IRCCS San Giovanni di Dio
Fatebenefratelli

The Contribution of TMS-EEG Coregistration in the Exploration of the Human Connectome

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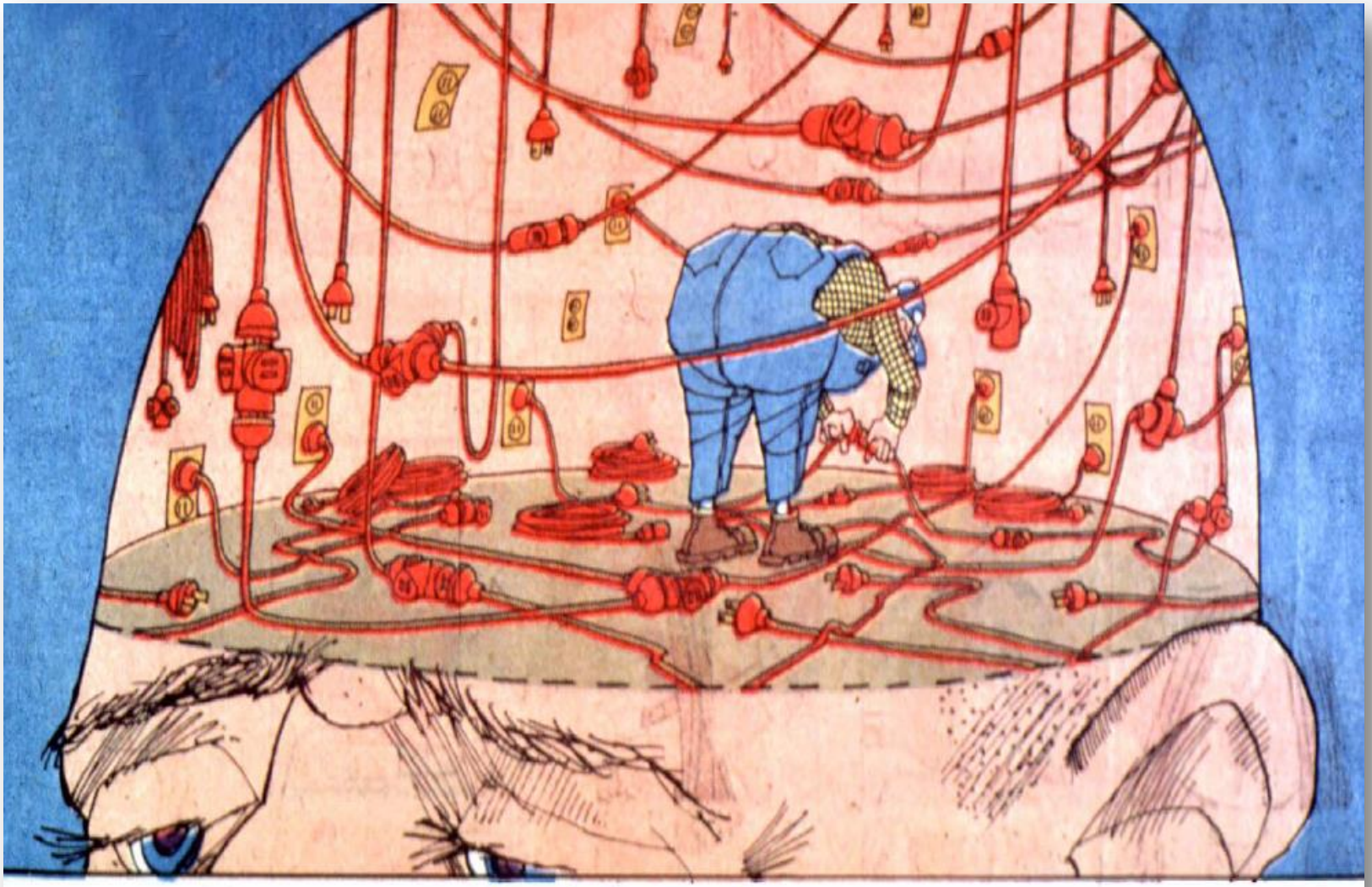
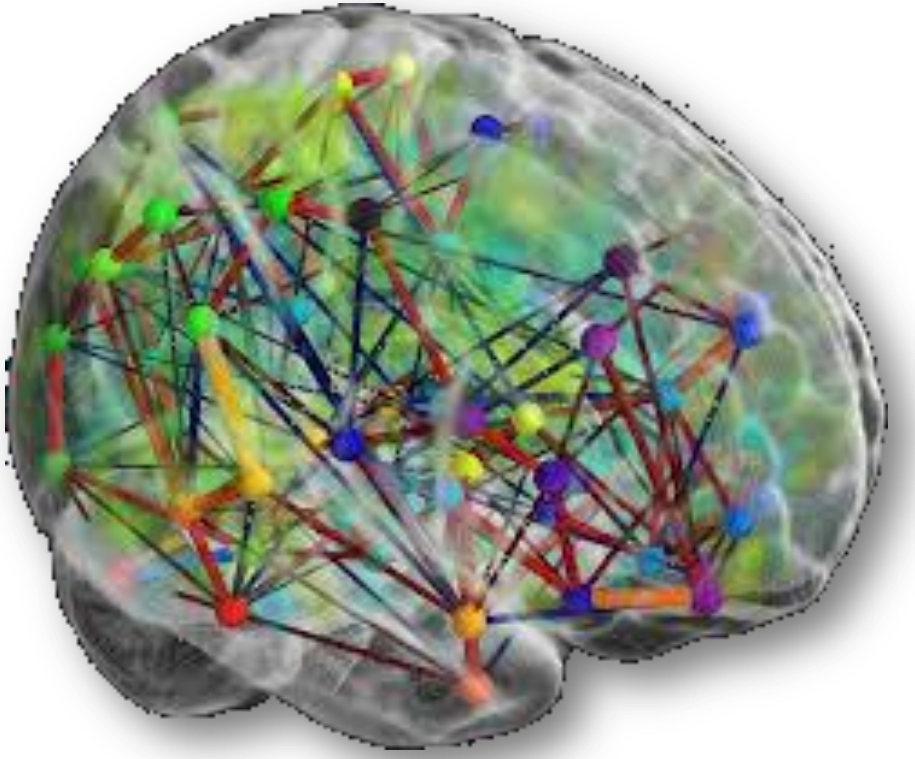
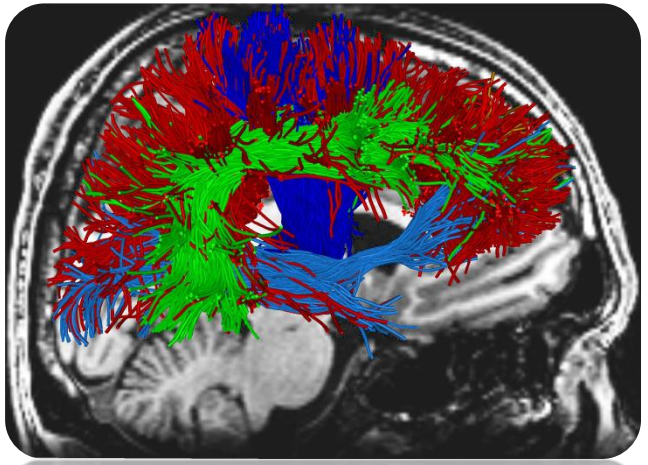
Functional networks



Functional networks & Neuroimaging

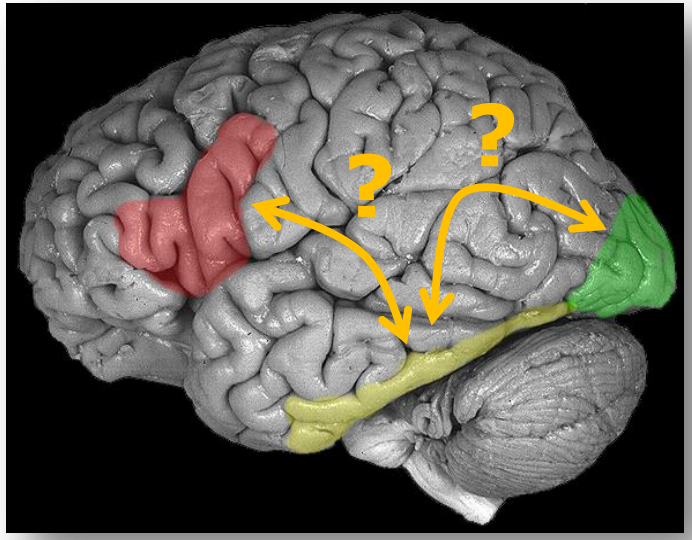
A great advantage of neuroimaging (e.g., diffusion MRI) and functional neuroimaging (e.g., fMRI) is the ability to acquire simultaneous measurements of activity in the entire brain, thus providing a broad picture of the cortical responses to an event.





Functional networks

Cognitive (perception, motor, etc.) efficiency does not only rely on the local processing of information in specialised areas but also on the integration of information (i.e., *connectivity*) through the coordinated activity of multiple areas.



