

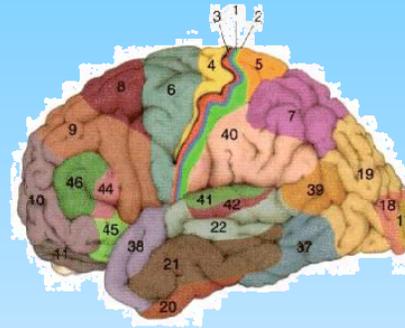
Fundamentals of Electroencephalography, Magneto-encephalography and Functional Magnetic Resonance Imaging

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and Gian Luca Romani ⁴

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2. A.Fa.R. Osp. FBF; Isola Tiberina, Rome, Italy;
3. Hospital San Raffaele Cassino, Italy;
4. ITAB, Università di Chieti, Italy



ESA2009

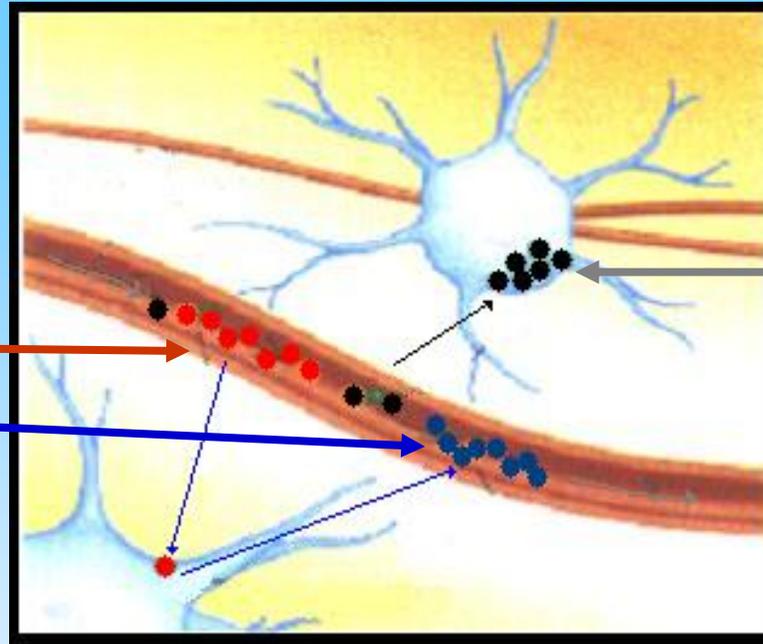
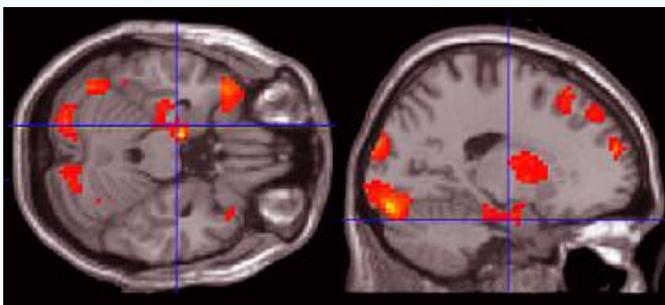


HOW TO STUDY THE BRAIN?

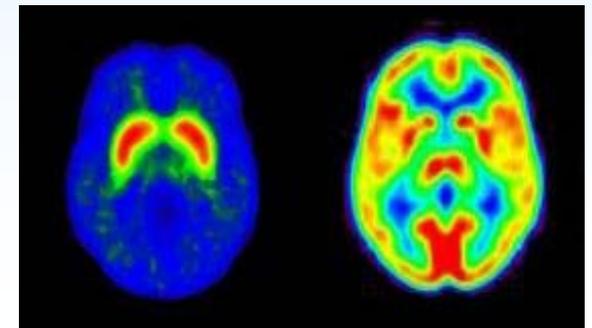
Genesis of fMRI and PET signals

fMRI measures regional cerebral blood flow in relation to

oxyhemoglobin
deoxyhemoglobin
(BOLD response)



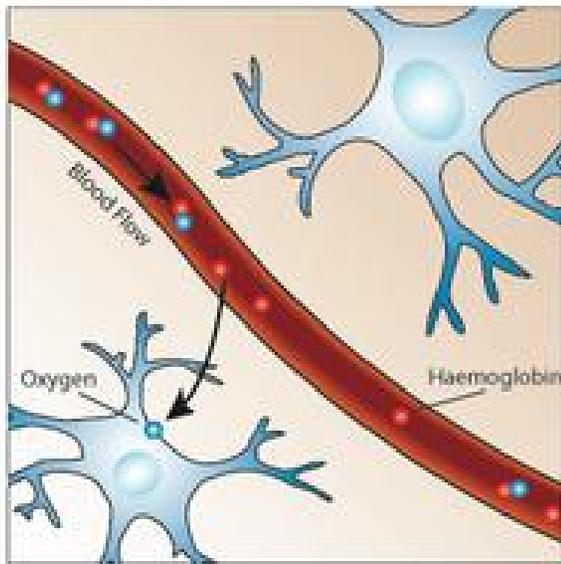
PET measures the accumulation of radioactive injected substance (2-deoxyglucose or ^{15}O) in the neural cells



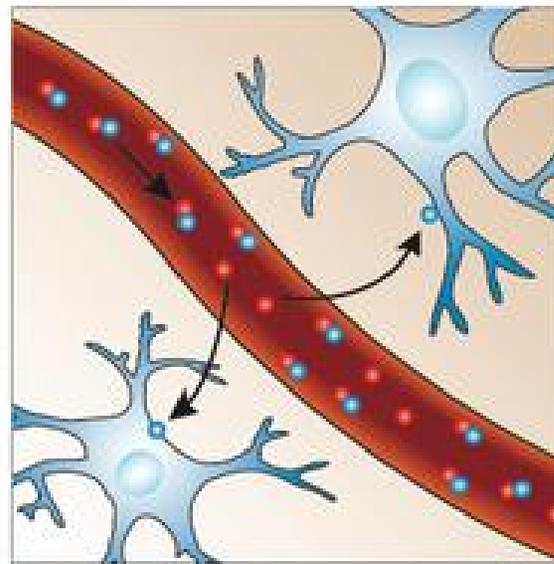
Neuroimaging:

- High spatial resolution (1 - 2 mm)
- Low temporal resolution (1 - 2 s)

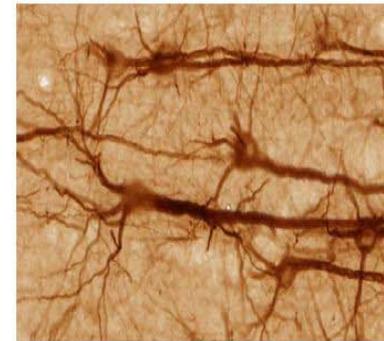
Genesis of fMRI signals



Resting



Activated

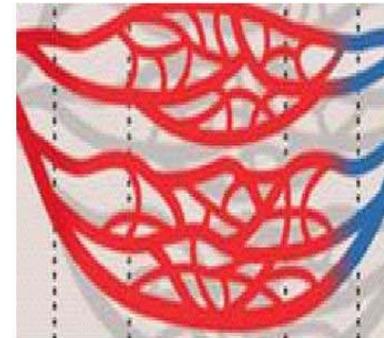


Neural activity



Neurovascular coupling

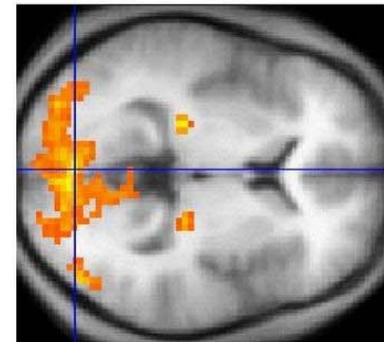
Change in metabolic demand



Haemodynamic response changes in blood flow and blood volume

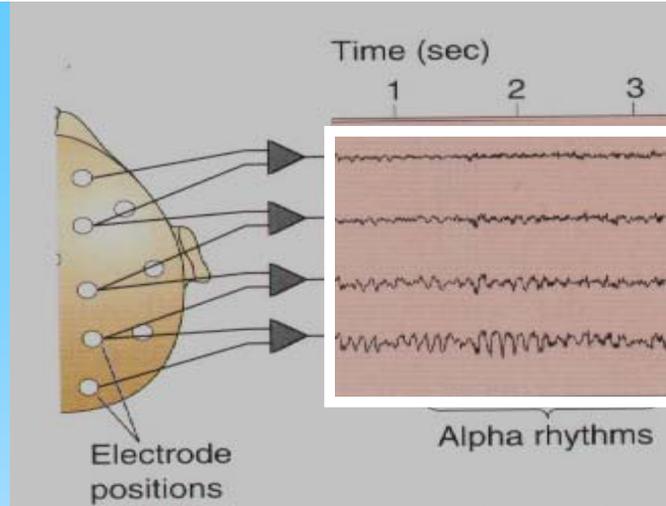


Change in blood oxygenation BOLD

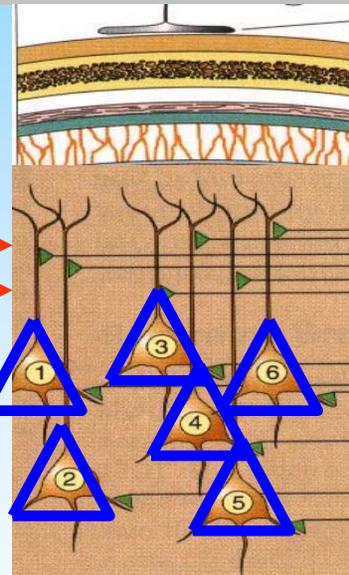


fMRI image

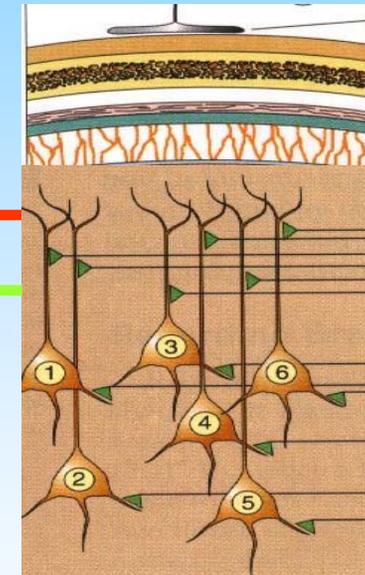
REST



Dominant resting (eyes-closed) **alpha rhythms** are **coherent over wide cortical areas** and corresponding **thalamic nuclei**



pyramidal neurons oscillating at synchronized alpha frequencies



Reticular neurons

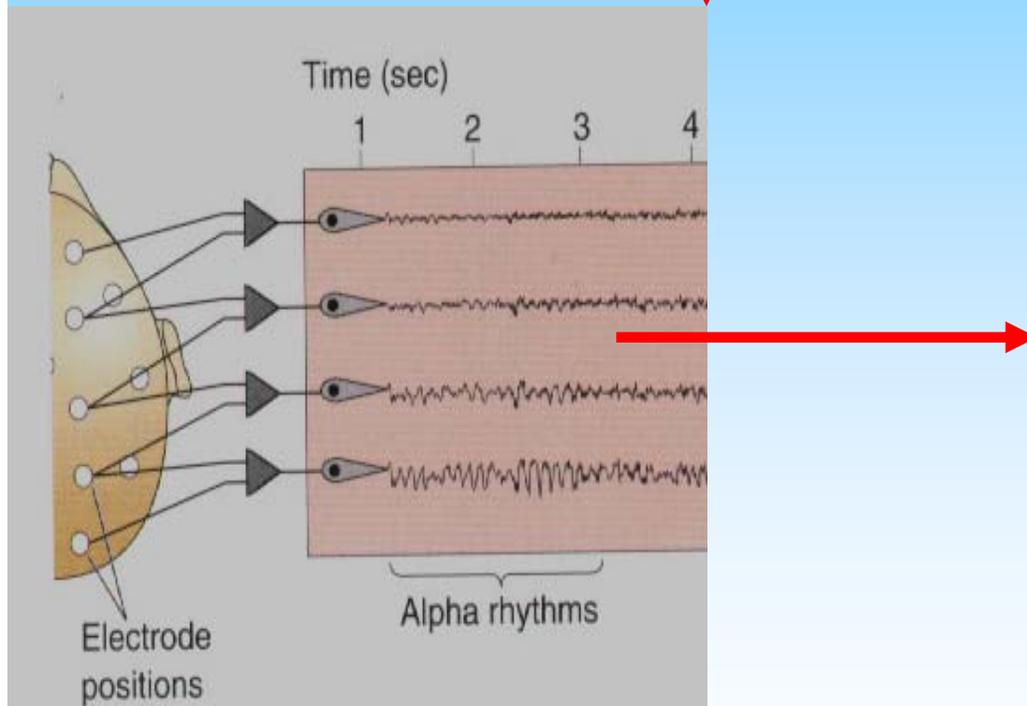
Relay neurons

BRAIN STEM

THALAMUS

Alpha rhythms are high in dorsal stream **before** visuo-spatial consciousness

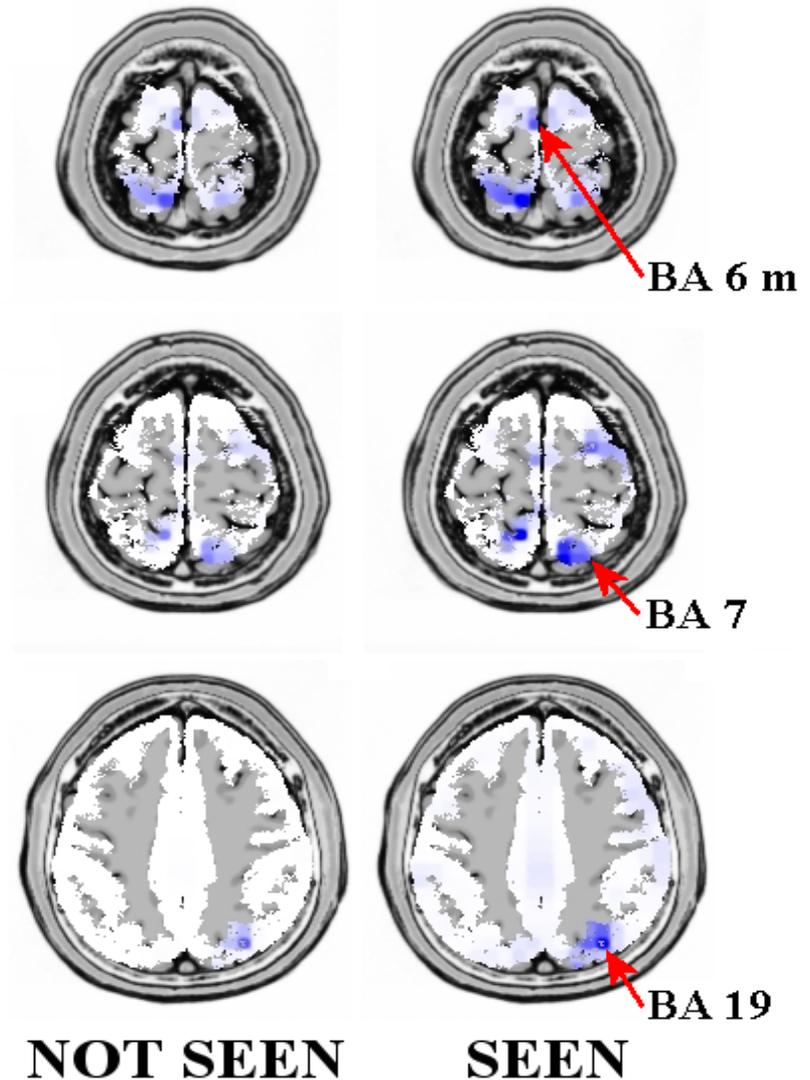
visual stimulus onset
(threshold=50% of seen stimuli)



