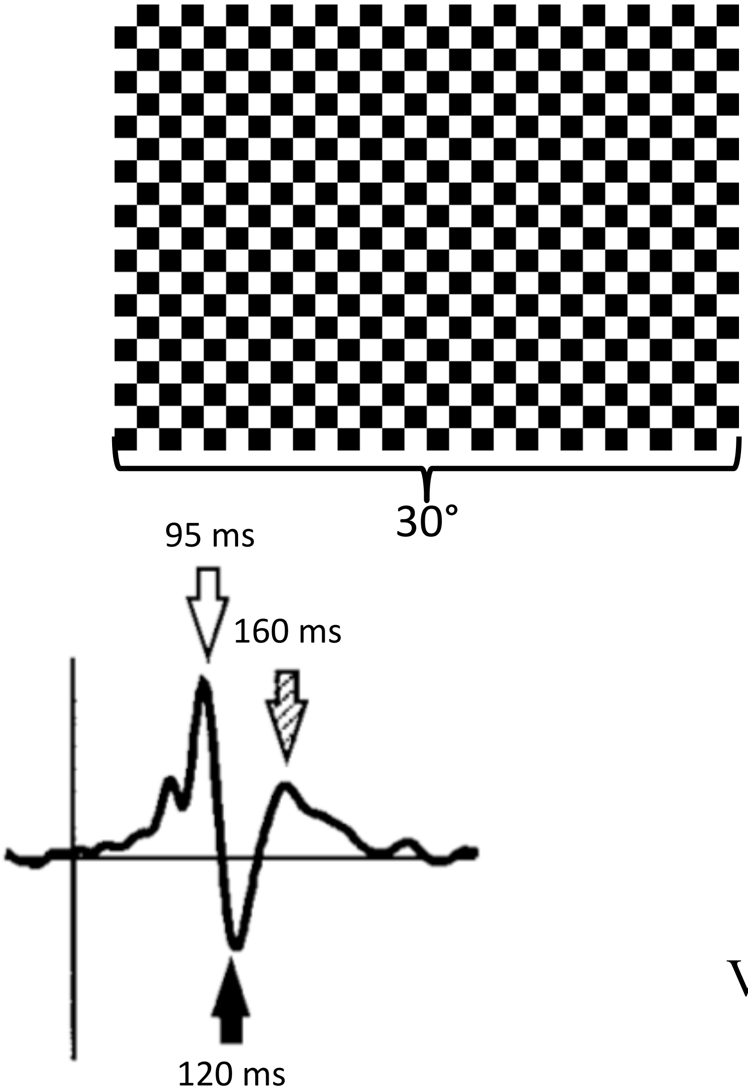


Resting state networks and correlation maps can be *compared* across various conditions, and the way brain disorders affect them can be assessed…

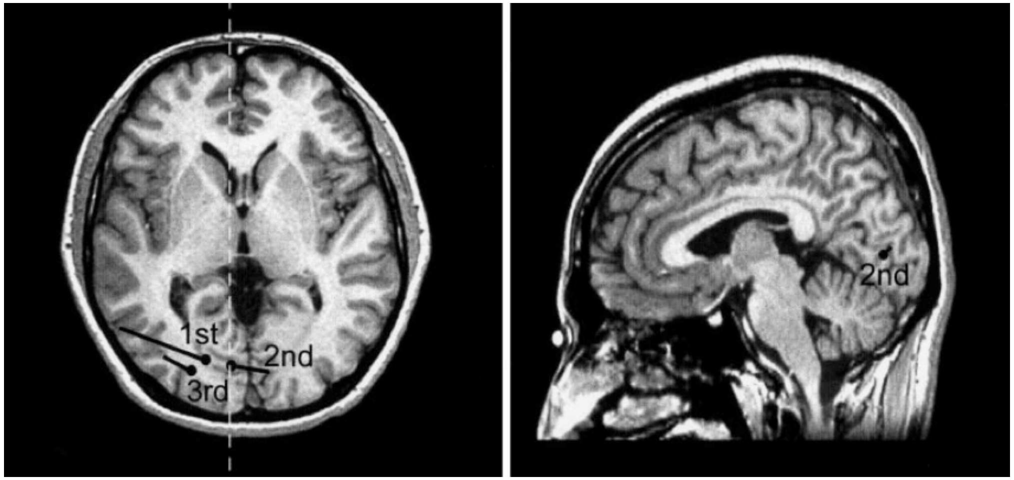
Those networks can also be used as priors for source-space synchrony analysis…