Imbalances in connectivity patterns have been proposed to be strongly associated with neurological ... disorders

doi:10.1093/brain/awh622 *Brain* (2005), **128**, 2224–2239

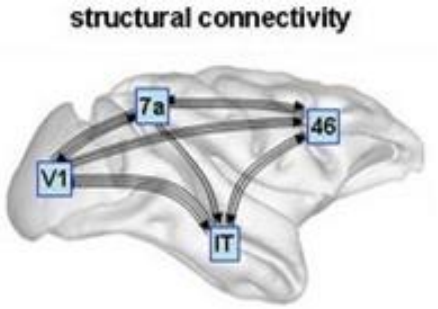
REVIEW ARTICLE

The rises and falls of disconnection syndromes

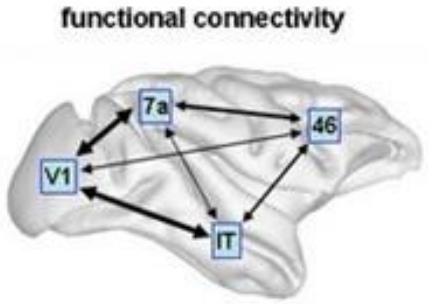
Marco Catani and Dominic H. ffytche

Brain connectivity measures

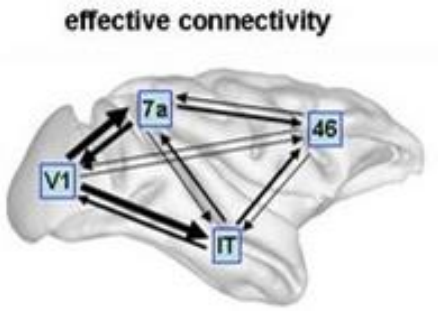
Anatomical connectivity: presence of axonal connections that determines which neural units can directly interact with each other (Stephan et al 2008).



Functional connectivity: temporal correlations between neural systems (Friston et al., 1993 JCBFM).



Effective connectivity: the causal (directed) influence that one neural system exerts over another (Friston et al., 1993 HBM).

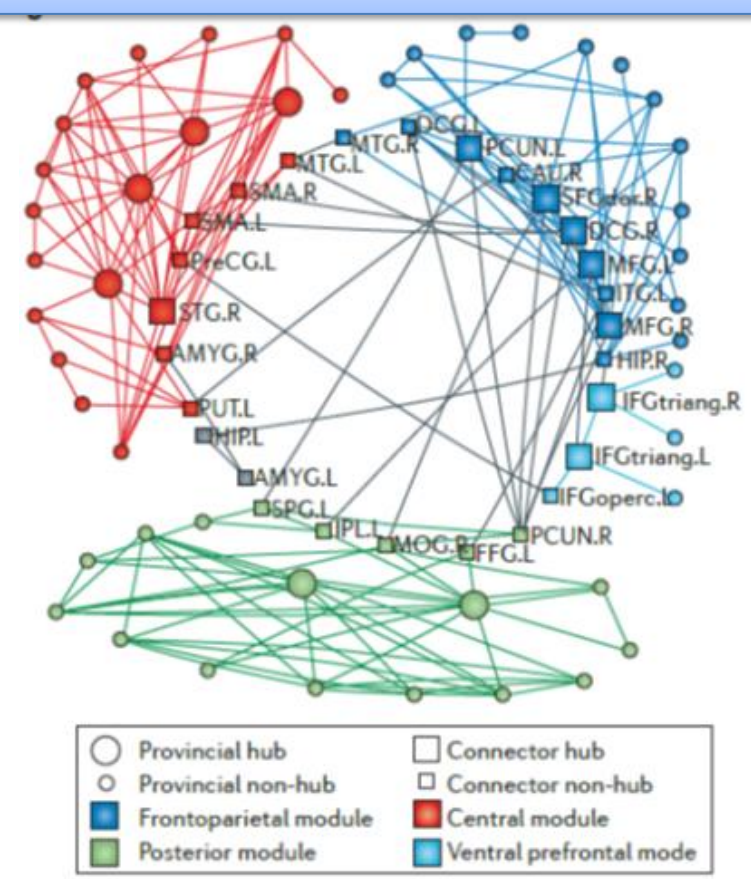


Sporns 2007

Functional networks & Graph Theory

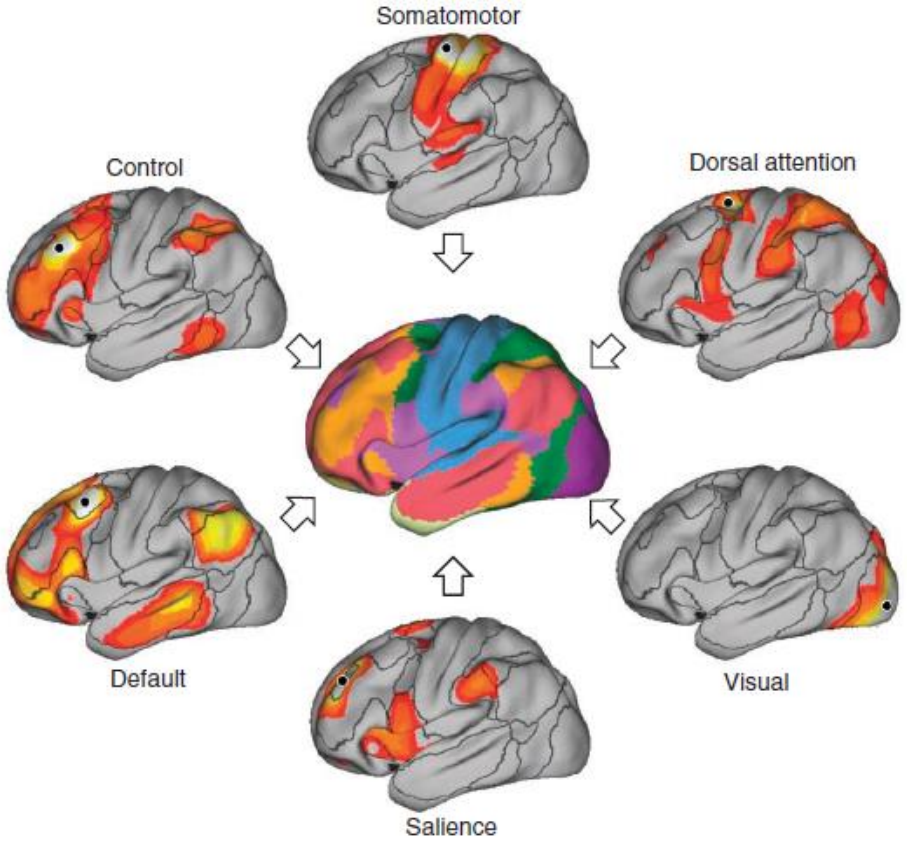
Connectivity implemented with complex network analyses from Graph Theory has shown:

Hierarchical modular organisation



Bullmore & Sporns Nat. Rev. Neurosci. 2012

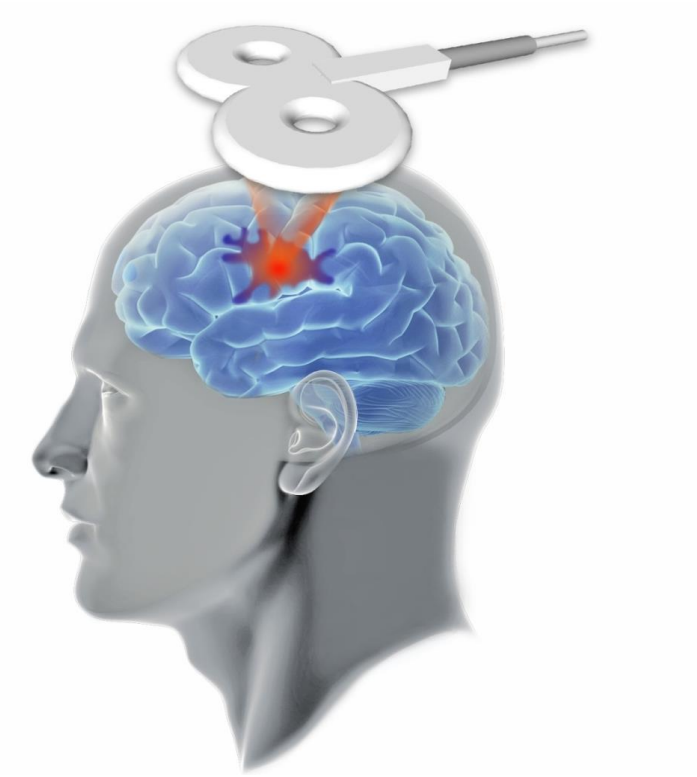
Large-scale functional networks



Buckner et al NN 2013

The multimodal approach

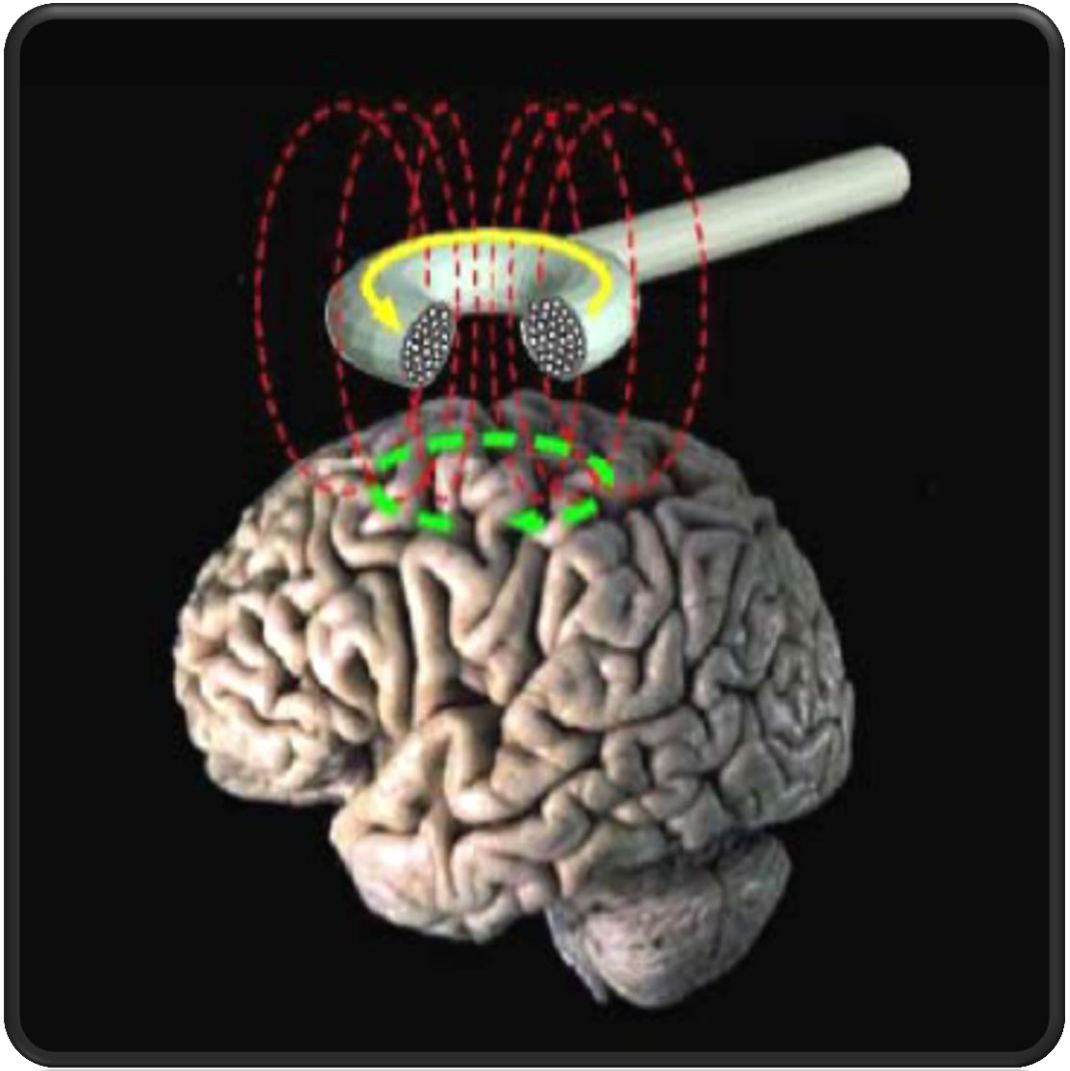
We need tools to alter the activity in an area (node of a network) in order to test the effects on the whole system, i.e., direct (causal) evidences.



TMS

Transcranial Magnetic Stimulation – TMS

Neurostimulation

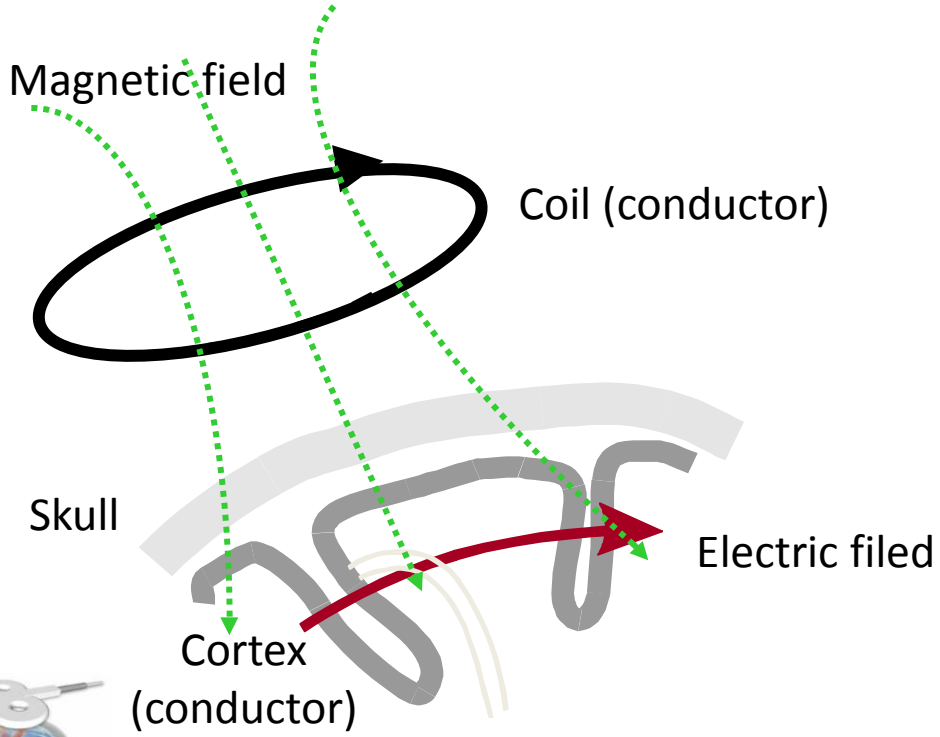


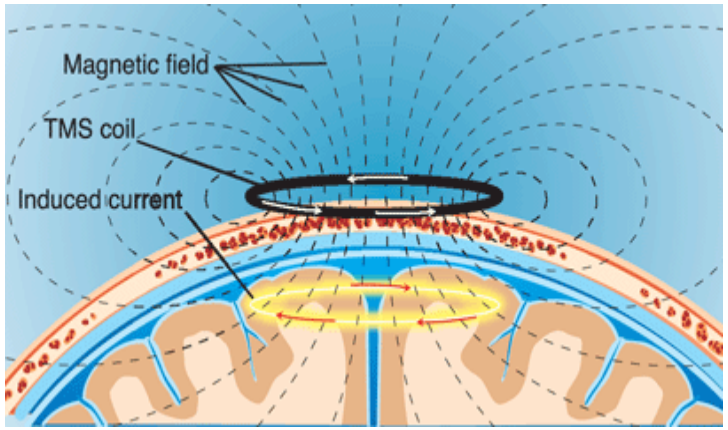
Modify cortical activity under the coil

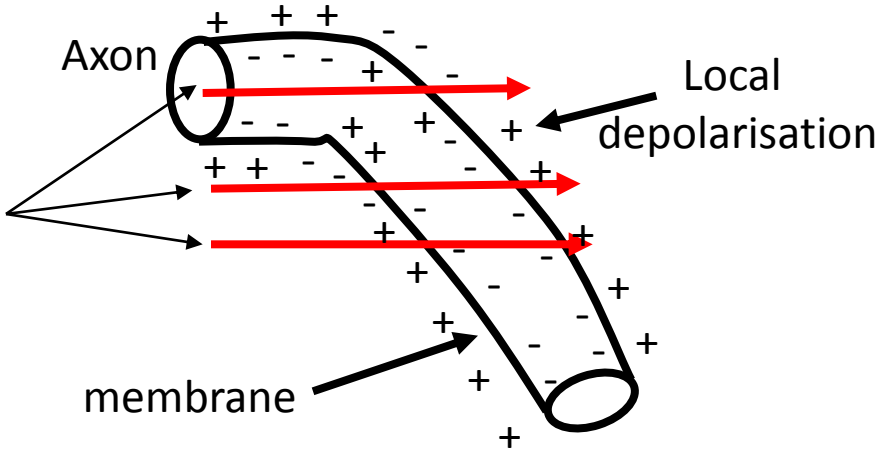
TMS depolarises neurons

Magnetic field passes unimpeded through skull.
Rapid rise and fall in magnetic field induces electrical currents in brain