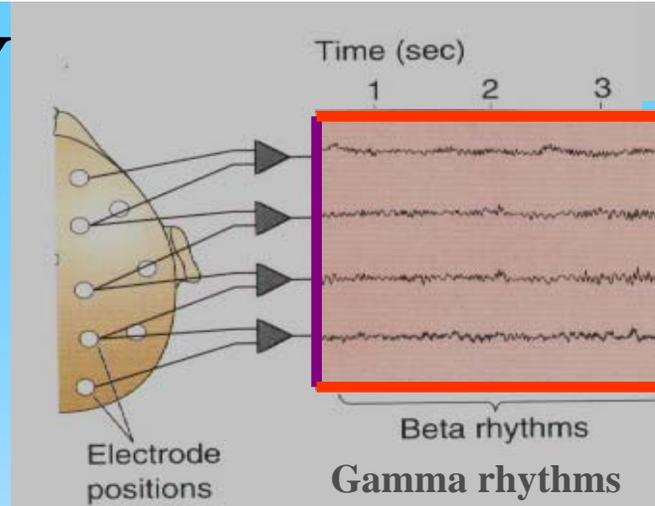
C. Babiloni, F. Vecchio, GL Romani and PM Rossini. Visual-spatial consciousness is related to pre- and post-stimulus alpha rhythms: a high-resolution EEG study. *Cerebral Cortex* 2006

LORETA sources

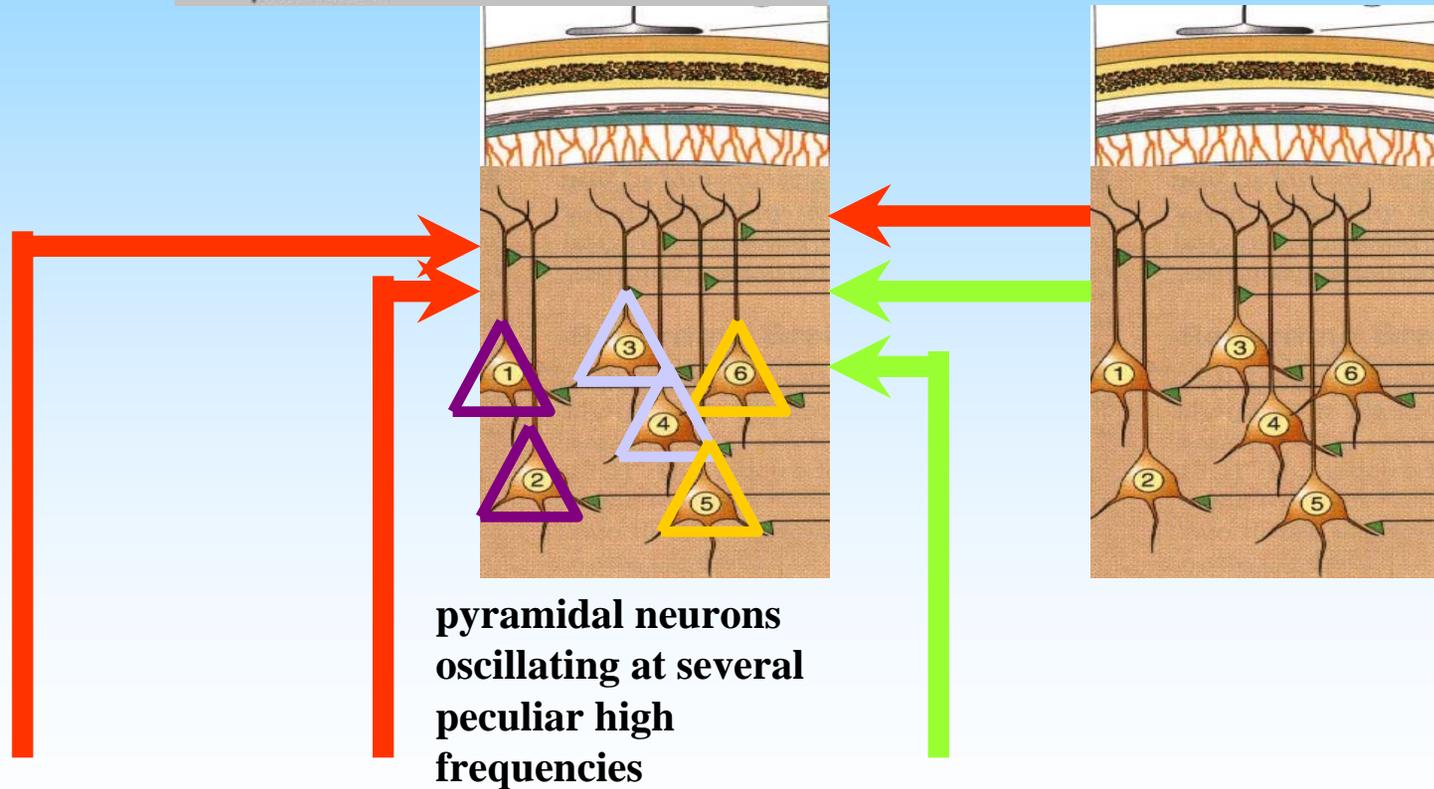
ALPHA 1



ACTIVITY



High-frequency EEG rhythms substitute alpha rhythms during activity



Reticular neurons

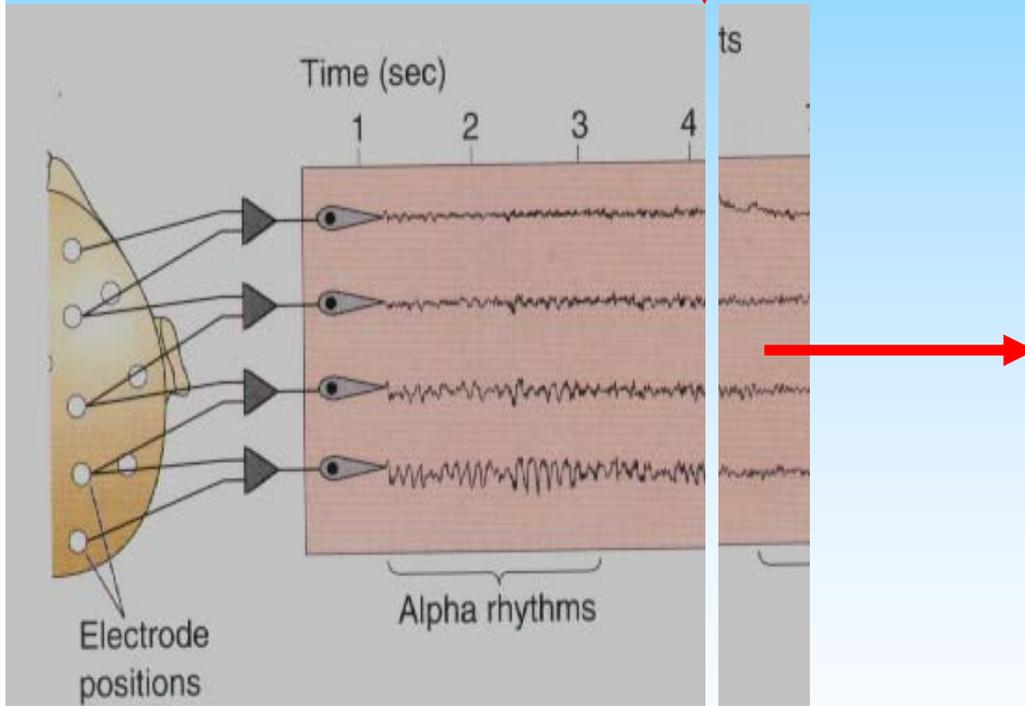
Relay neurons

BRAIN STEM

THALAMUS

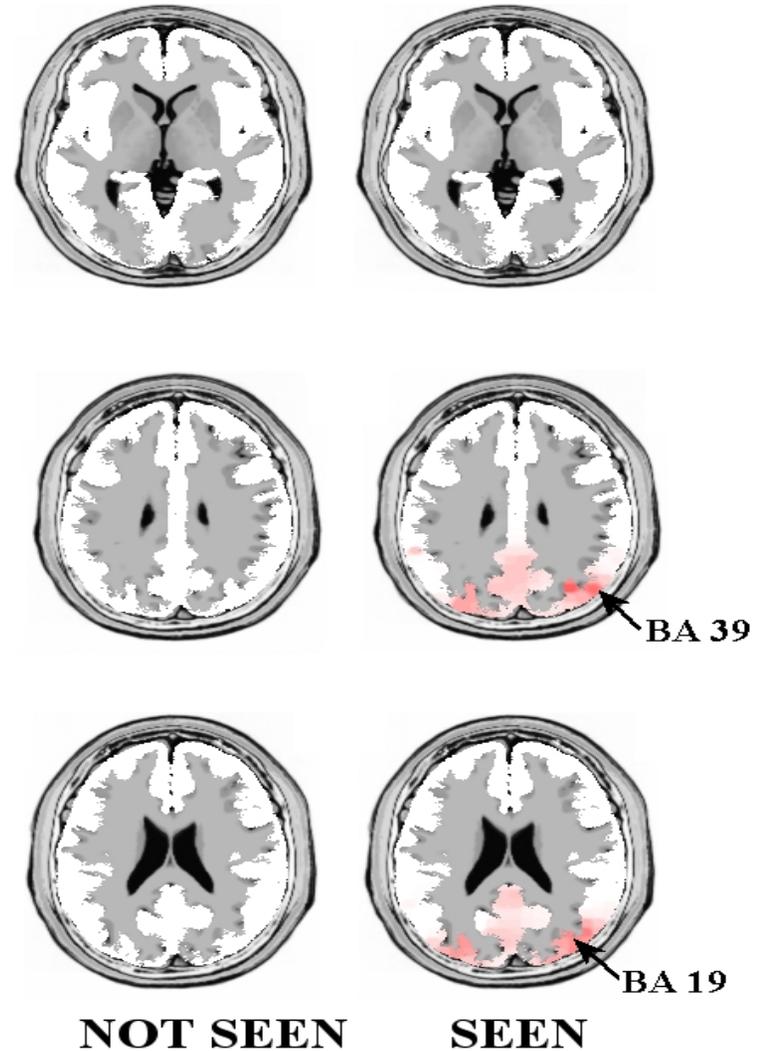
Alpha ERD is high in dorsal stream **during** visuo-spatial consciousness

visual stimulus onset
(threshold=50% of seen stimuli)