Sensory stimulations

Visual evoked fields (checkerboard)



Hashimoto et al, 1999



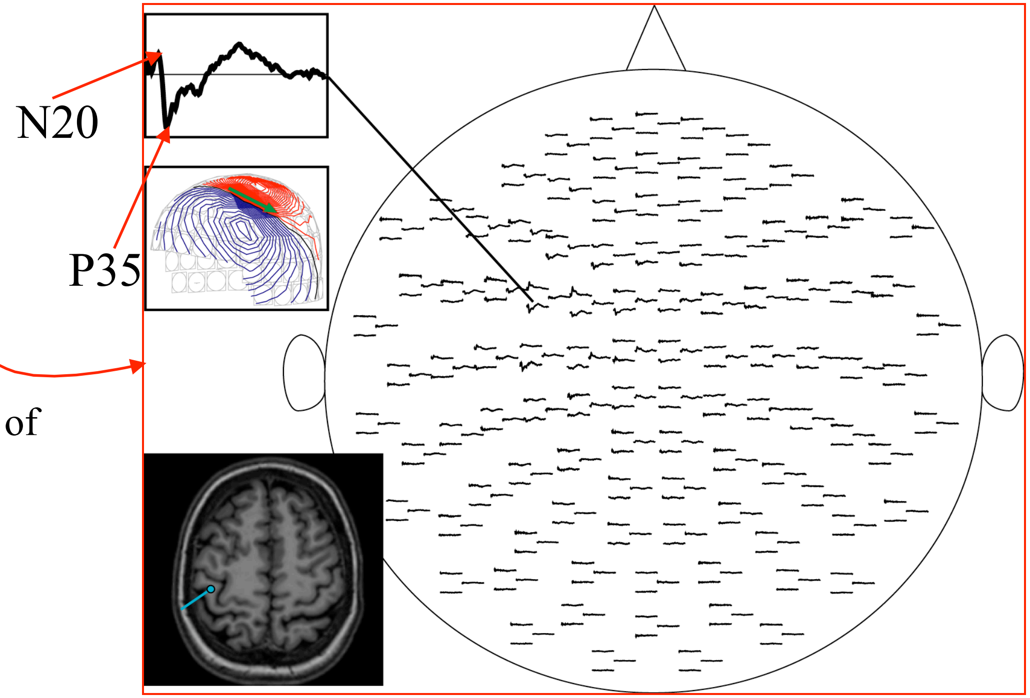
Hashimoto et al, 1999

Visual paradigms may be unsuited in DOCs

Sensory stimulations

Somatosensory evoked fields (tactile stimulation or peripheral nerve stimulation)

Example: median nerve



MI dipole strength due to median nerve stimulation of the stroke-affected hand positively correlated with neurological motor function scores

ELSEVIER

Clinical Neurophysiology 115 (2004) 820–833

MEG response to median nerve stimulation correlates with recovery of sensory and motor function after stroke

M. Huang[a,b,*], L.E. Davis[a,c], C. Aine[a,b,c], M. Weisend[a,b], D. Harrington[a,c], R. Christner[a], J. Stephen[a,b], J.C. Edgar[a], M. Herman[a], J. Meyer[a], K. Paulson[a], K. Martin[a], R.R. Lee[a,b]