TMS a pulse of < 1 msec



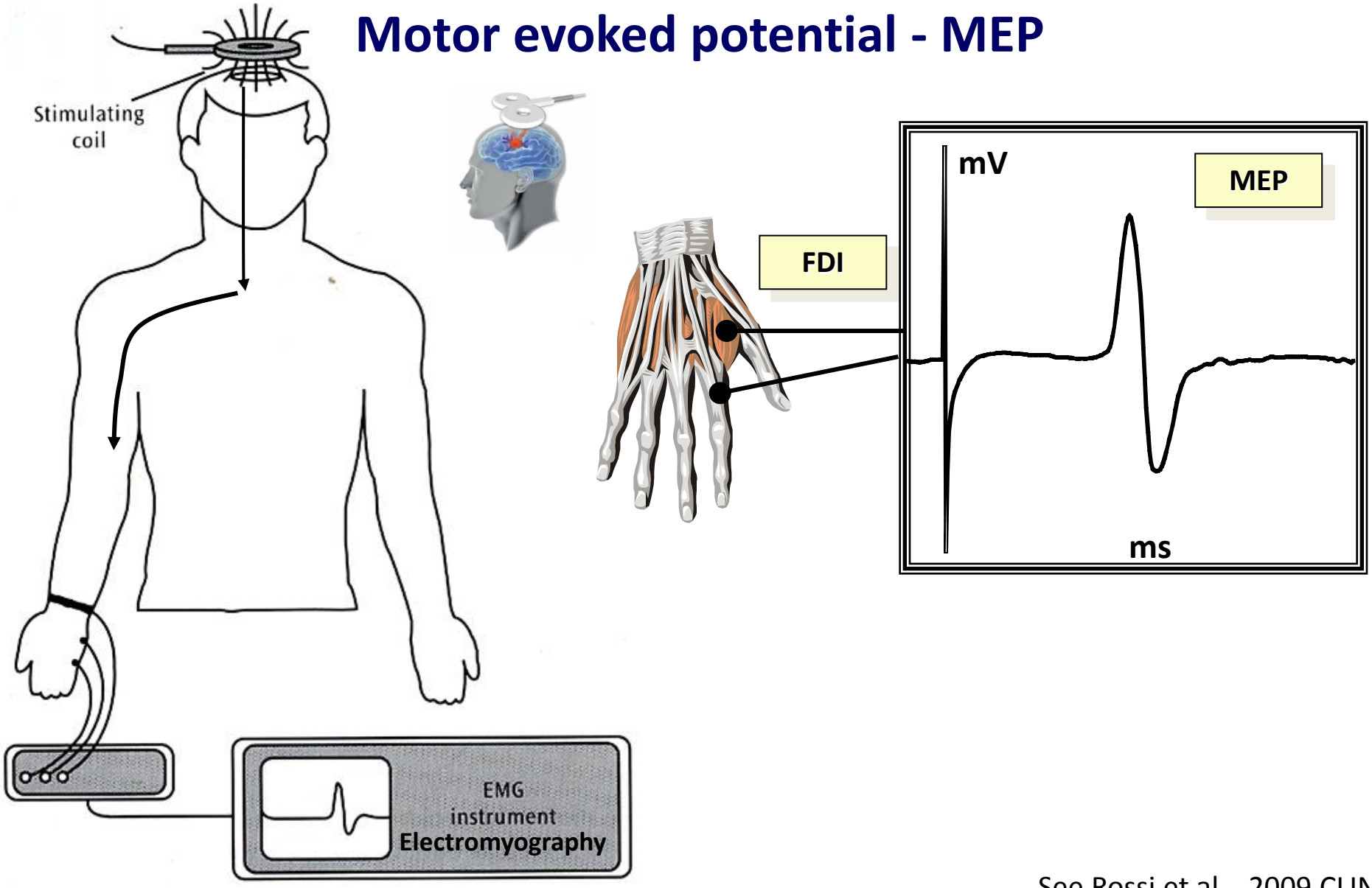




Ruohonen J. Suppl Clin Neurophysiol. 2003;56:3-12

Stimulation of the motor system

Motor evoked potential - MEP

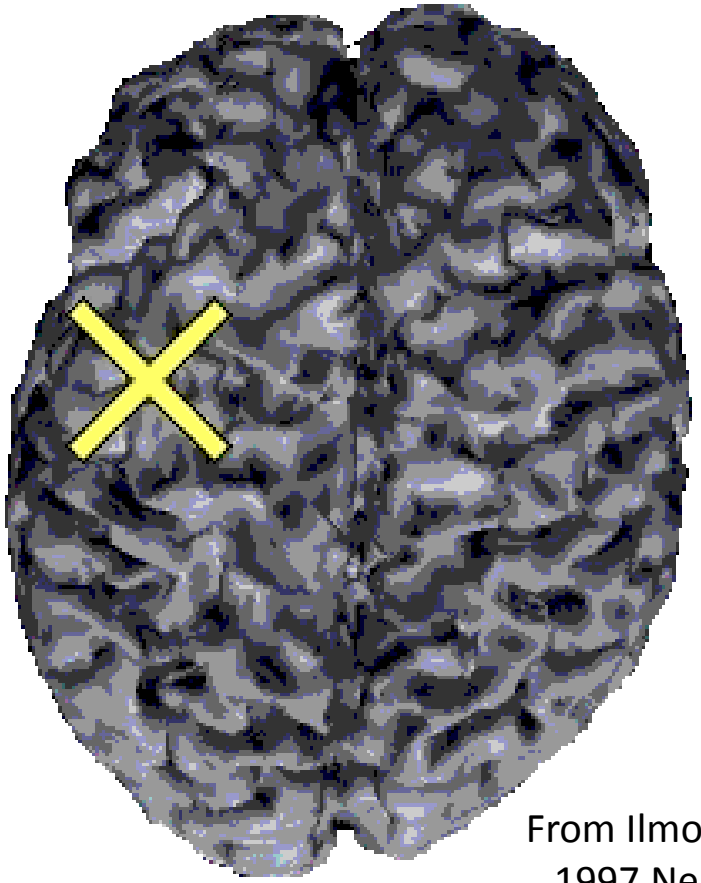


See Rossi et al., 2009 CLINP

TMS in cognitive neuroscience

Effects induced by TMS are site specific, but not site limited

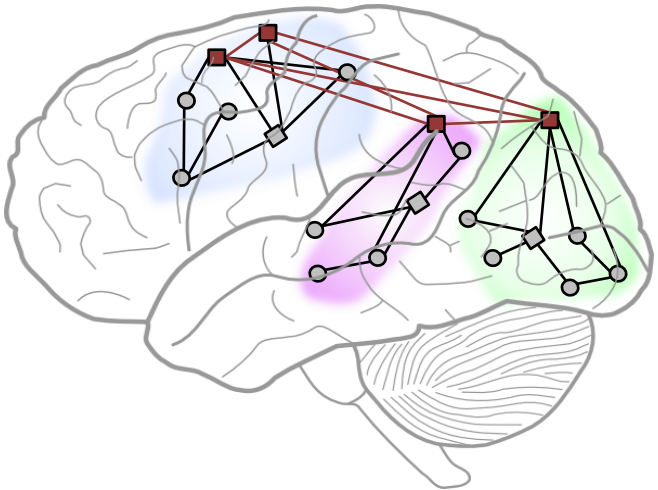
Induction of activity, in a neural network, by TMS

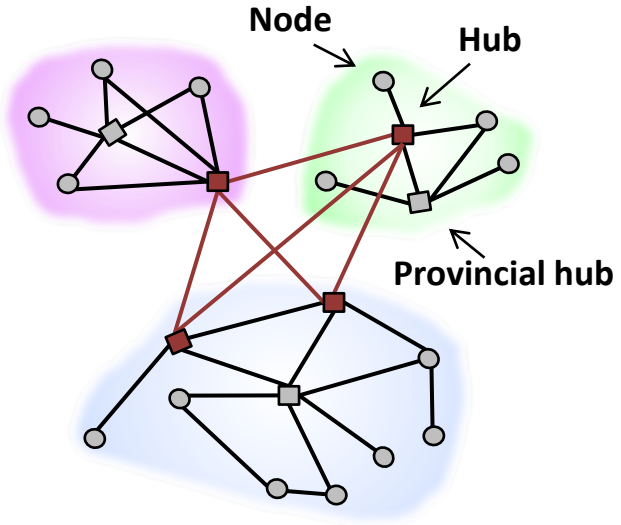


From Ilmoniemi et al., 1997 Neuroreport

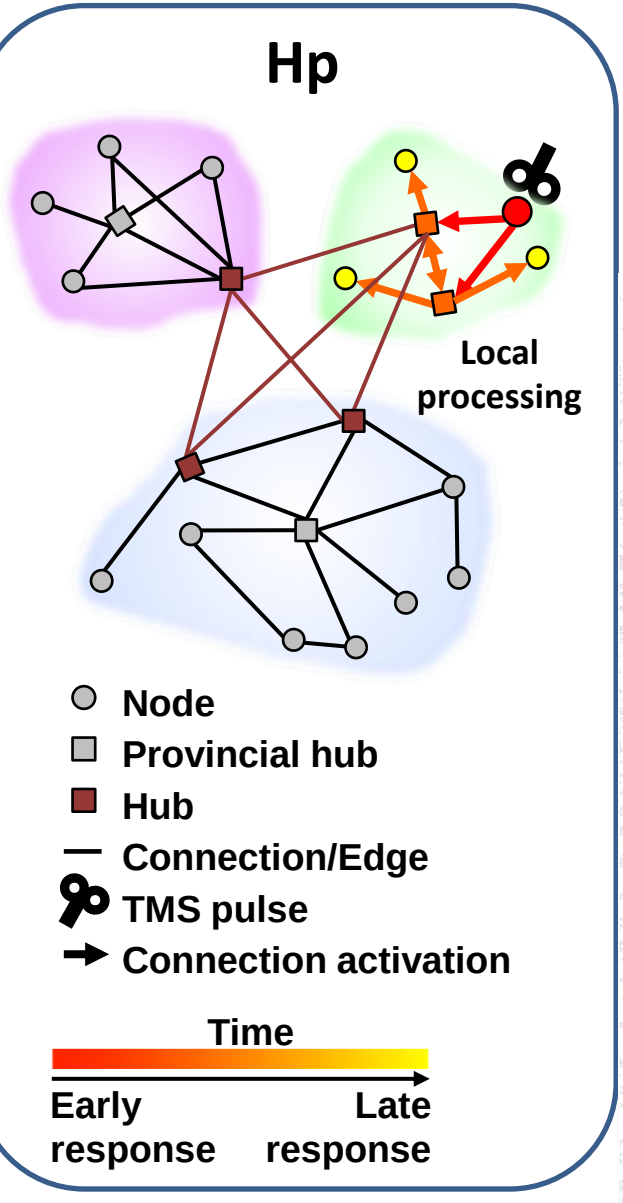
Testing the connectome with TMS-EEG

- During the resting state, network segregation increases: **Nodes** should mainly connect with other nodes of the same functional network .
- Hubs mediate inter-module comunication: Activation from nodes of the same network should converge to the same **hubs**
- Hubs flexibly change connections according to cognitive demands: The spread of activation from hubs to nodes should be **task dependent**