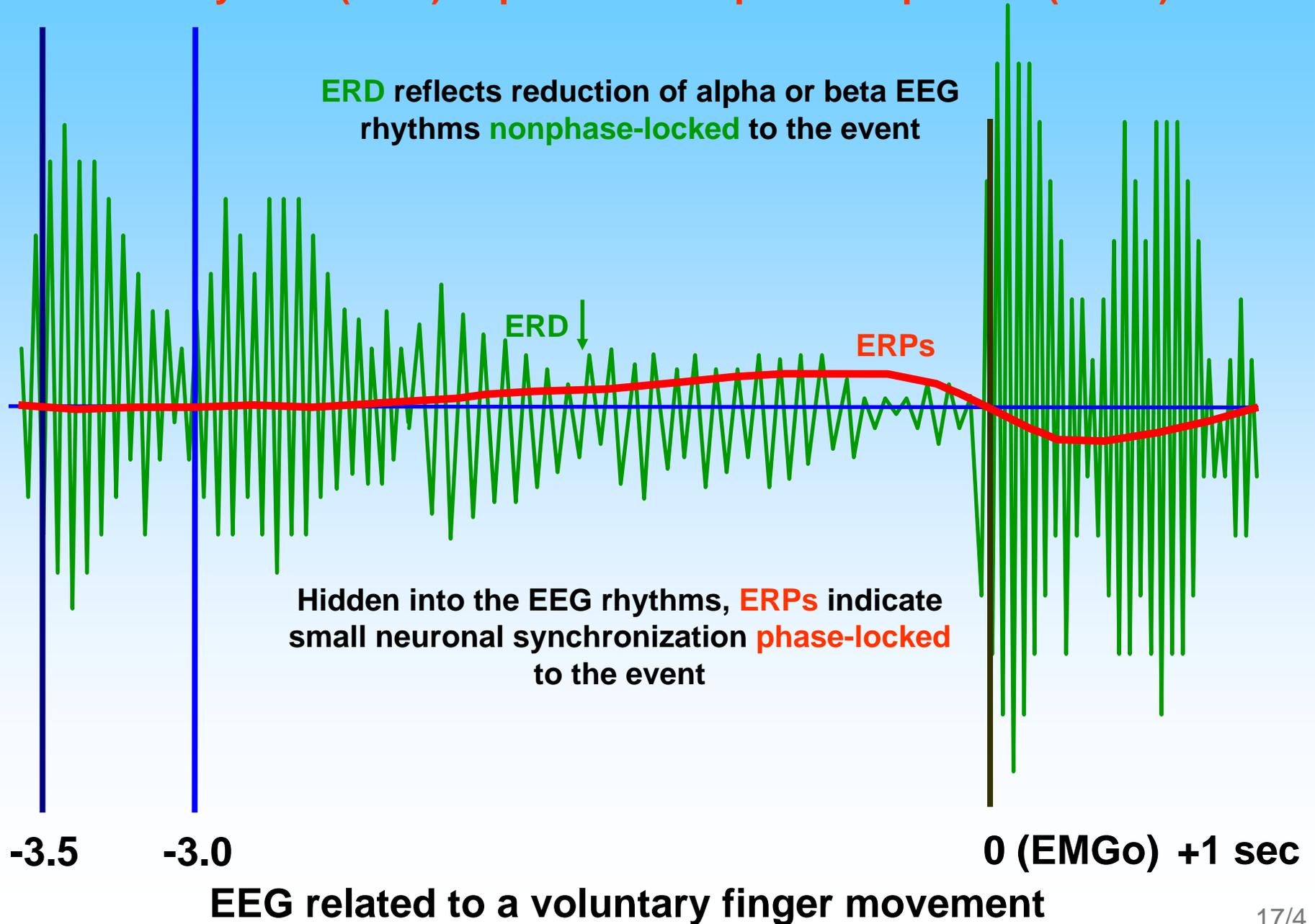
LORETA sources

ALPHA 3



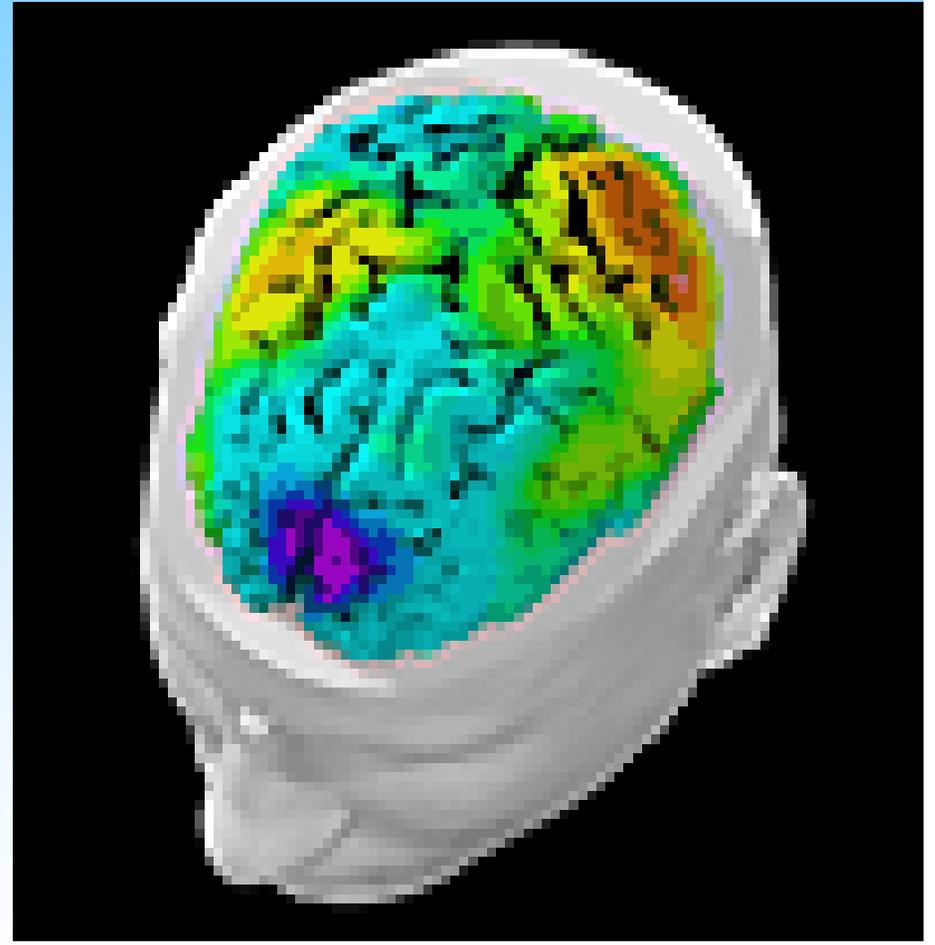
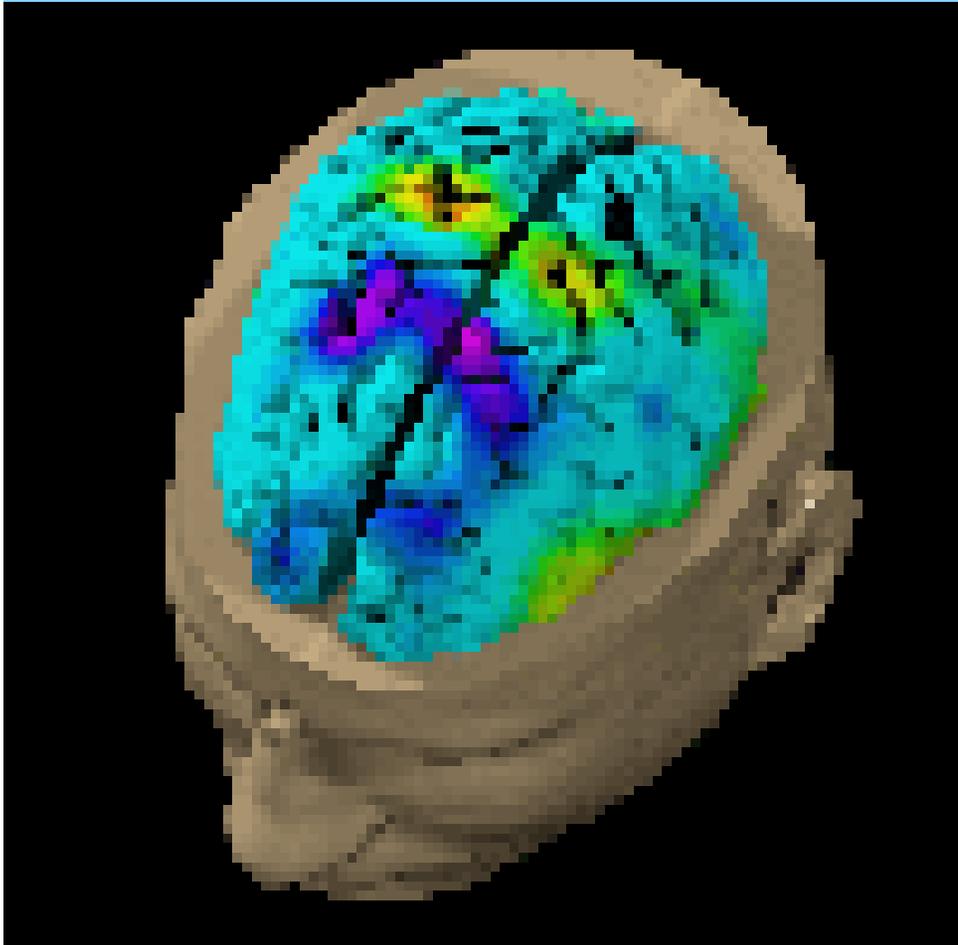
C. Babiloni, F. Vecchio, GL Romani and PM Rossini. Visual-spatial consciousness is related to pre- and post-stimulus alpha rhythms: a high-resolution EEG study. *Cerebral Cortex* 2006

EEG rhythms (ERD) in parallel to impulse responses (ERPs)



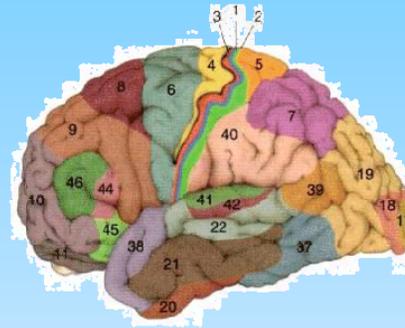
MRP and alpha ERD reveal **different** brain dynamics

From -1 before (movie start) to +0.1 sec post-movement



MRPs Right finger movement **alpha ERD**

Babiloni C. et al., 2000; NeuroImage

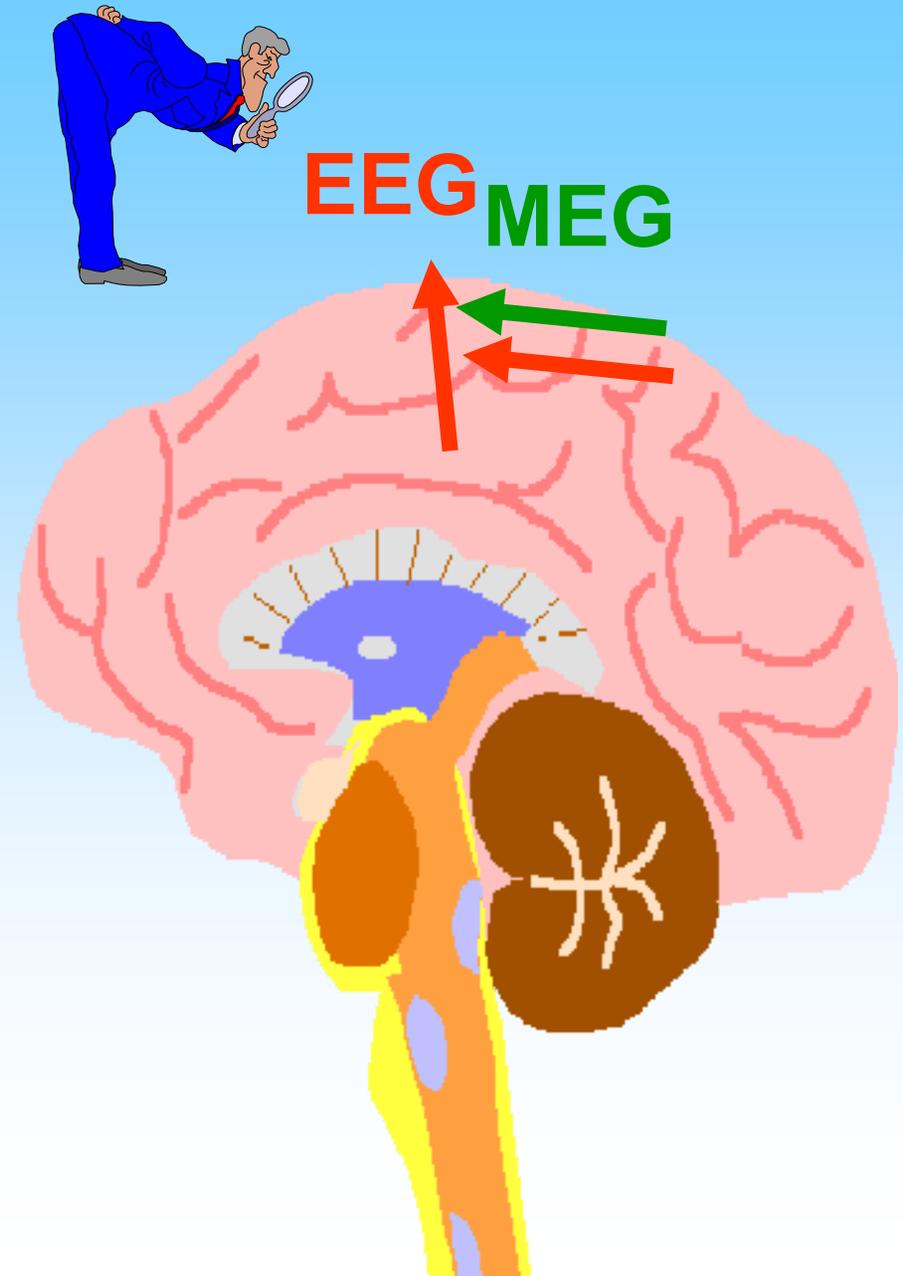


**WHERE ARE THE SOURCES
OF EEG (MEG) SIGNALS?**

Which sources of EEG and MEG?

EEG is sensitive to radial and tangential sources

MEG is the magnetic counterpart of EEG. **MEG** is sensitive **only** to tangential sources (radial + tangential sources cannot be confounded by MEG)



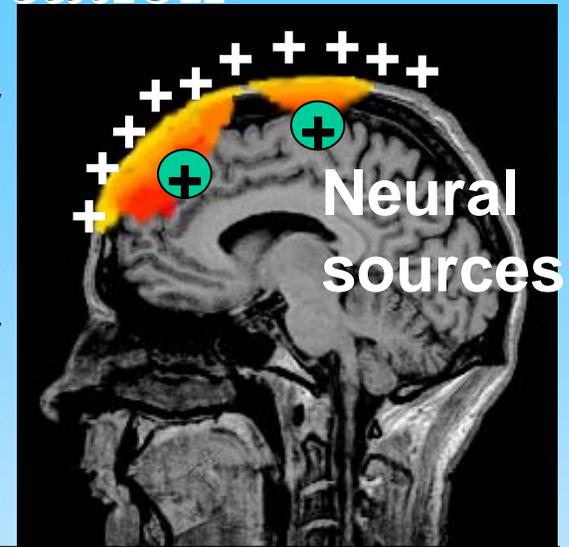
Obstacles to EEG source location



electrical
reference
depresses
near
sources

EEG

poorly
conductive
skull blurs
spatially
scalp
potentials



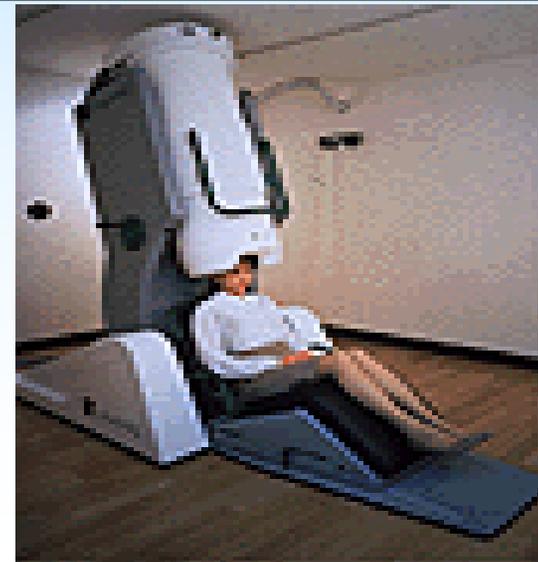
High temporal resolution (ms)