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[b]*Department of Radiology, School of Medicine, Health Sciences Center, University of New Mexico, Albuquerque, NM 87131, USA*
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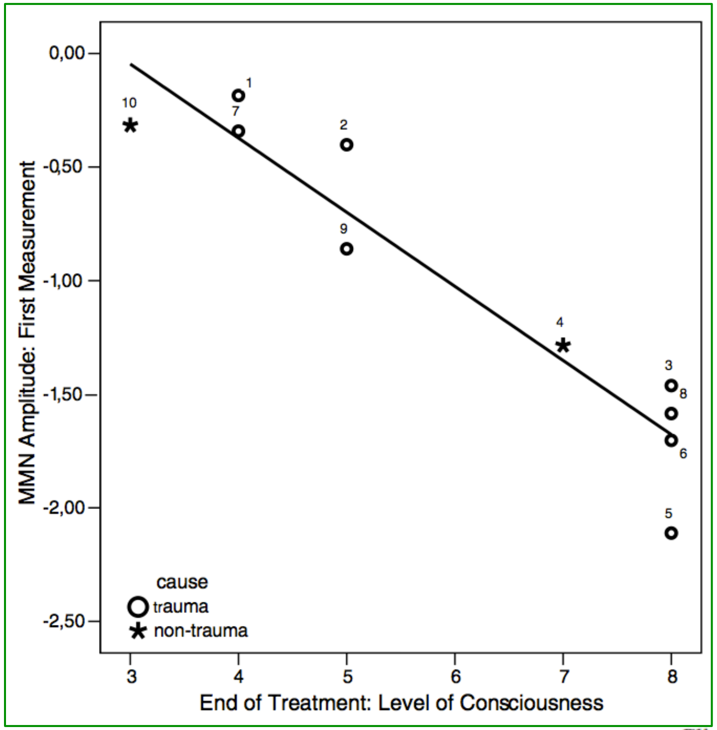
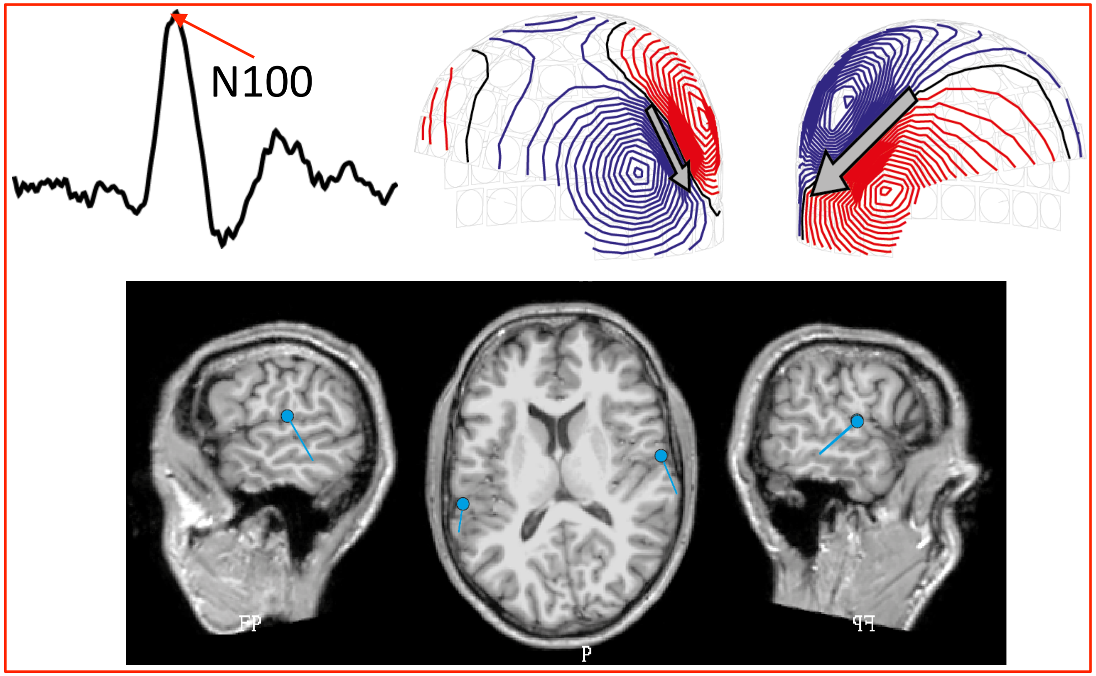
Accepted 17 November 2003

Sensory stimulations

Auditory evoked fields (pure tone, mismatch negativity)