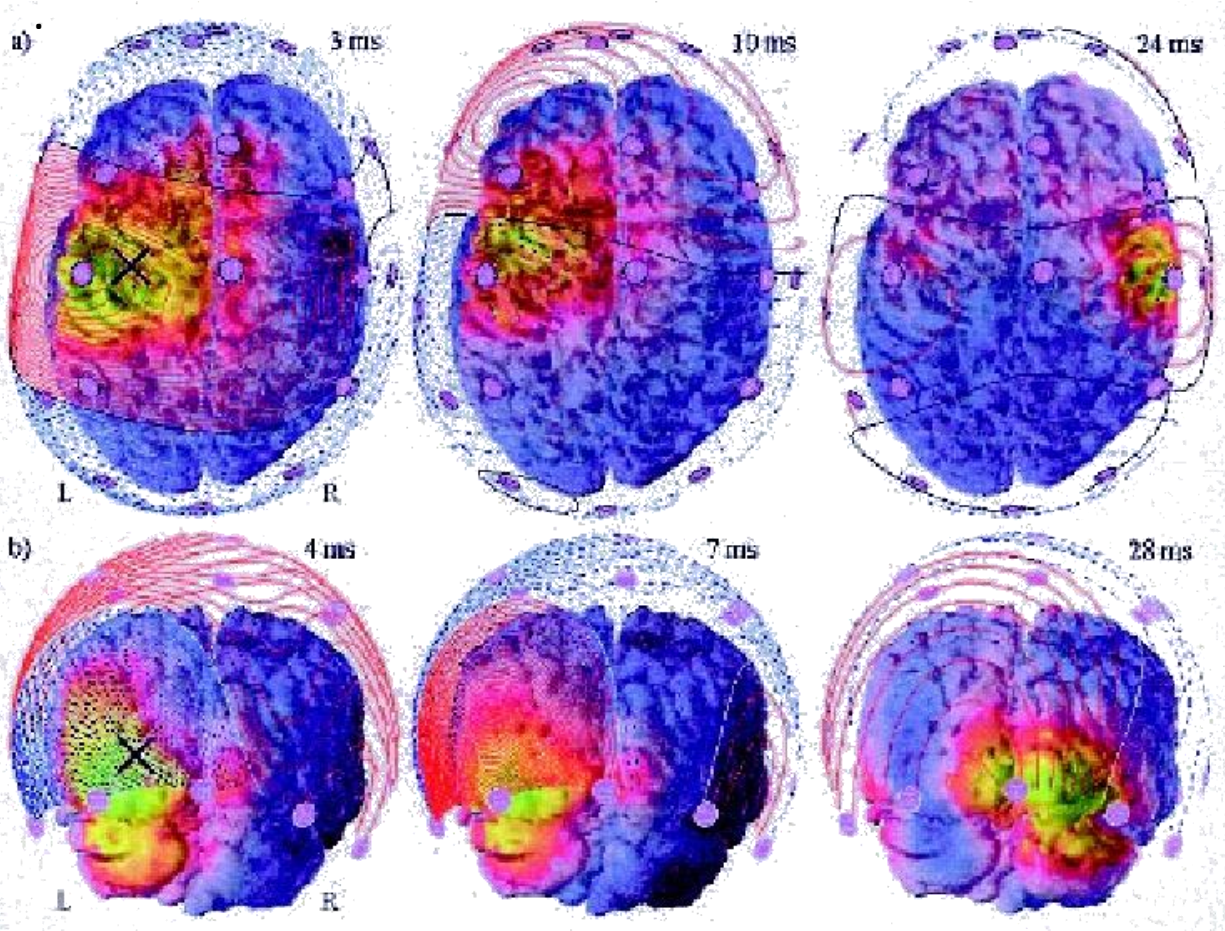


Segregation of functional networks at rest



Neuronal responses to magnetic stimulation reveal cortical reactivity and connectivity

R J. Ilmoniemi, J Virtanen, J Ruohonen, J Karhu, HJ. Aronen, R Näätänen and T Katila 1997



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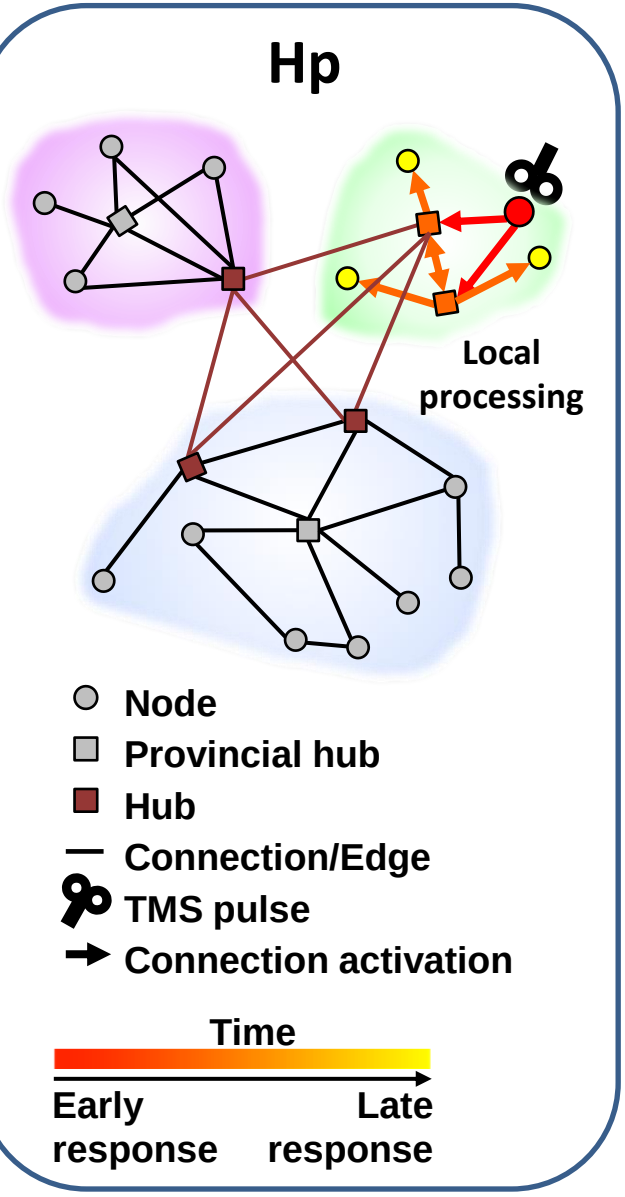
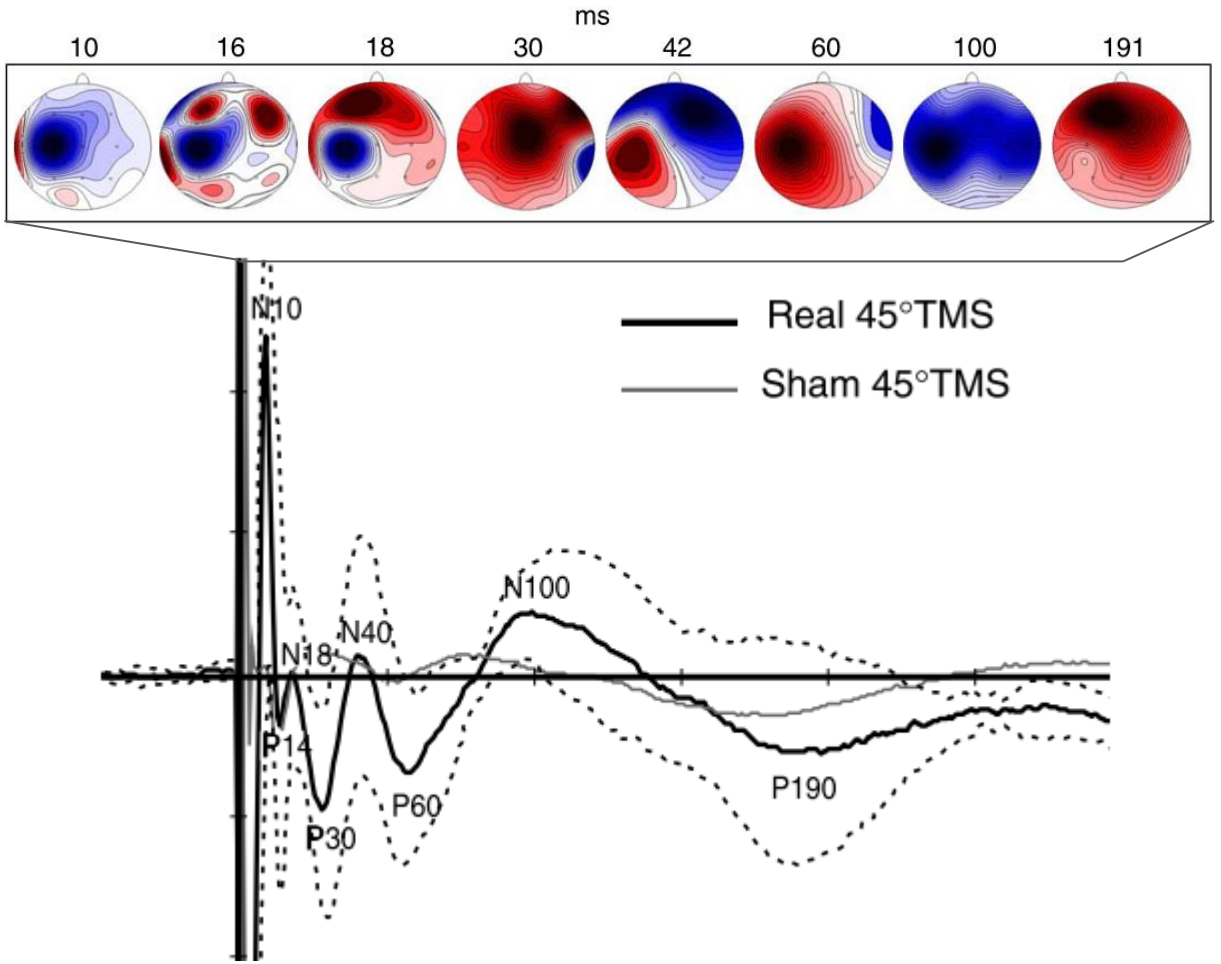
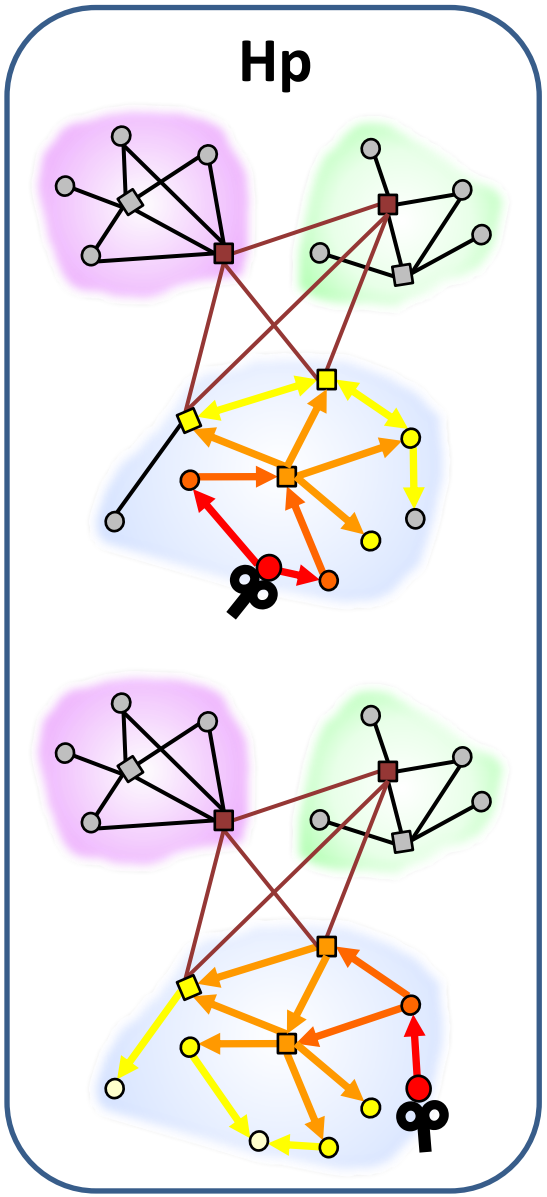