Low spatial resolution (cm)

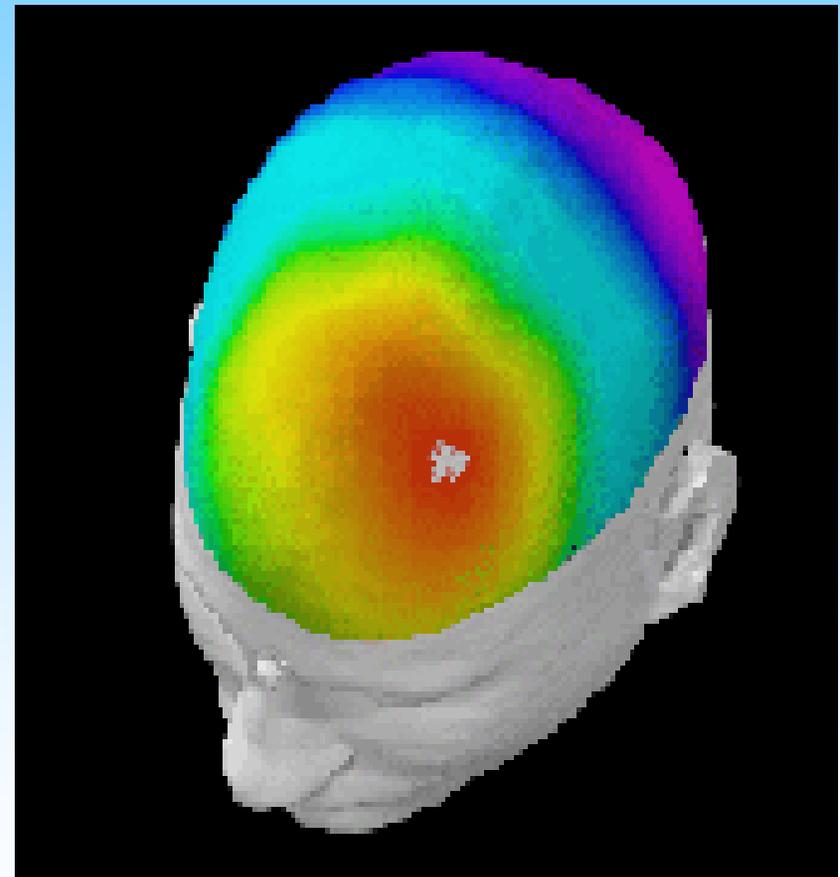
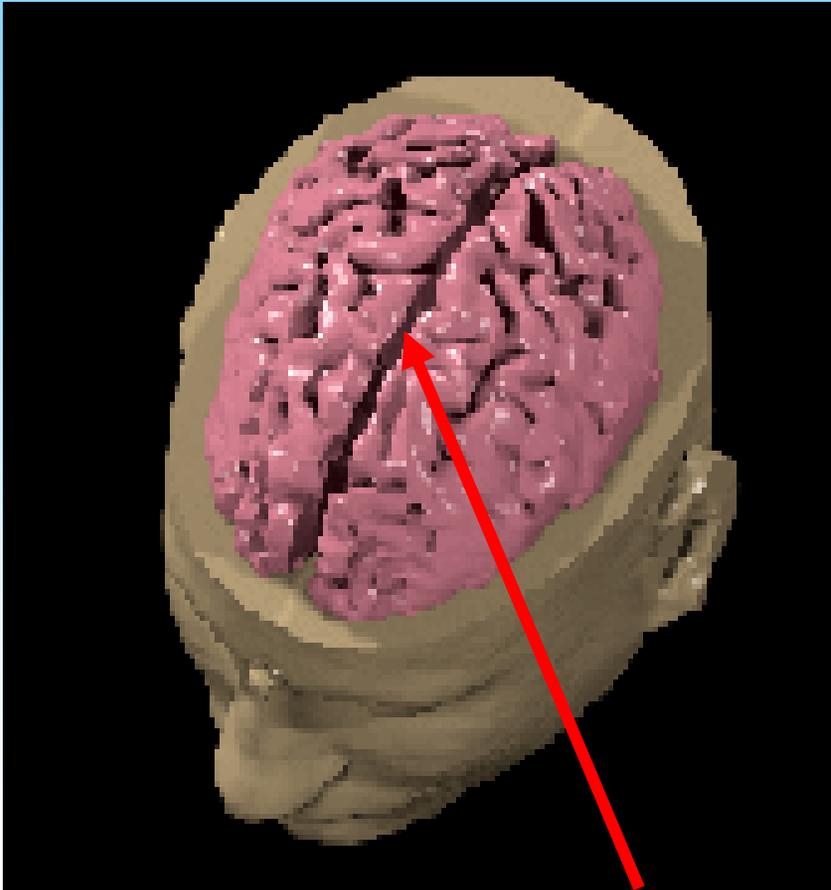


MEG

no reference
effect, transparent
to many tissues.
Relatively higher
spatial resolution



EEG sources by **Surface Laplacian** (no explicit source modeling)

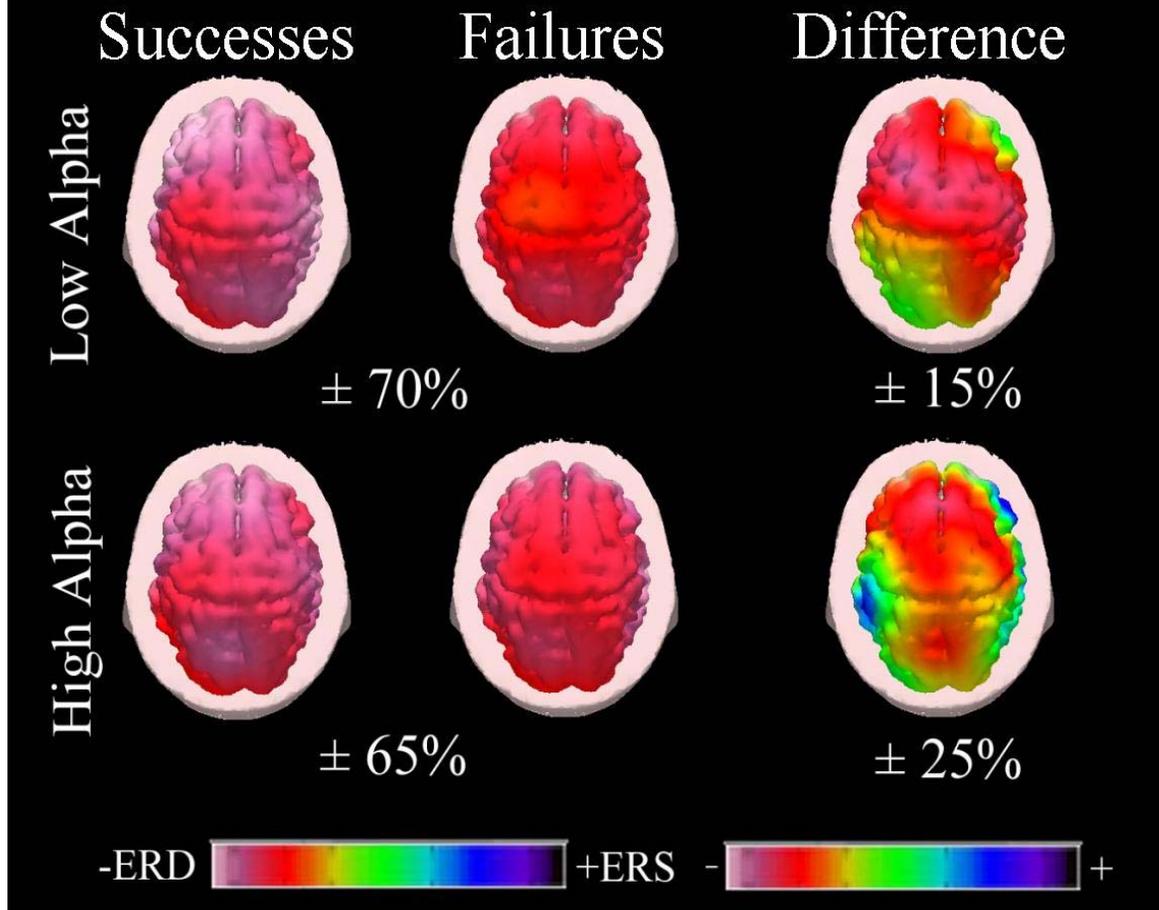


Your speaker has a brain

Right finger movement

Laplacian mapping: amplitude of alpha ERD over frontal midline and right primary sensorimotor areas was stronger in expert golfers in successful than unsuccessful putts

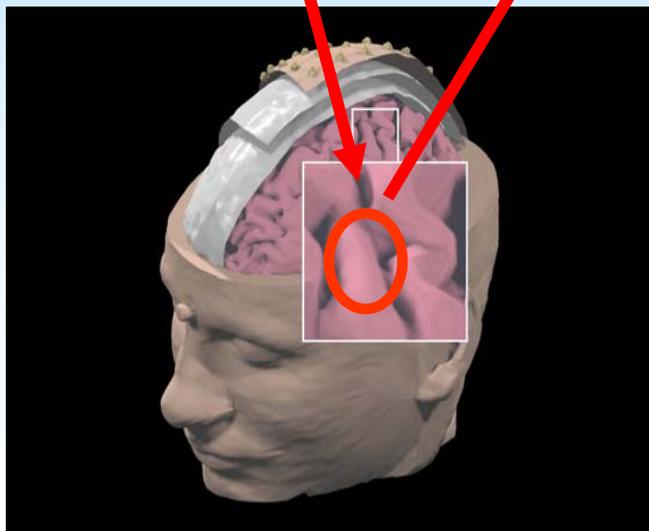
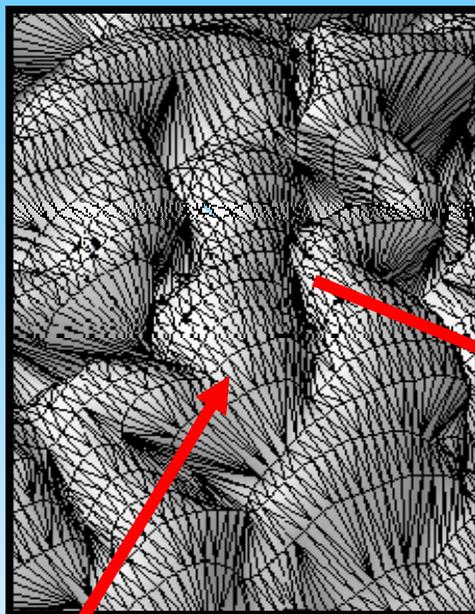
ERD/ERS DURING GOLF PUTTS



Claudio Babiloni, Claudio Del Percio, Francesco Infarinato, Nicola Marzano, Marco Iacoboni, Pierluigi Aschieri, Fabrizio Eusebi: Sensorimotor rhythms related to precise golf putts: a high resolution EEG study Journal of Physiology, 2008

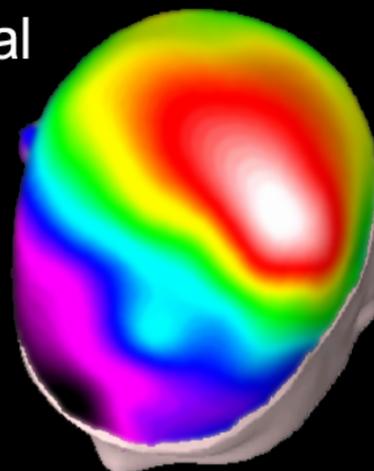
Distributed source estimation: thousands of dipoles

Scalp EEG

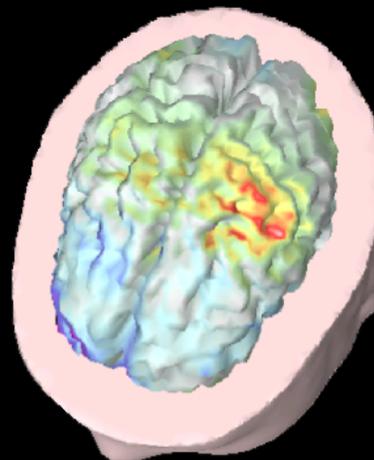


Right finger
movement
(EMGo)

Potential

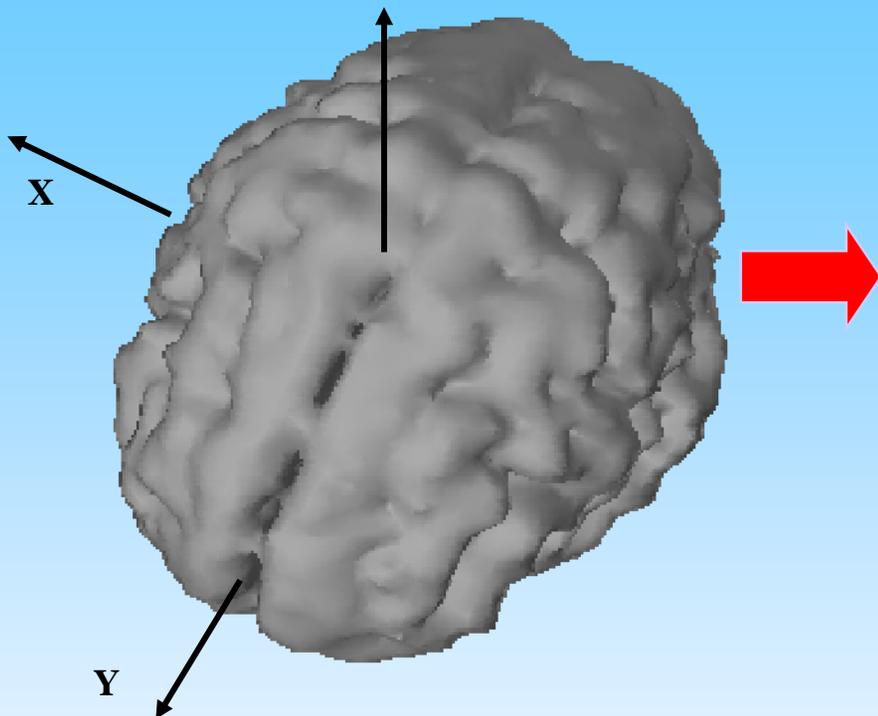


LE



“Virtual” electrode Babiloni C. et al., 2002 in Recent advances in Clinical Neurophysiology