Example: 1 kHz pure tone



Clinical Neurophysiology 118 (2007) 597–605

www.elsevier.com/locate/clinph

Mismatch negativity predicts recovery from the vegetative state

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[a] *Tilburg University, Department of Psychology and Health, Cognitive and Affective Neuroscience Laboratory, Warandelaan 2, 5000 LE Tilburg, The Netherlands*

[b] *Rehabilitation Centre Leijpark, Research Division, project VLB-NAH, Prof. Stoltehof 3, 5022 KE Tilburg, The Netherlands*

[c] *Athinoula A. Martinos Center for Biomedical Imaging, Harvard Medical School, Charlestown, MA, USA*

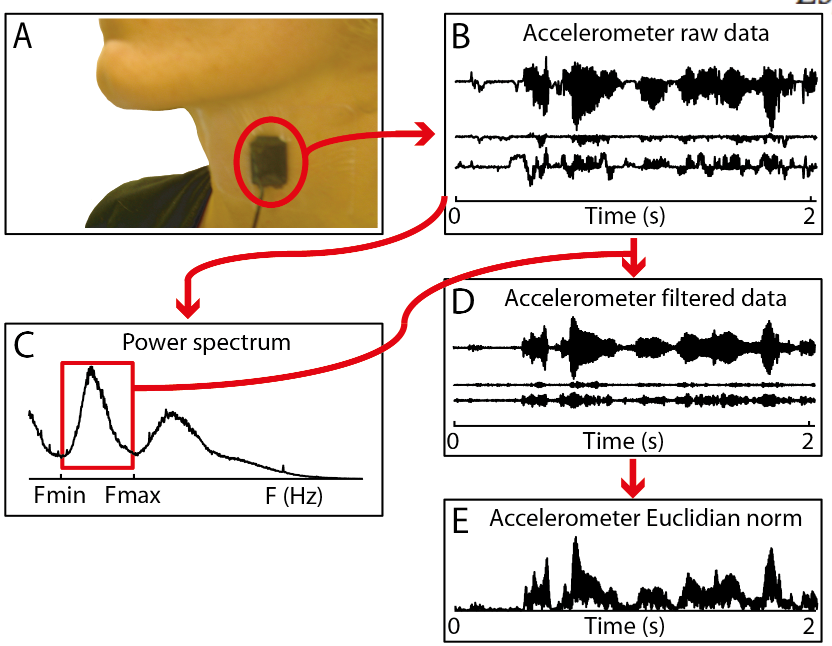
Sensory stimulations

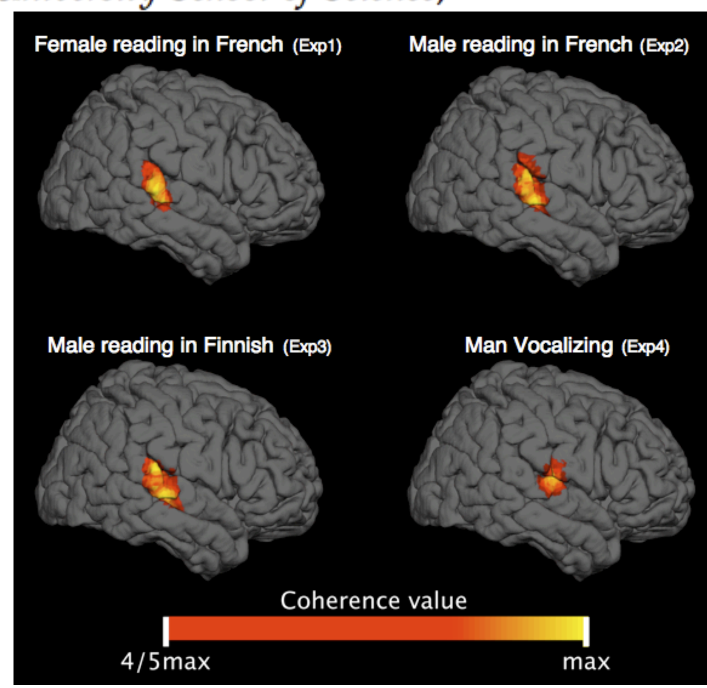
◆ Human Brain Mapping 00:00–00 (2012) ◆

The Pace of Prosodic Phrasing Couples the Listener's Cortex to the Reader's Voice