Transcranial magnetic stimulation and cortical evoked potentials : A TMS / EEG co-registration study.

Bonato C., Miniussi C., Rossini P.M. 2006

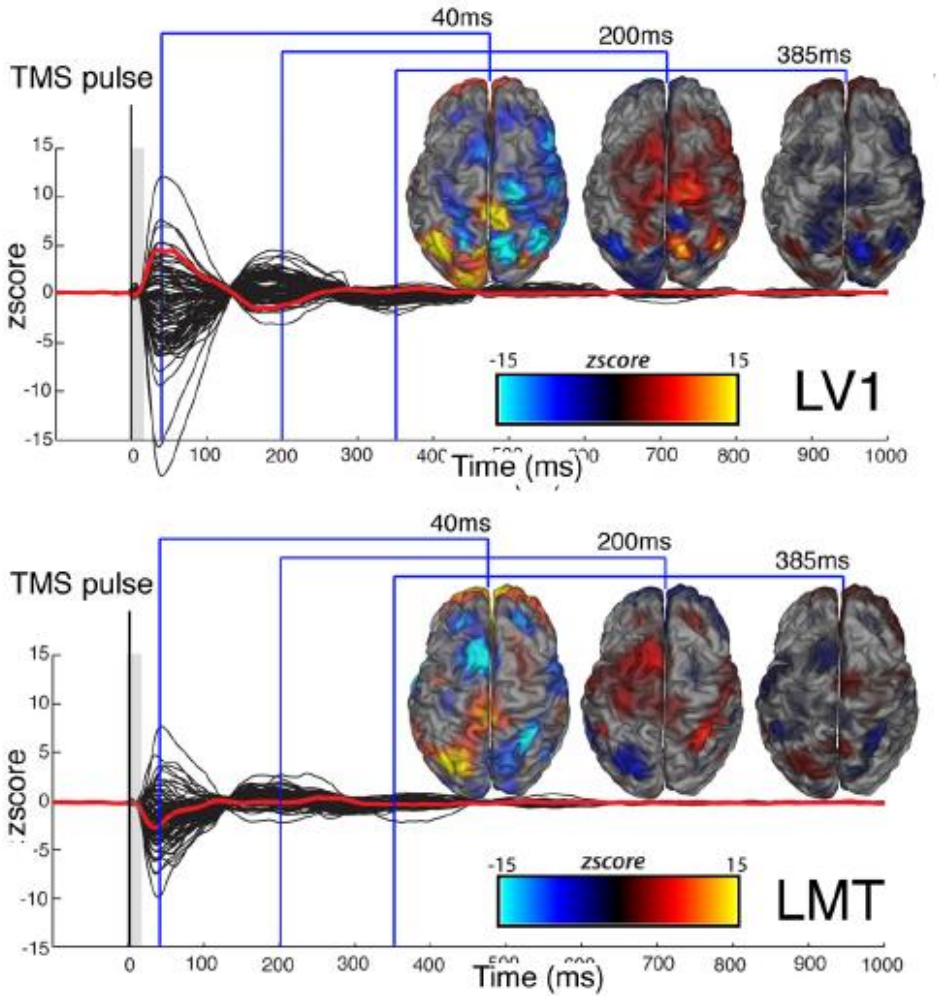


Convergence from nodes to hubs



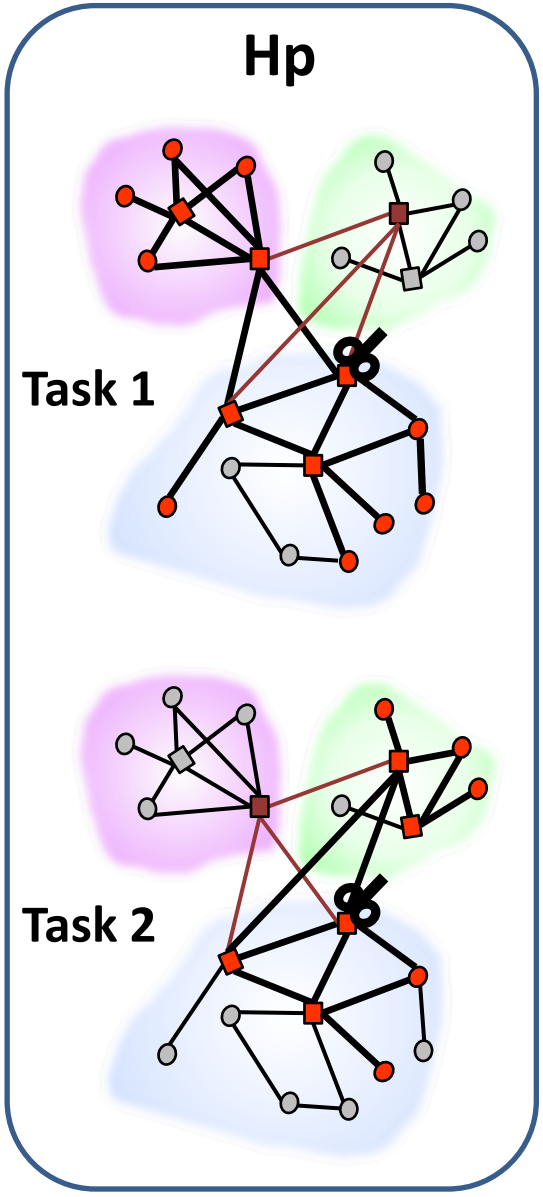
Evoked potentials in large-scale cortical networks elicited by TMS of the visual cortex.