Towards an EEG/MEG tomography: **LORETA** (Low Resolution Electromagnetic Tomography)



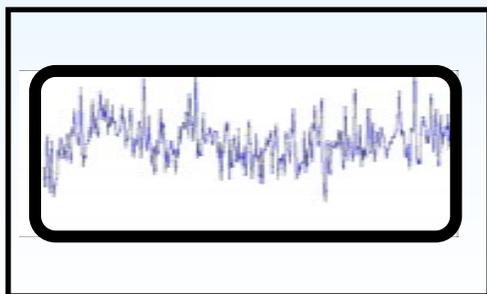
3-D linear solutions

Three shell-spherical head model

Co-registered to Talarach brain atlas

LORETA sources= **2.394 voxels** (7 mm resolution) each containing an **equivalent current dipole**

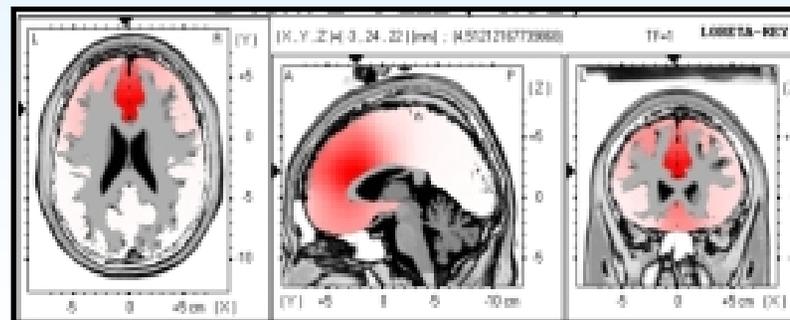
EEG/MEG data



Inverse linear estimation

Matrix inversion regularization through minimization of the Laplacian solution at sources

Visualization of 3-D LORETA solutions

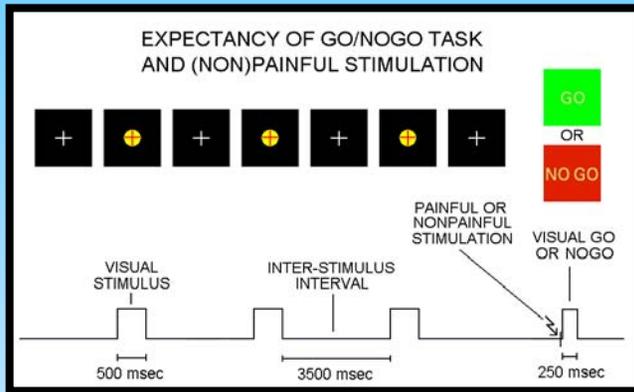


Axial

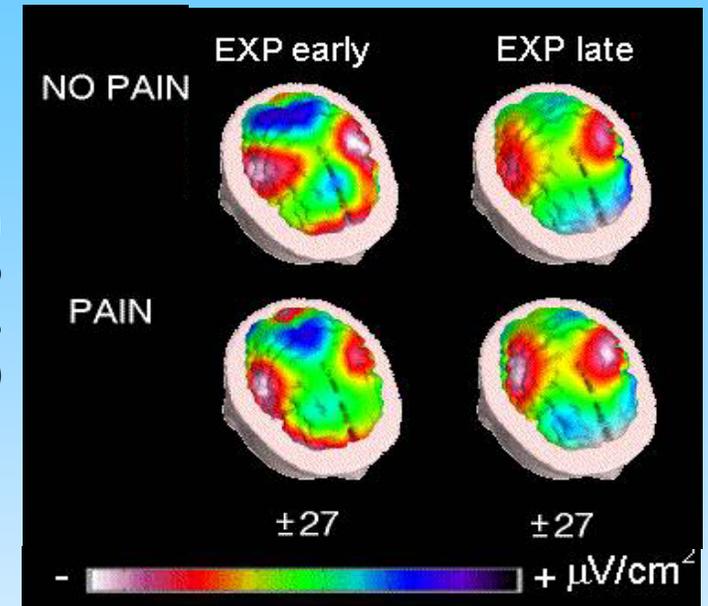
Sagittal

Coronal

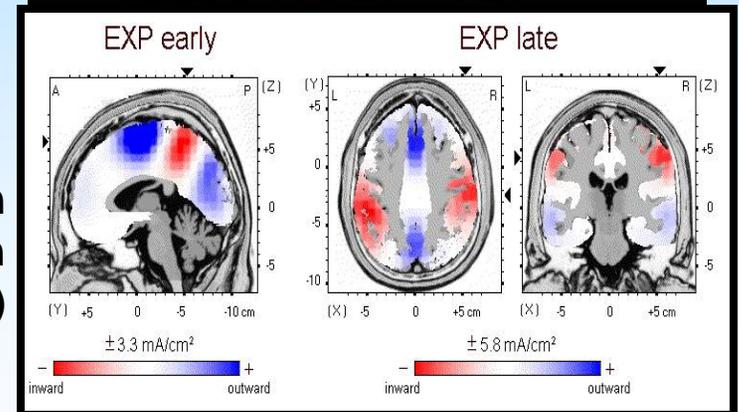
source estimation by independent EEG techniques (i.e. **Laplacian**, **LORETA**) and multi-modal approaches (EEG, MEG, fMRI)



CNV generators in the painful and no pain conditions (**Laplacian**)



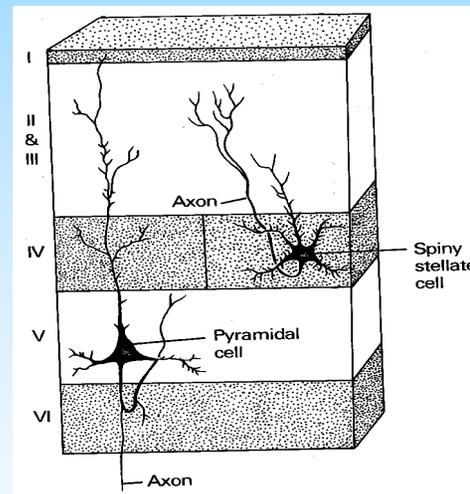
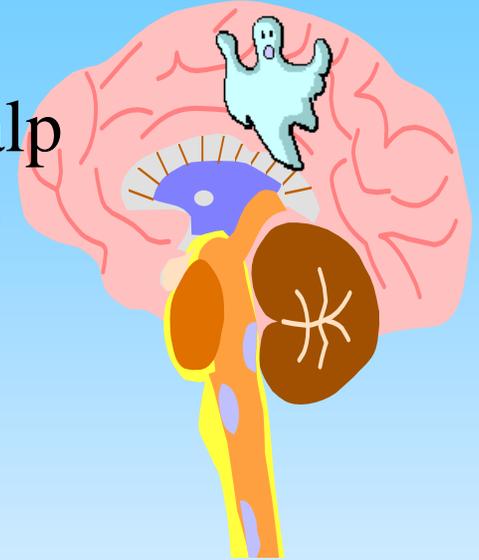
CNV generators in the painful condition (**LORETA**)



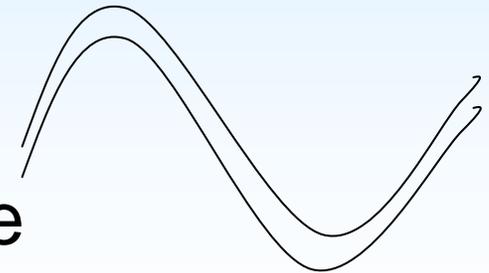
Babiloni C, Brancucci A, Capotosto P, Romani GL, Arendt-Nielsen L, Chen ACN, Rossini PM, Slow cortical potential shifts preceding sensorimotor interactions. *Brain Research Bulletin* 2005.

Does a unique “activation map” exist?

Stellate neurons (15% of neocortical neurons): strong metabolic/rCBF but no scalp EEG (closed “ghost” electromagnetic fields)



Pyramidal neurons: 1% of synchronously active neurons produce 95% of scalp EEG



Parallel but different physiological processes are captured by fMRI and EEG-MEG

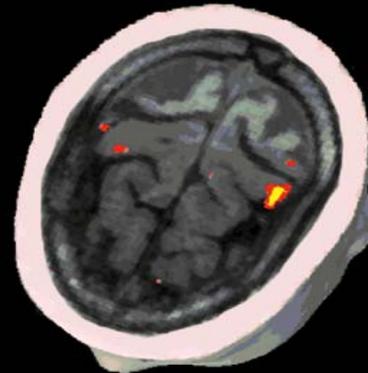
fMRI (blood/oxygen supply)

MRPs (excitability, event-phase locking)

ERD (ThC channels, brain rhythms)

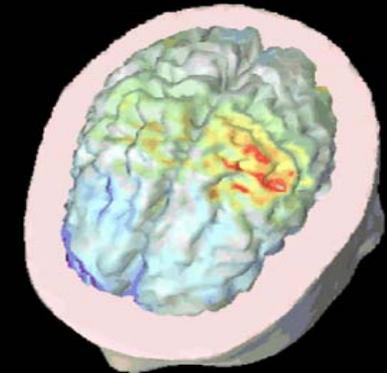
SELF-PACED RIGHT MOVEMENT

fMRI



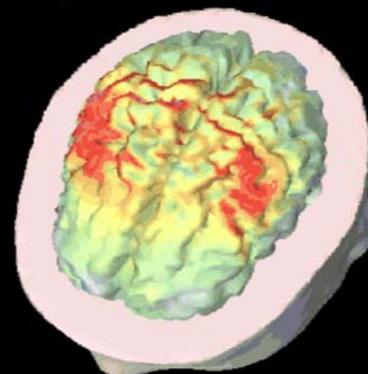
0%  4%

MRPs (EMGo)

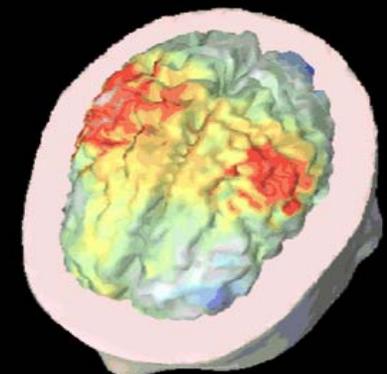


-100%  100%

alpha ERD



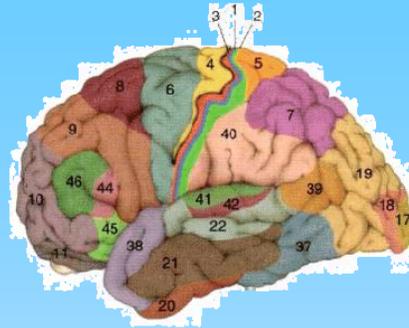
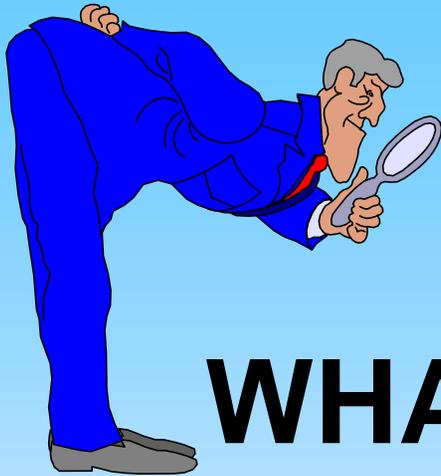
beta ERD



ERD  ERS

ERD  ERS

Babiloni C., Babiloni F., Carducci F., Cincotti F, Del Percio C., Hallett M., Moretti D.V., Romani G.L. and Rossini P.M.
“High Resolution EEG of Sensorimotor Brain Functions: Mapping ERPs or Mu ERD?” Advances in Clinical Neurophysiology (Supplements to Clinical Neurophysiology Vol. 54: 365-371) Editors: R.C. Reisin, M.R. Nuwer, M. Hallett, C. Medina, 2002, Shannon, Ireland, Elsevier Science B.V.