Mathieu Bourguignon,[1] Xavier De Tiège,[1]* Marc Op de Beeck,[1] Noémie Ligot,[1] Philippe Paquier,[1] Patrick Van Bogaert,[1] Serge Goldman,[1] Riitta Hari,[2] and Veikko Jousmäki[1,2]

[1]*Laboratoire de Cartographie Fonctionnelle du Cerveau, ULB-Hôpital Erasme, Université Libre de Bruxelles, 1070 Brussels, Belgium*
[2]*Brain Research Unit, Low Temperature Laboratory, Aalto University School of Science, Espoo, Finland*

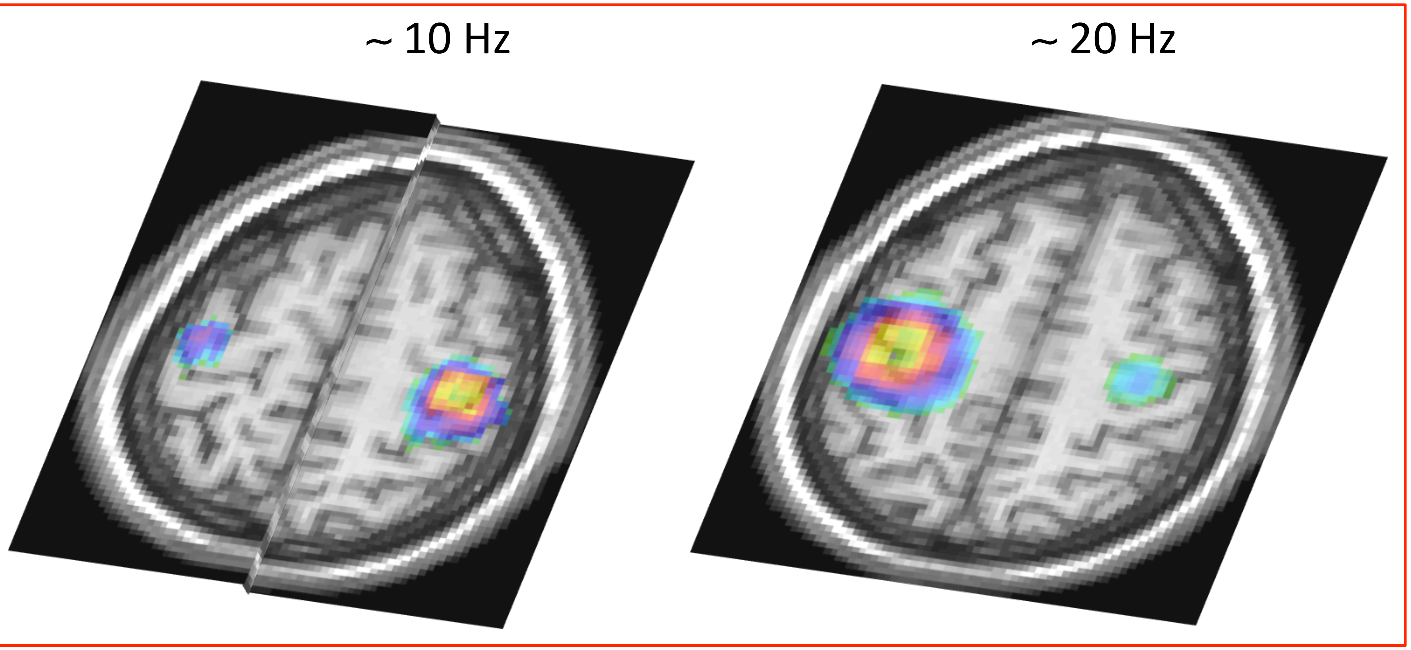




Brain rhythm modulation

Brain rhythm modulation:

Towards the MEG detection of intentional brain activity



Bedside detection of awareness in the vegetative state: a cohort study

Damian Cruse, Srivas Chennu, Camille Chatelle, Tristan A Bekinschtein, Davinia Fernández-Espejo, John D Pickard, Steven Laureys, Adrian M Owen

THE

Thank you

for your attention

END