Garcia J.O., Grossman E.D., Srinivasan R. 2011



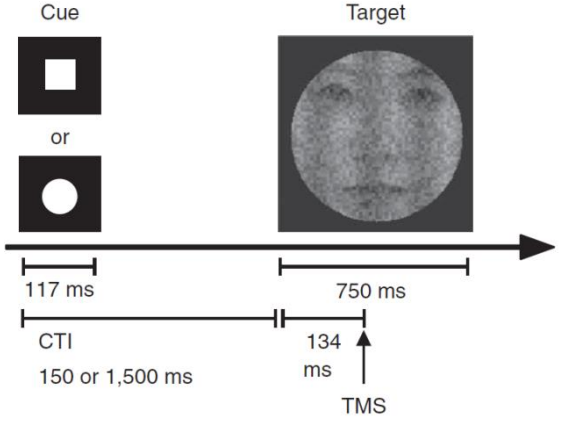
frontal and parietal EEG signature

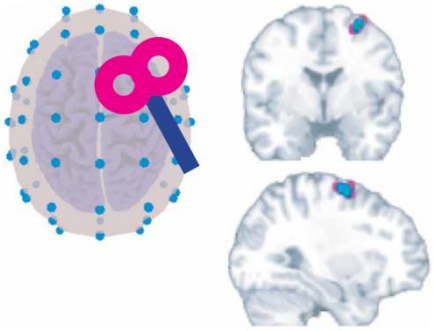
Task-dependent hub flexibility

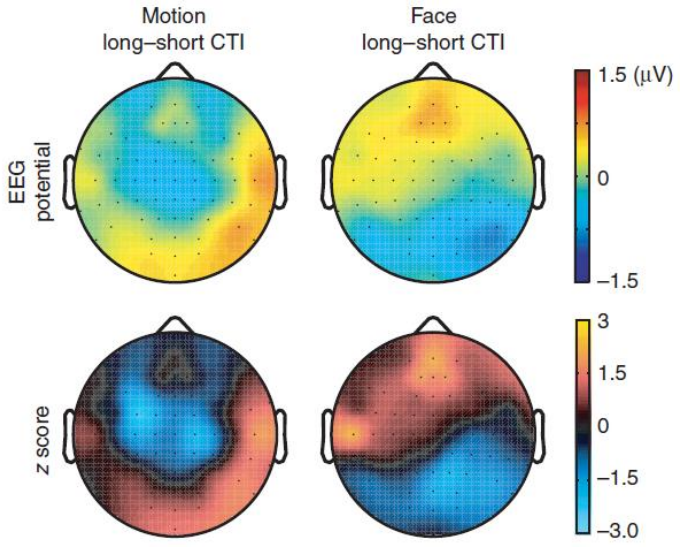


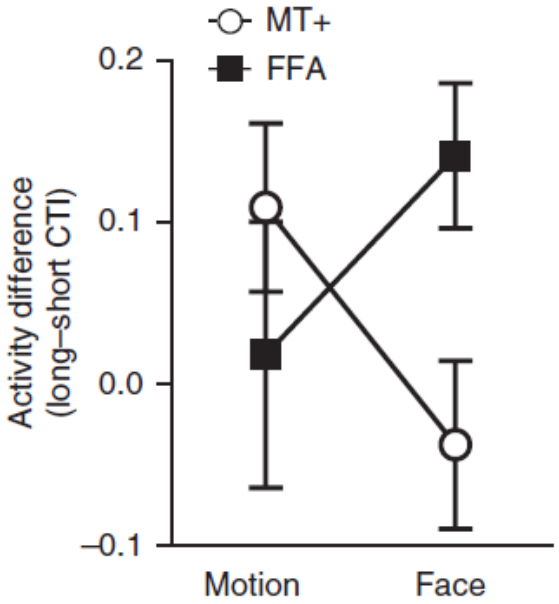
Task-specific signal transmission from prefrontal cortex in visual selective attention

Morishima Y., Akaishi R., Yamada Y., Okuda J., Toma K., Sakai K. 2009





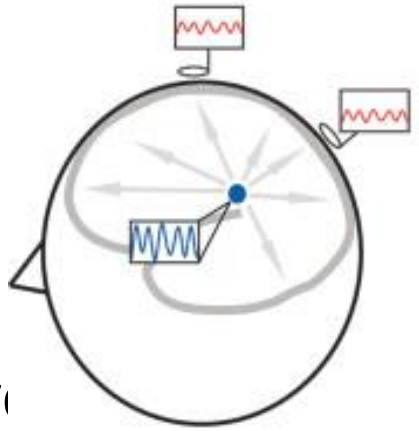




Limitations:

- Spurious connectivity due to volume conduction:

- Comparing appropriate experimental conditions
- Applying connectivity measures less sensitive to volume conduction
  - Applying source localization

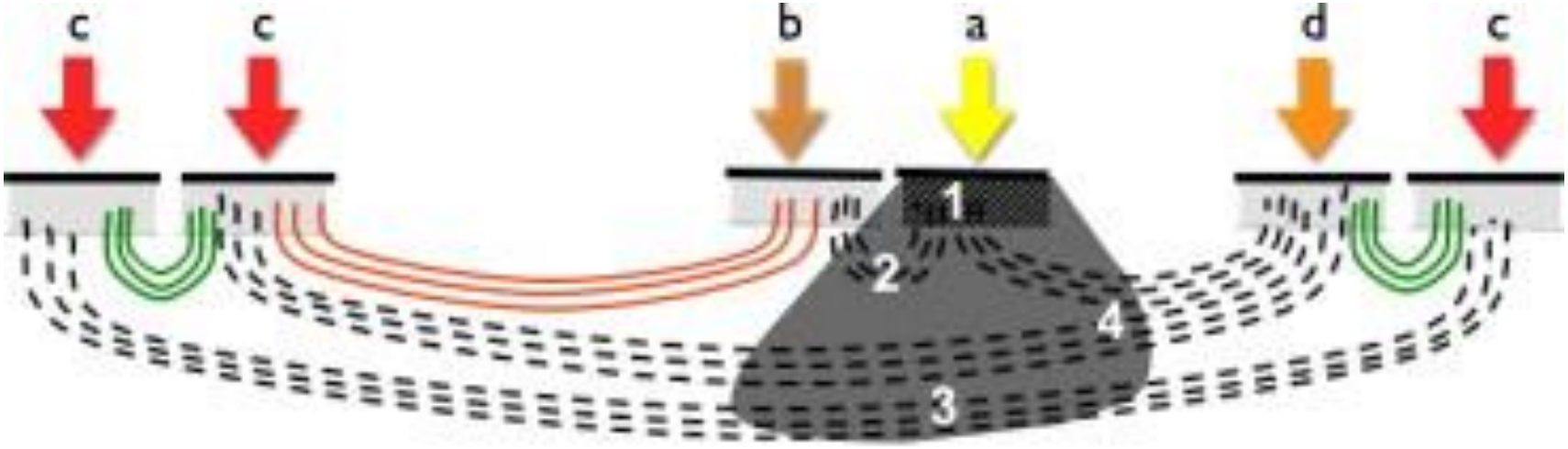


Schoffelen and Gross 2009

- Low spatial resolution:
  Preferred for the study of long range connections

Clinical Applications

A hypothetical lesion



1. cortical damage
2. subcortical damage to the most superficial fibers of the tract
3. subcortical damage to the deepest fibers of the tract.
4. subcortical damage to the superficial and deepest fibers of the tract.

Catani & Ffytche Cortex 46 2010

Clinical applications: Disorders of Consciousness

Vegetative versus Minimally Conscious States: A Study Using TMS-EEG, Sensory and Event-Related Potentials.

Ragazzoni A., Pirulli C., Veniero D., Feurra M., Cincotta M., Giovannelli F., Chiaramonti R., Lino M., Rossi S., Miniussi C. 2013

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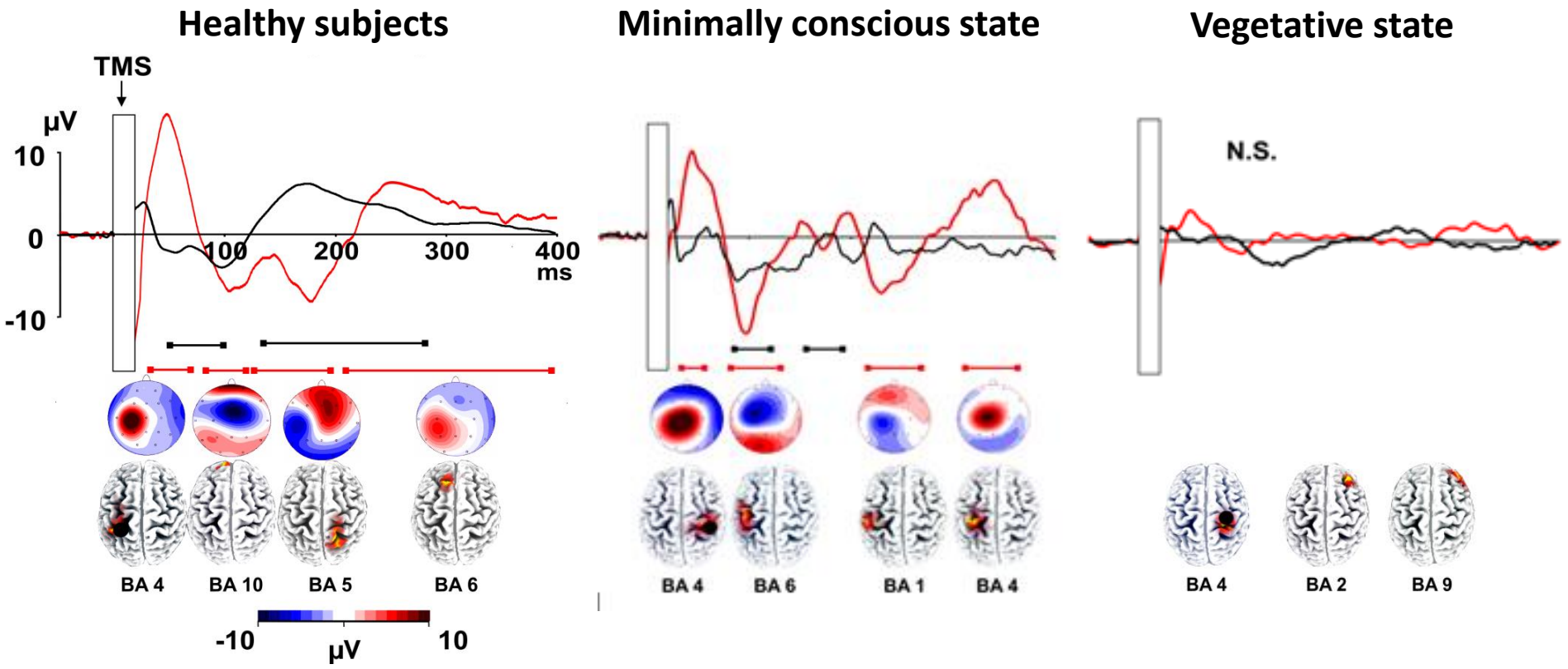
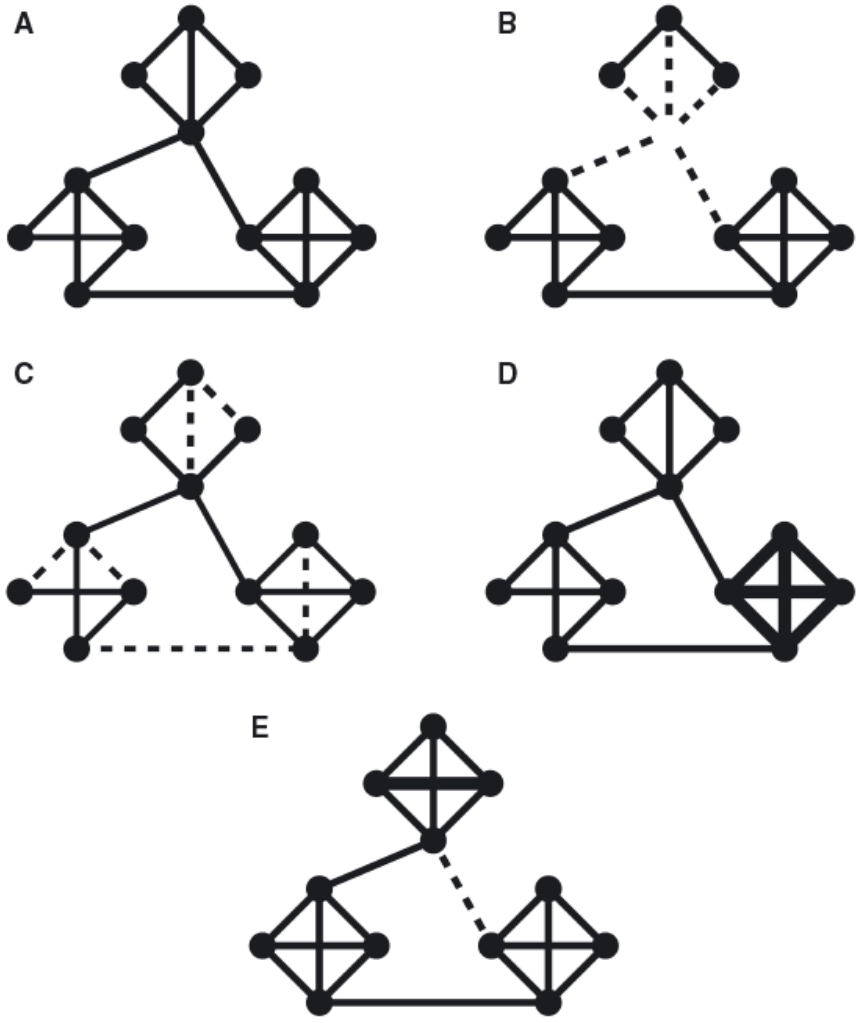