**WHAT ABOUT “THE
NETWORK”?
THE ISSUE OF
FUNCTIONAL
CONNECTIVITY**

Neural networks integrate their activity by linear and non-linear functional coupling of EEG rhythms

Linear coupling

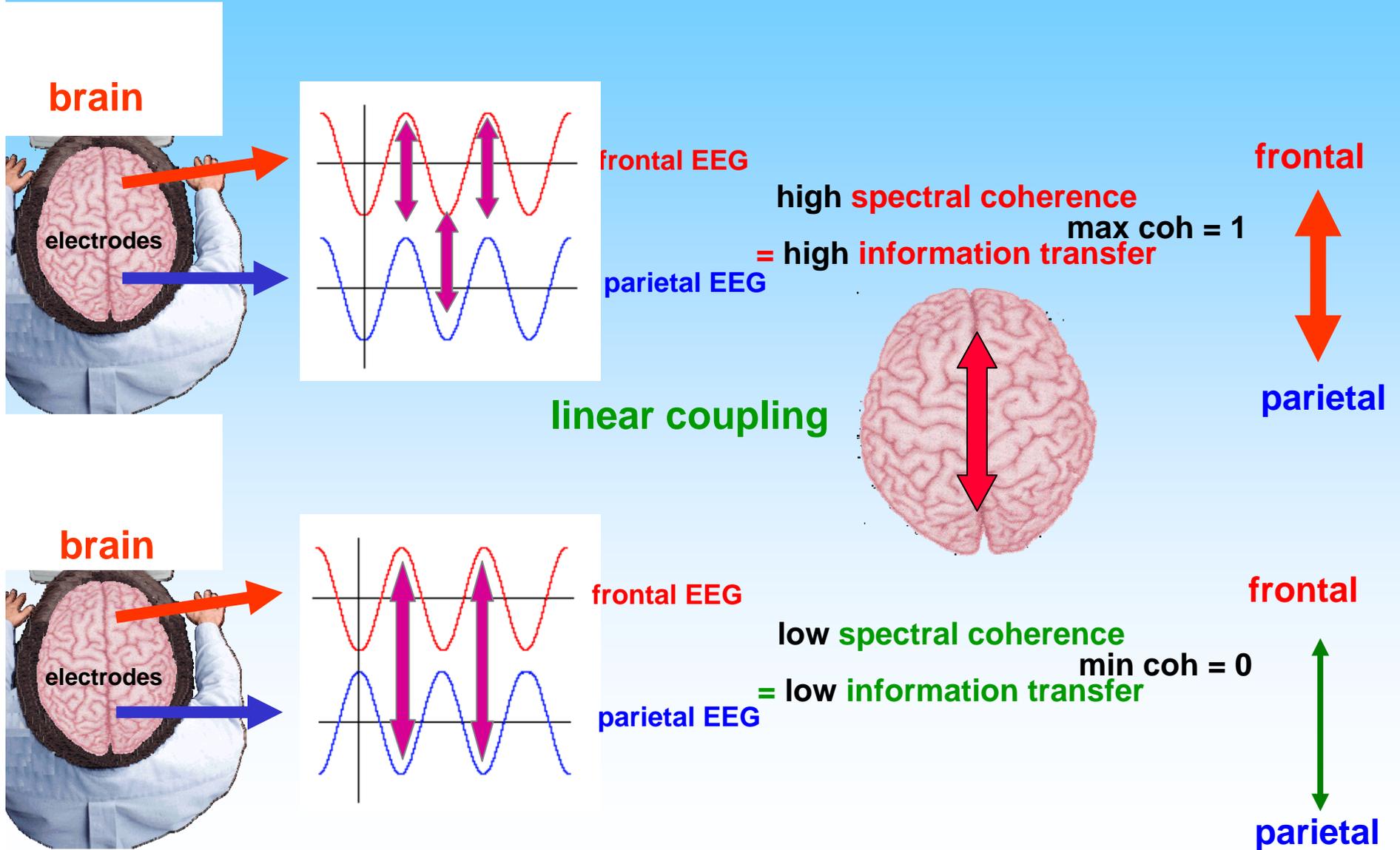


Non-linear coupling

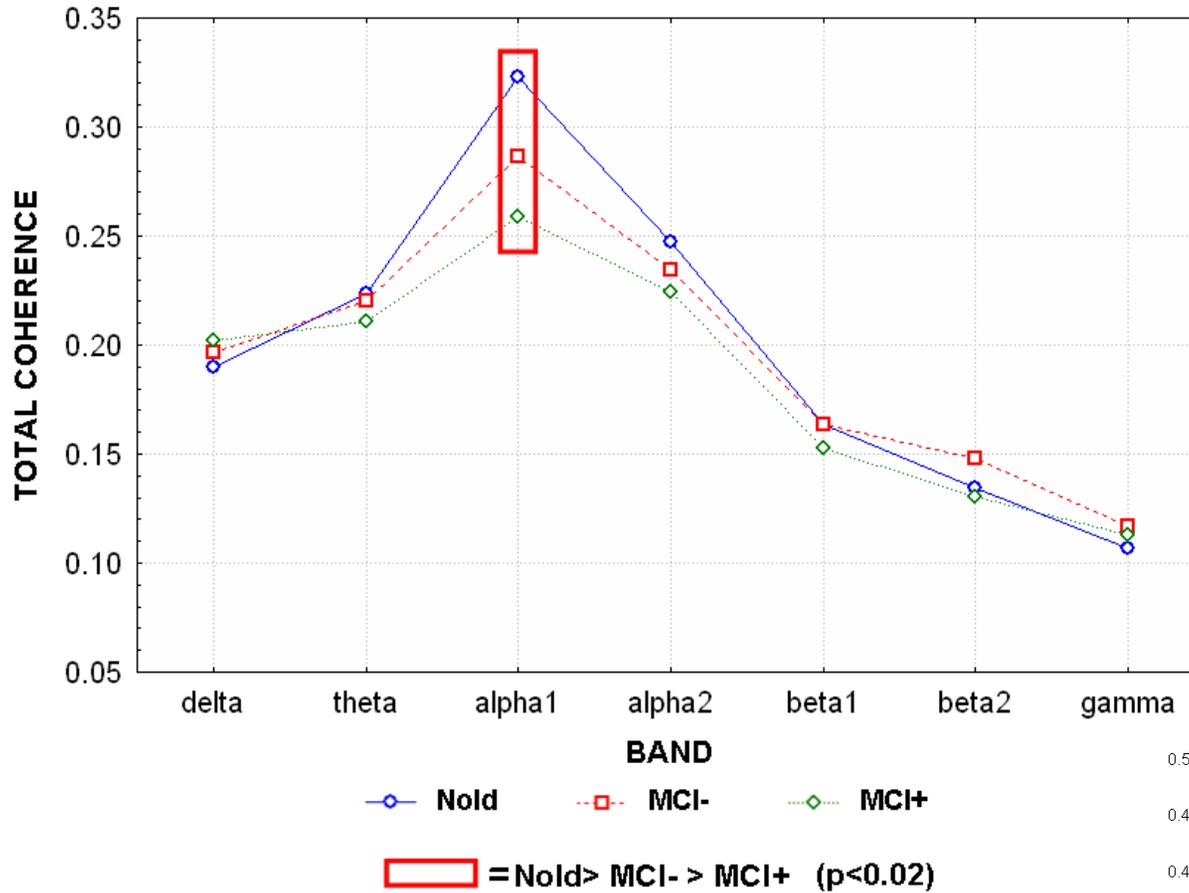


Both should be considered

Linear temporal synchronization (coherence) of EEG rhythms at electrode pairs as an index of functional cortico-cortical coupling (information transfer)



STATISTICAL ANOVA INTERACTION between GROUP and BAND



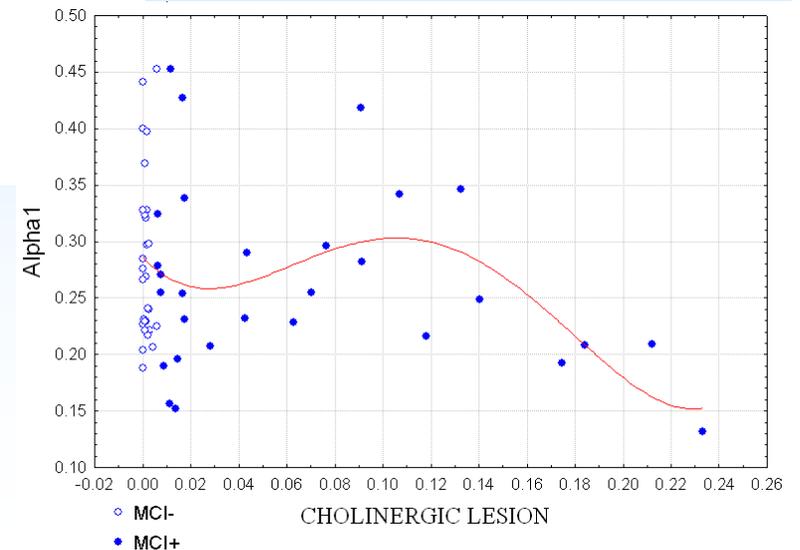
Resting EEG
data:

28 Nold

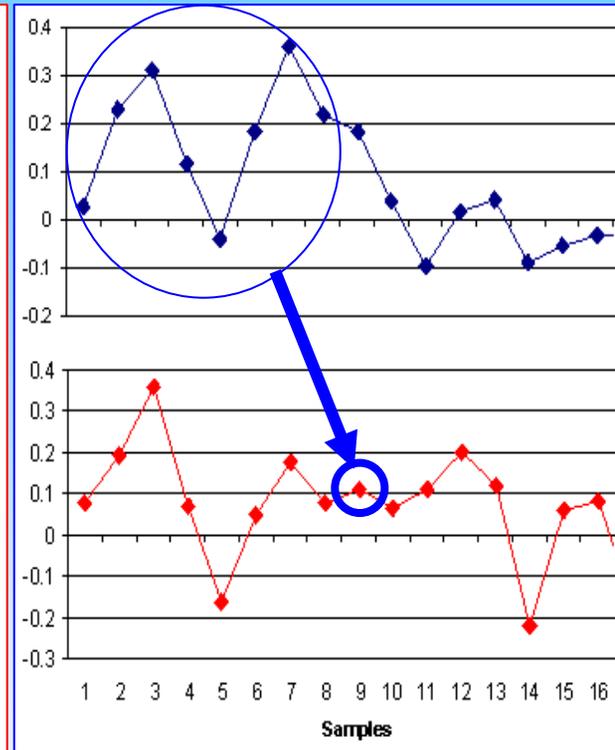
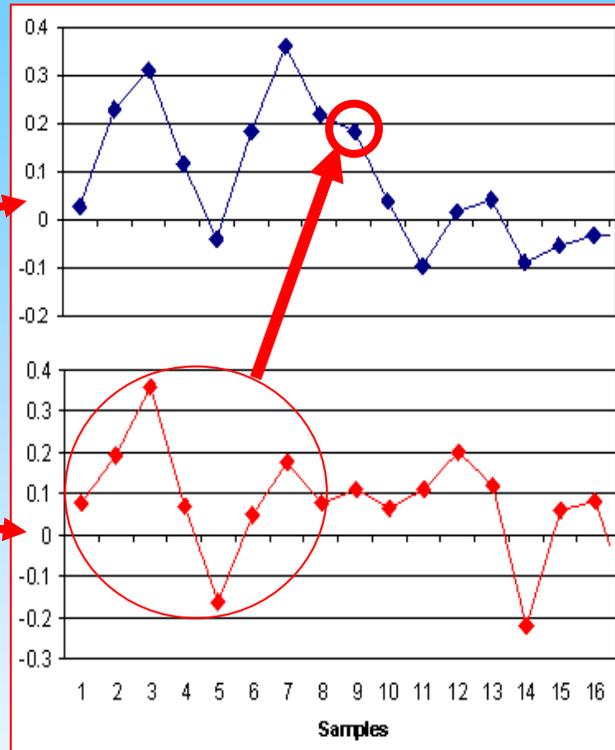
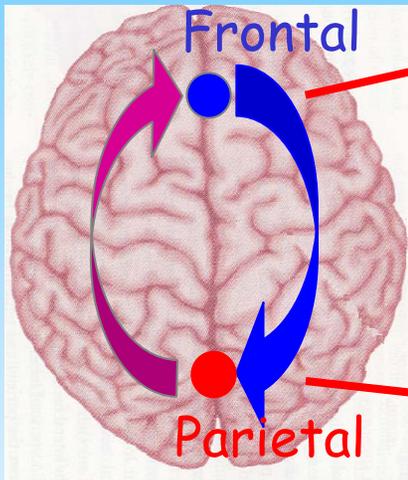
29 MCI ACh-
(MCI C-)

28 MCI ACh+
(MCI C+)

Babiloni Claudio, Frisoni Giovanni B, Vecchio Fabrizio, Pievani Michela, Geroldi Cristina, De Carli Charles, Ferri Raffaele, Lizio Roberta, and Rossini Paolo M. Global functional coupling of resting EEG rhythms is related to white-matter lesions along the cholinergic tracts in subjects with amnesic mild cognitive impairment. Journal of Alzheimer's Disease (under review)

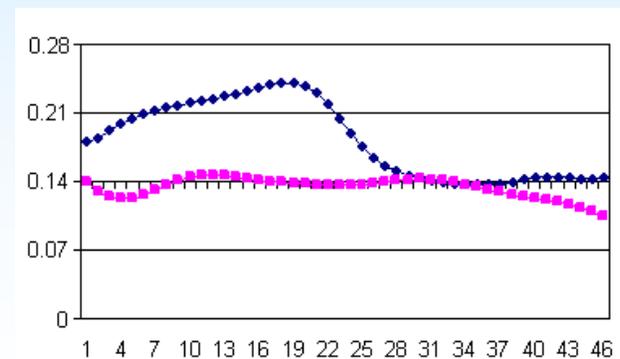


“Directionality” (directed transfer function, DTF) of EEG rhythms at electrode pairs reflects **fluxes of information** within cortico-cortical coupling



$$DTF_{ij}(F) = \frac{|H_{ij}|^2}{\sum_{m=1}^L |H_{im}(f)|^2}$$

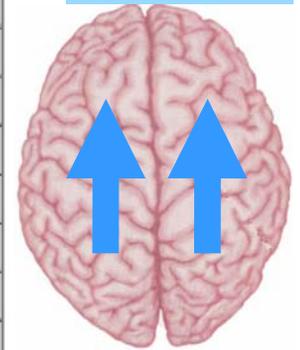
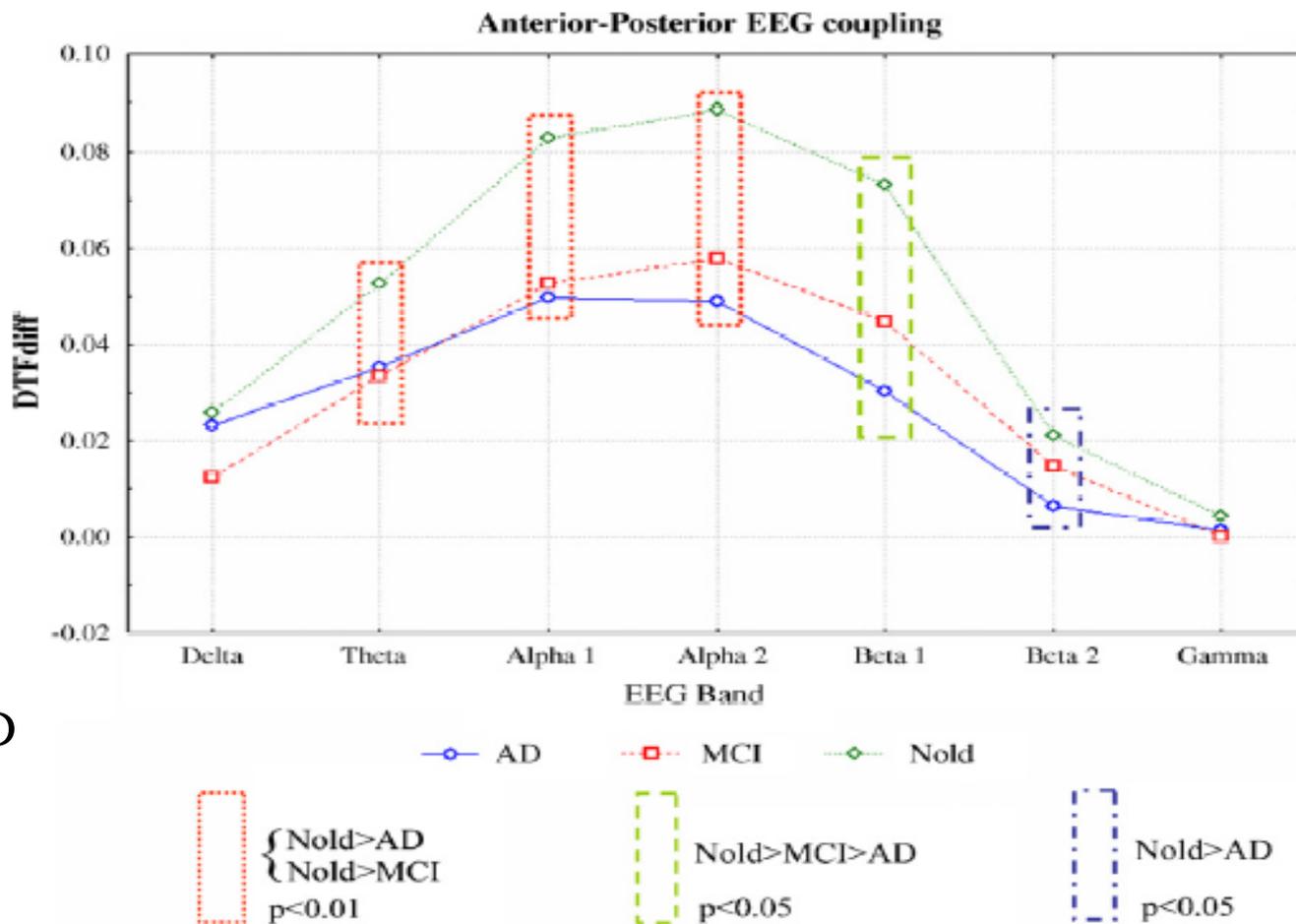
MVAR model estimates “**direction**” of information flow by DTF



Probability of prediction

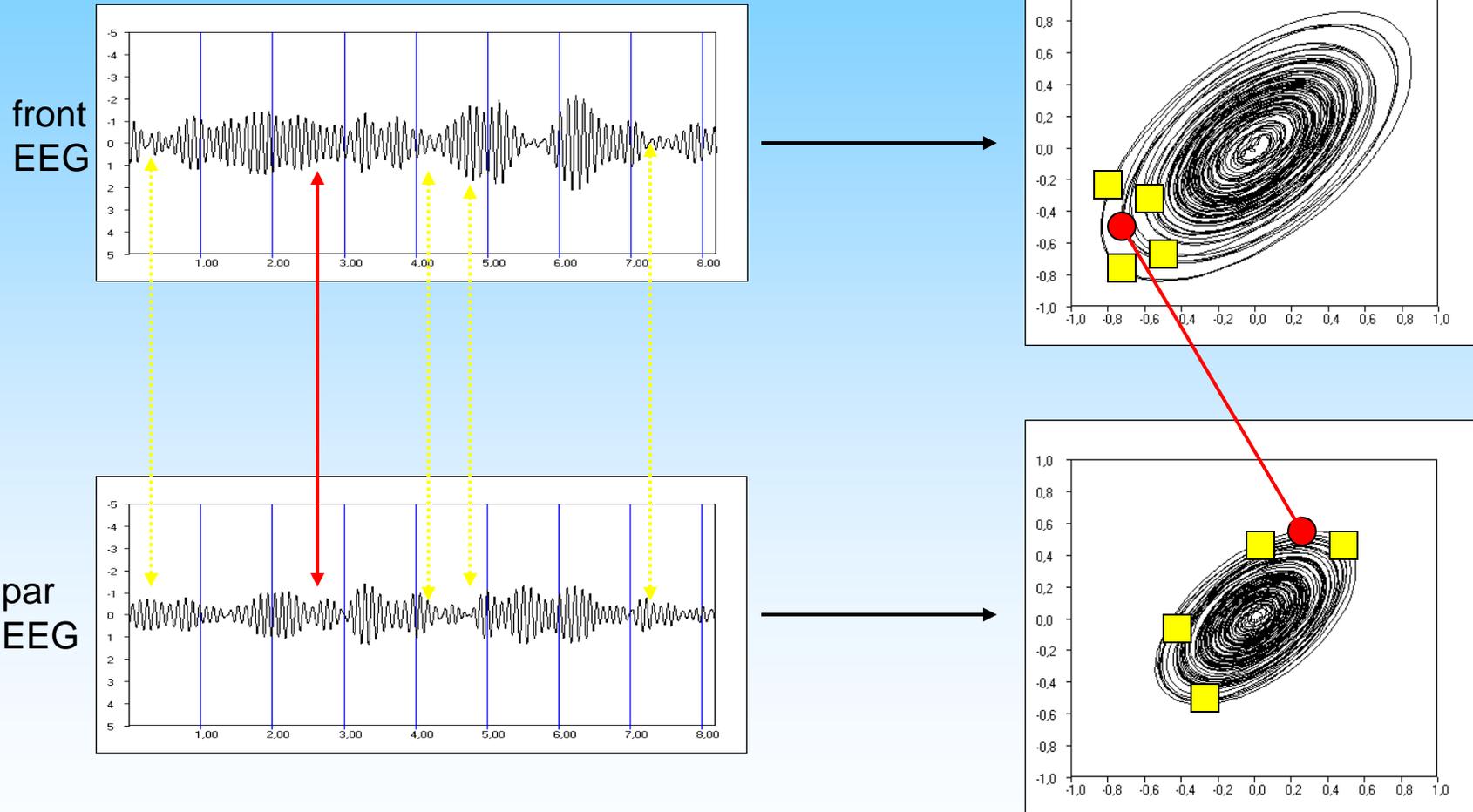
Parietal to frontal direction of the information flux within EEG functional coupling was stronger in Nold than in MCI and/or AD subjects

Resting
EEG data:
64 Nold
67 MCI
73 mild AD



Synchronization likelihood measures linear plus non-linear functional coupling of EEG rhythms

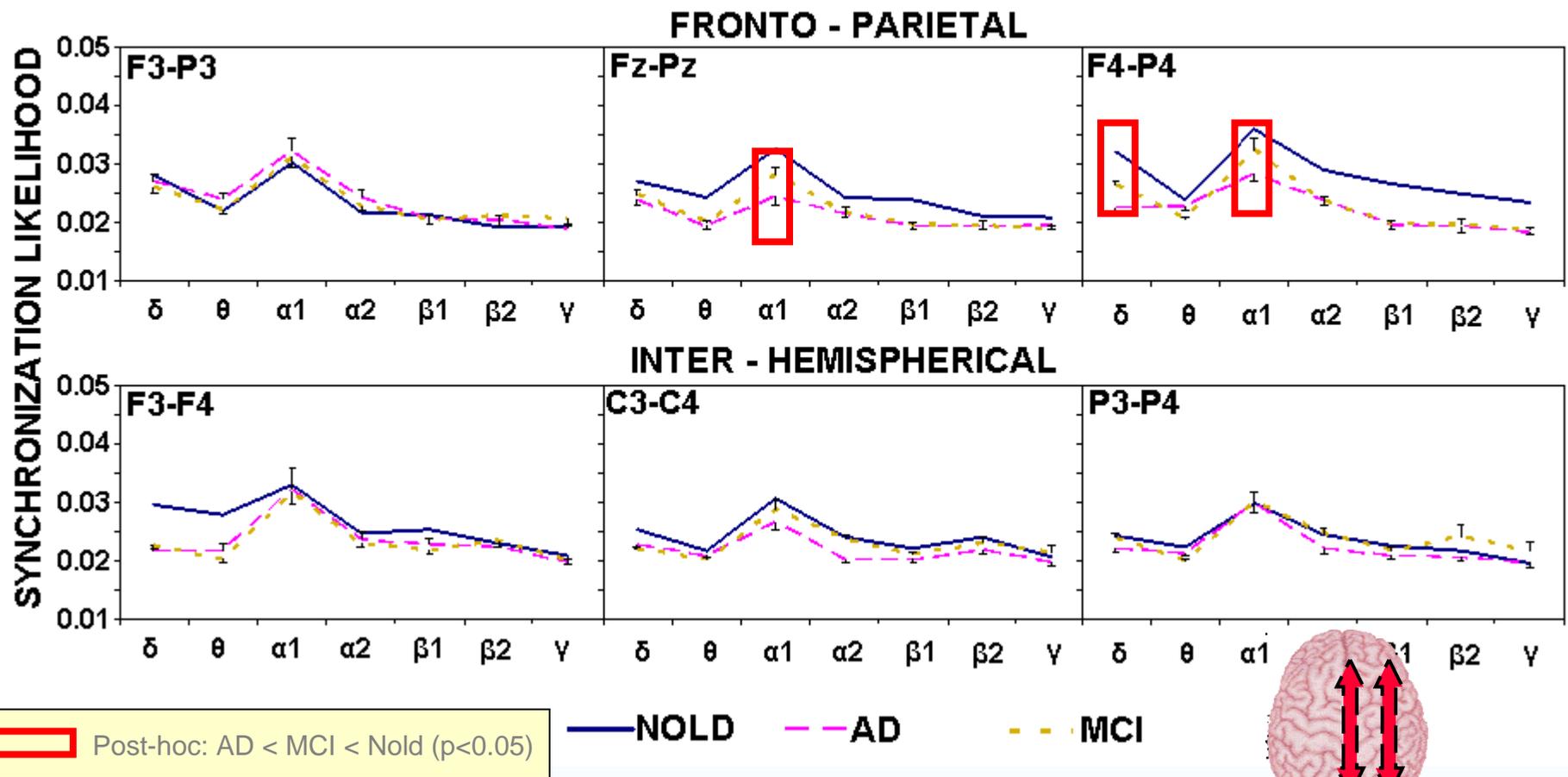
Measure of the synchronization between two signals sensitive also to nonlinear coupling



Stam, C.J., van Dijk, B.W., 2002. Synchronization likelihood: An unbiased measure of generalized synchronization in multivariate data sets. *Physica D*, 163: 236-241.).