Perspectives

- TMS-EEG to track alternative routes of neural input transmission as a function of task context and pathological conditions.

- Changes in effective connectivity associated with training and experience.

- Changes in effective connectivity during and after plasticity protocols.



Bortoletto et al., submitted; Shafi et al 2012

Conclusions

TMS-EEG co-registration offers a unique opportunity to study effective connectivity at high temporal resolution through simultaneous cortical stimulation and evaluation of induced cortical activity at both local and global levels.

Bortoletto et al submitted


Thank you
for your attention

NeuroImage 52 (2010) 1059–1069

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/ynimg

Complex network measures of brain connectivity: Uses and interpretations

Mikail Rubinov [a,b,c], Olaf Sporns [d,*]

[a] Black Dog Institute and School of Psychiatry, University of New South Wales, Sydney, Australia
[b] Mental Health Research Division, Queensland Institute of Medical Research, Brisbane, Australia
[c] CSIRO Information and Communication Technologies Centre, Sydney, Australia
[d] Department of Psychological and Brain Sciences, Indiana University, Bloomington, IN 47405, USA

Source Connectivity Analysis With MEG and EEG

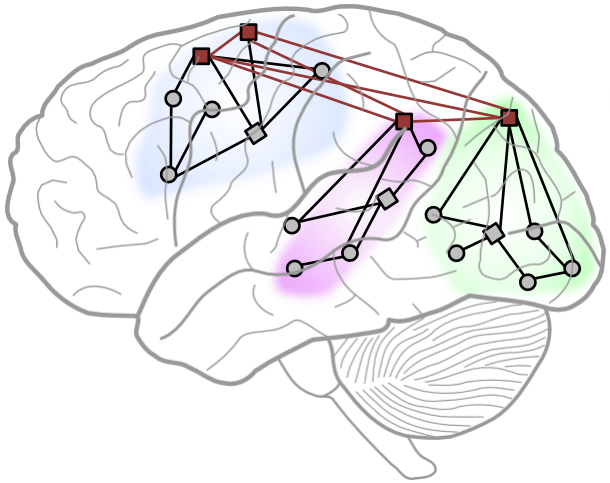
Human Brain Mapping 30:1857–1865 (2009)

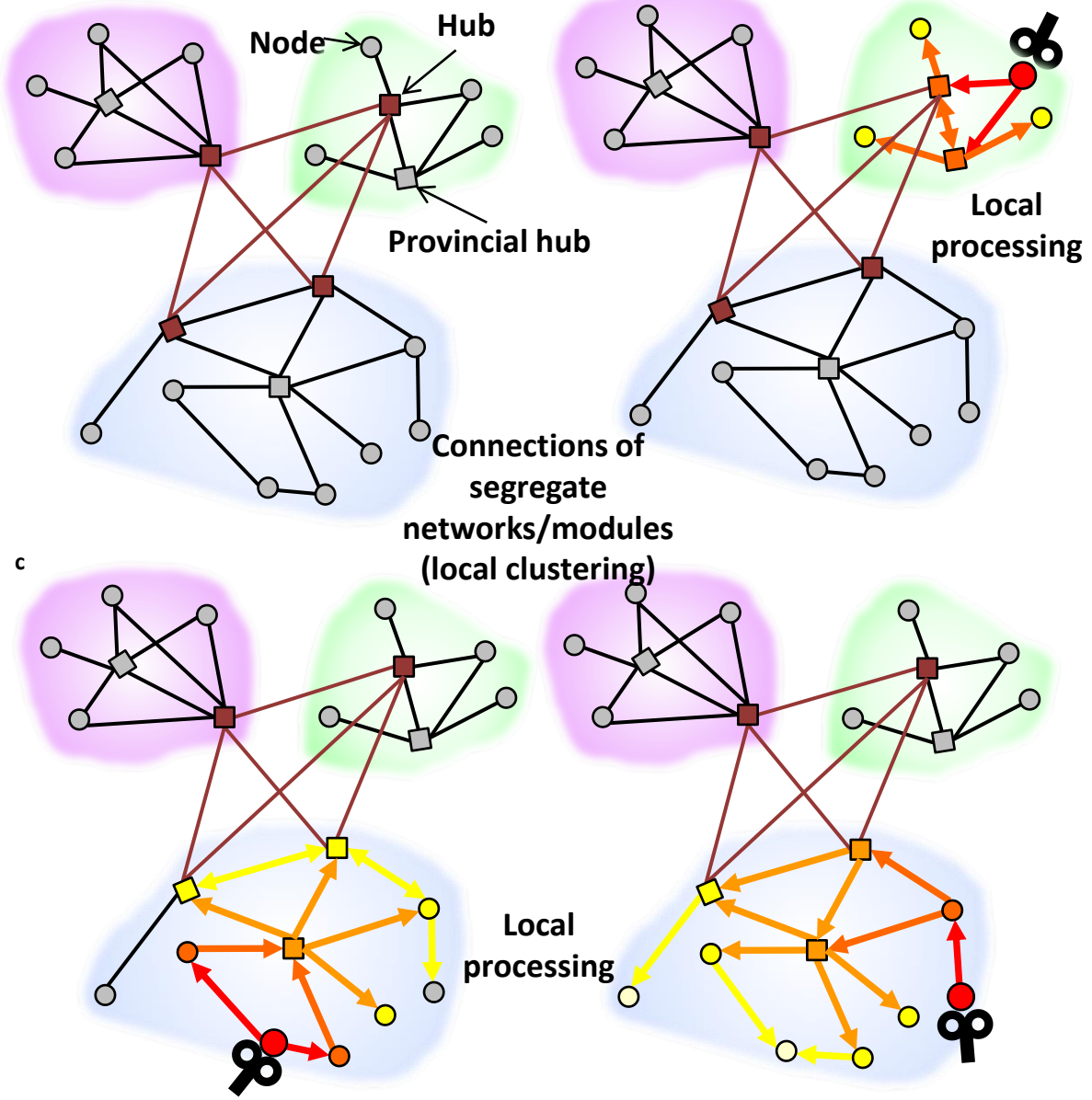
Jan-Mathijs Schoffelen* and Joachim Gross

Centre for Cognitive Neuroimaging (CCNi), Department of Psychology, University of Glasgow, Glasgow, United Kingdom

Directed coherence, imaginary coherence, phase-locking value, phase-lag index, etc

Connectivity of Cortical Networks at rest





- Node
- Provincial hub
- Hub
- Connection/Edge
- TMS pulse
- Connection activation

Time

Early response — Late response

Bortoletto et al. submitted