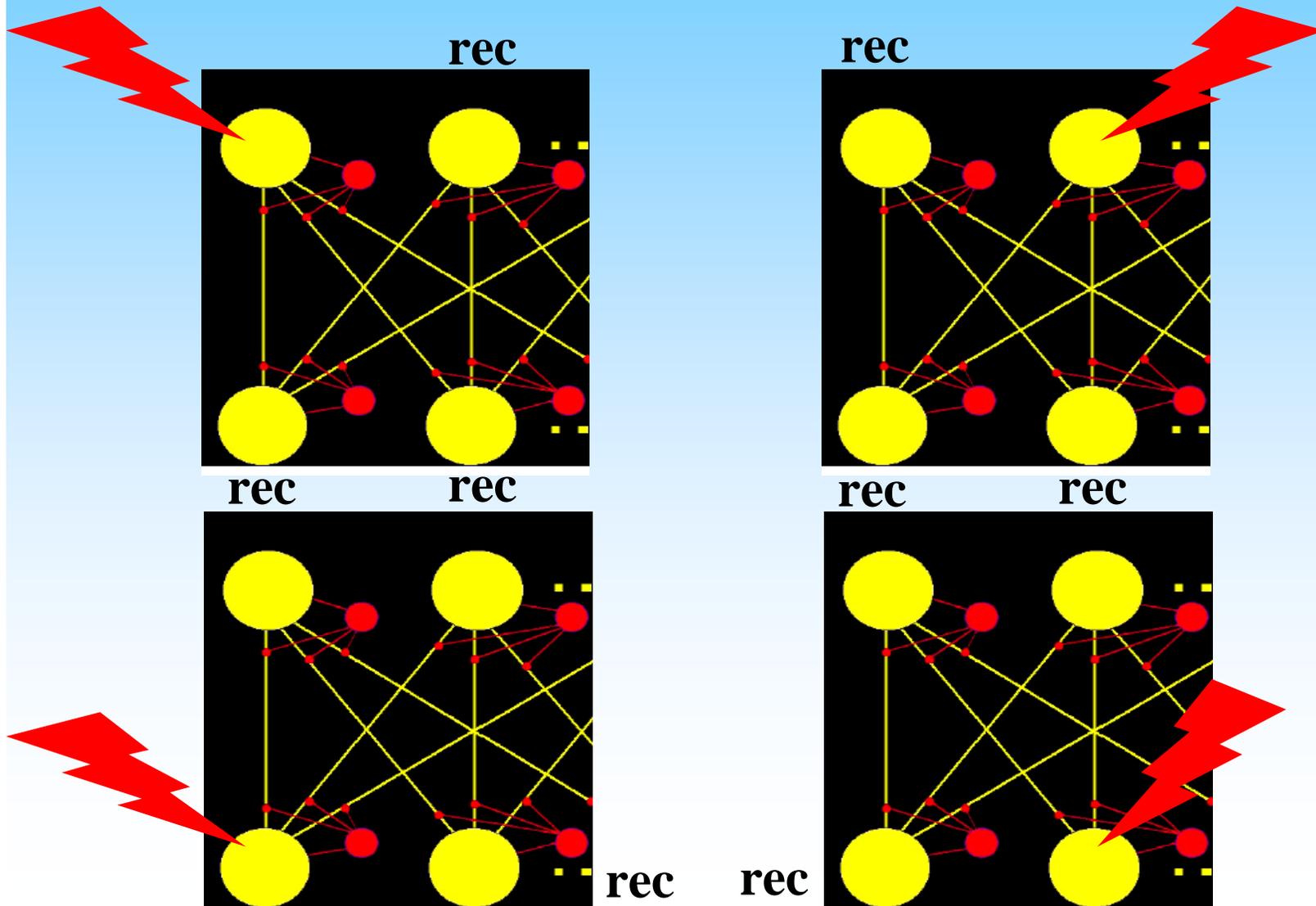
Synchronization likelihood

LAPLACIAN RESTING EEG IN NOLD, AD AND MCI SUBJECTS

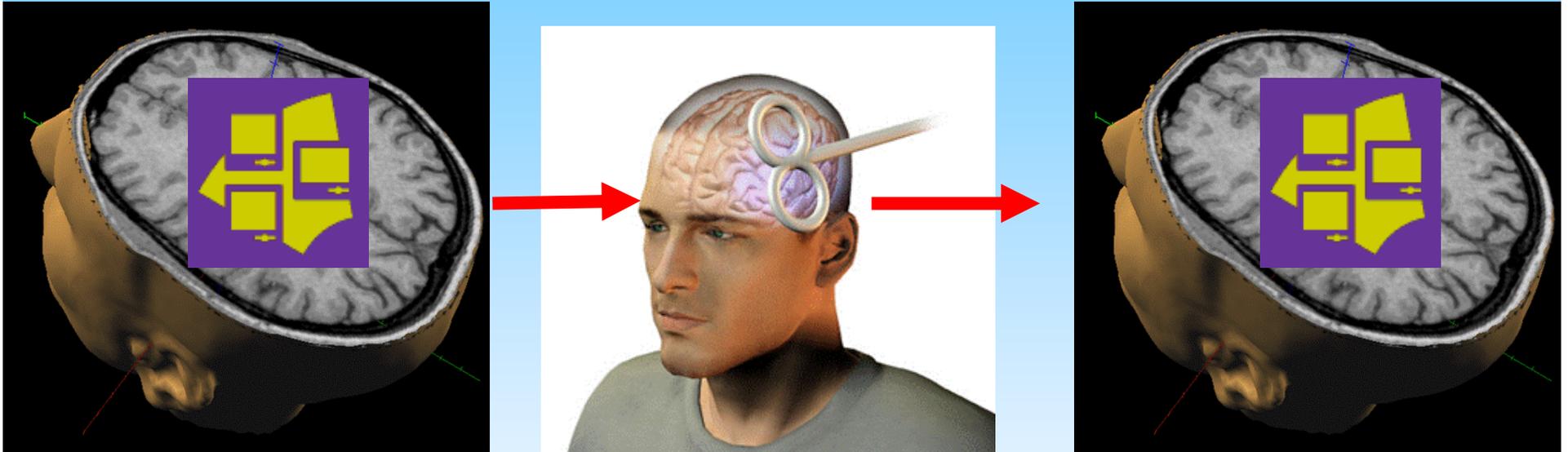


Babiloni C, Ferri R, Binetti G, Cassarino A, Dal Forno G, Ercolani M, Ferreri F, Frisoni GB, Lanuzza B, Miniussi C, Nobili F, Rodriguez G, Rundo F, Stam CJ, Musha T, Vecchio F, Rossini PM. Fronto-parietal coupling of brain rhythms in mild cognitive impairment: a multicentric EEG study. *Brain Res Bull.* 2006 Mar 15;69(1):63-73.

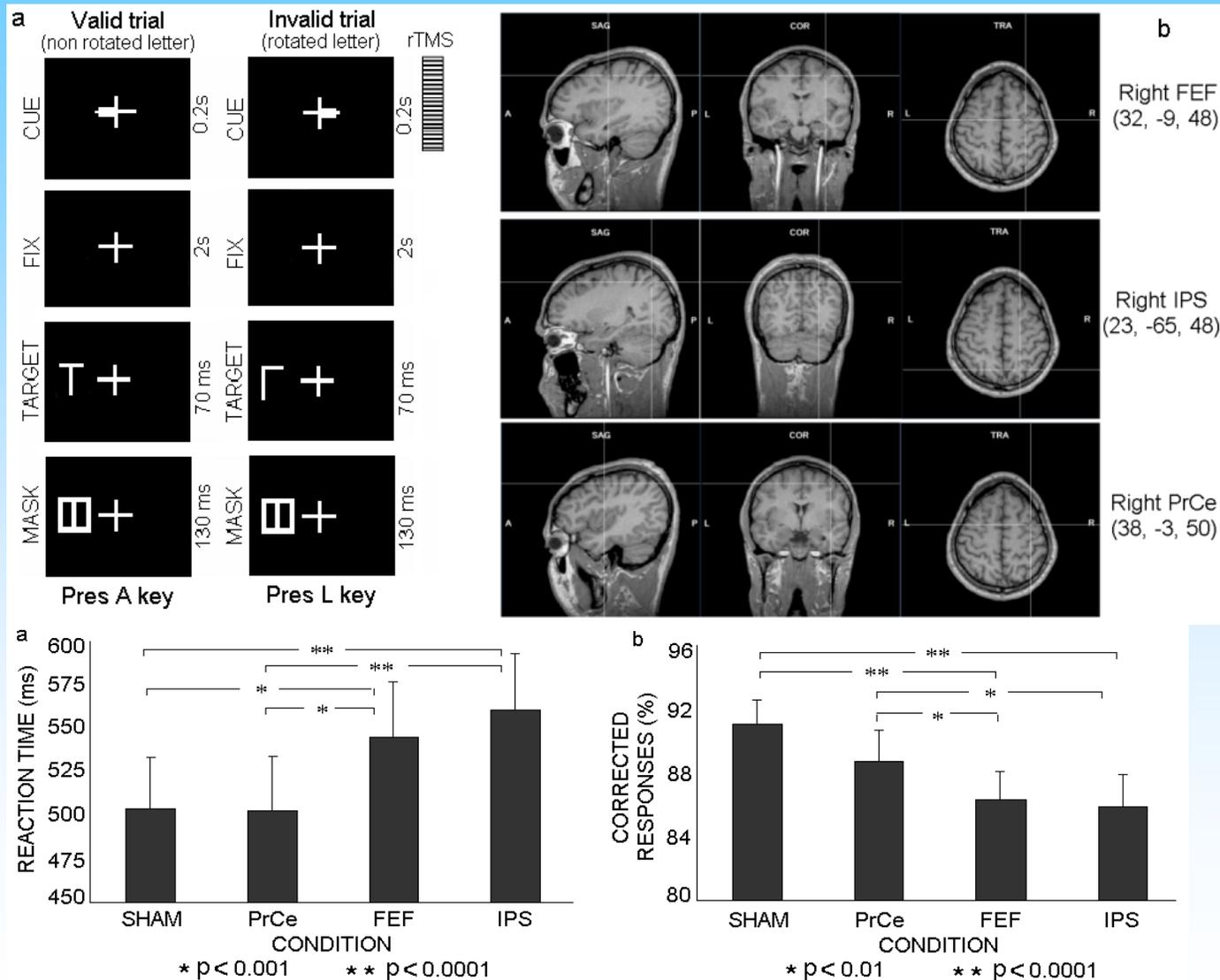
Effective connectivity: exploring the features of brain network by the perturbation of the nodes and the recording of the effects on the non-stimulated nodes



Repetitive transcranial magnetic stimulation (**TMS**) is able to interfere with the cortical information processes, testing the role of the stimulated cortical region in the **neural synchronization** generating EEG and **cognitive performance**

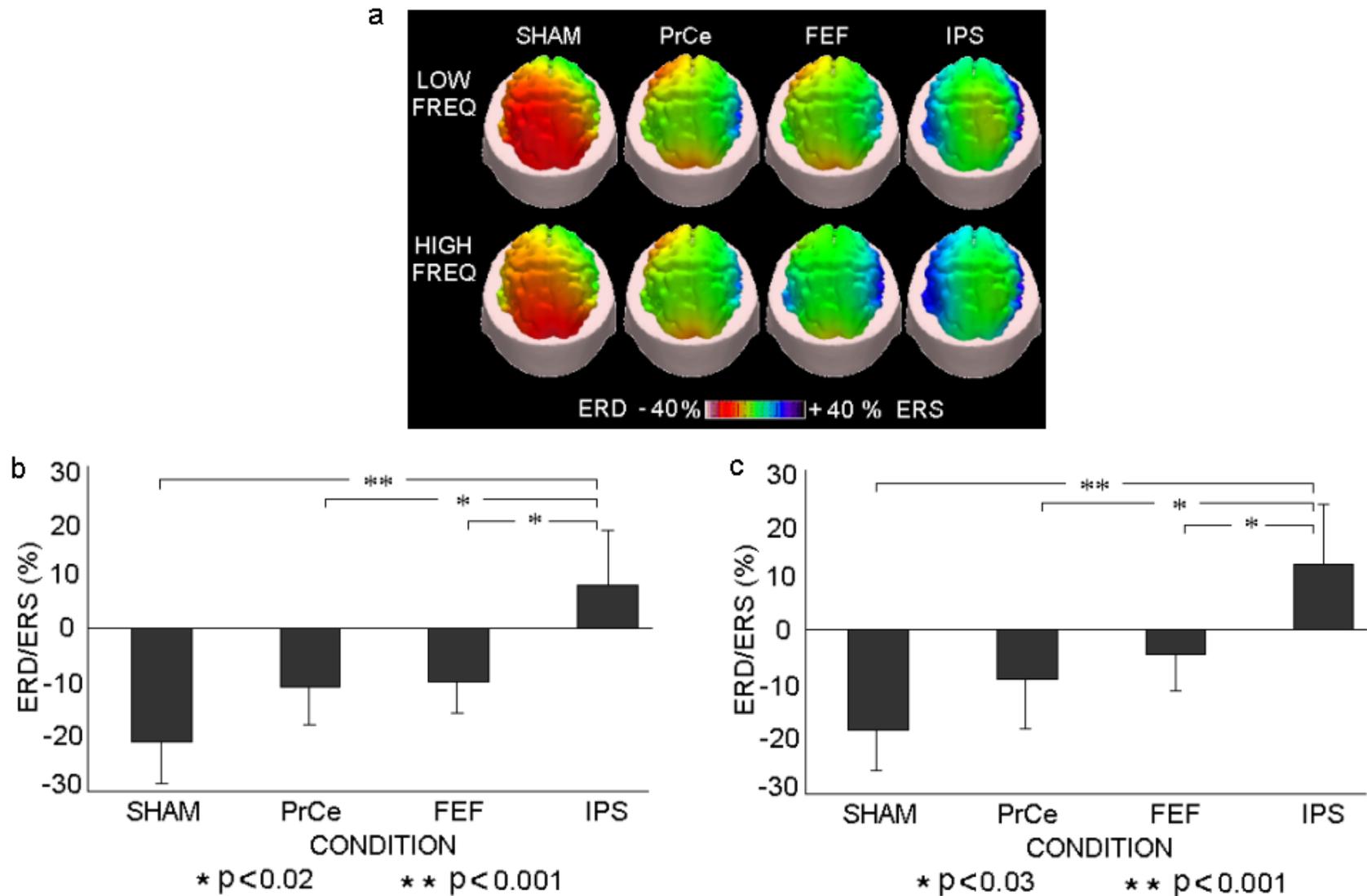


Effective connectivity by rTMS-EEG: linking cortical attentional networks (frontal eye field or FEF; precentral or PrCe; intraparietal sulcus, IPS), alpha rhythms, and behavior to Posner's test



Paolo Capotosto, Claudio Babiloni, Gian Luca Romani, and Maurizio Corbetta. Posterior parietal cortex controls spatial attention through modulation of anticipatory alpha rhythms. *Journal of Neuroscience* (2008, under major revisions)

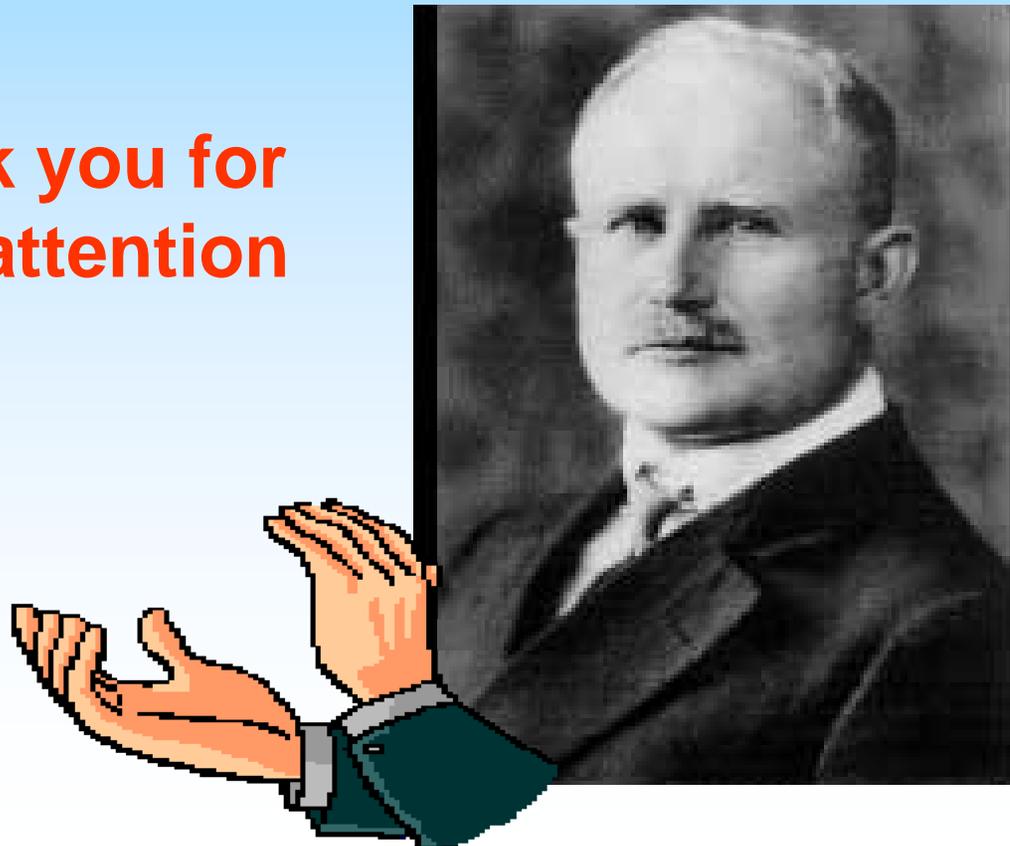
Effective connectivity by rTMS-EEG: rTMS of IPS linking cortical attentional networks (frontal eye field or FEF; precentral or PrCe; intraparietal sulcus, IPS), alpha rhythms, and behavior to Posner's test



Parieto-occipital electrodes

<http://www.brainon.it>

**Thank you for
your attention**



**The father of
EEG: H. Berger**