

Blood Oxygenation Level Dependent (BOLD) noise and behavior

Maurizio Corbetta

Washington University St.Louis

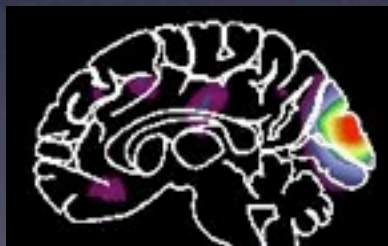
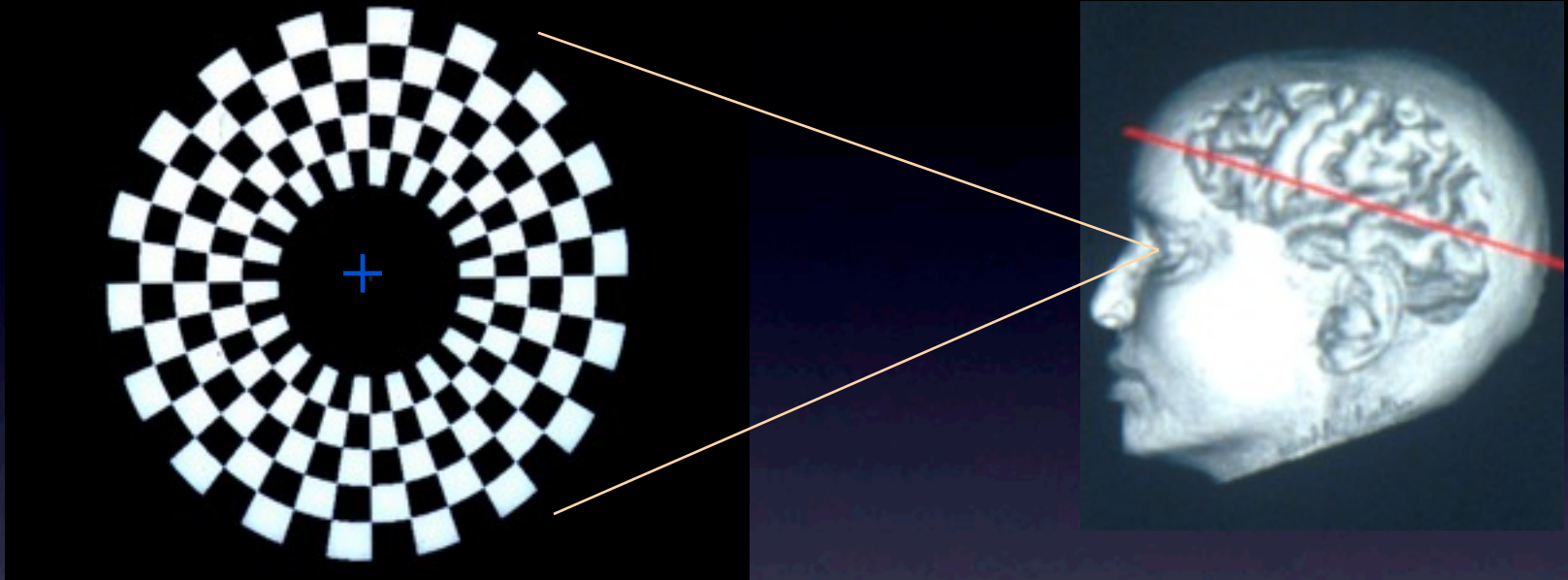
Cold Spring Harbor April 3-6, 2011

attention and brain recovery lab

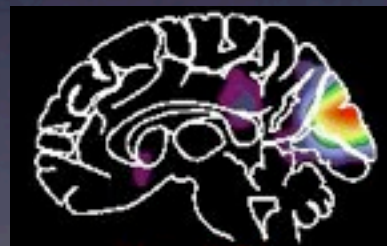
Department of Neurology, Radiology, Anatomy and Neurobiology



Brain imaging 1985-2005



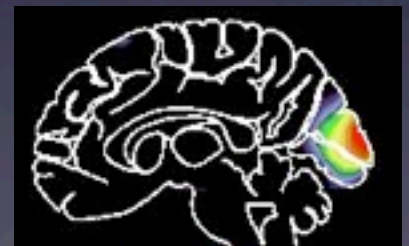
Glucose
Utilization



Blood Flow

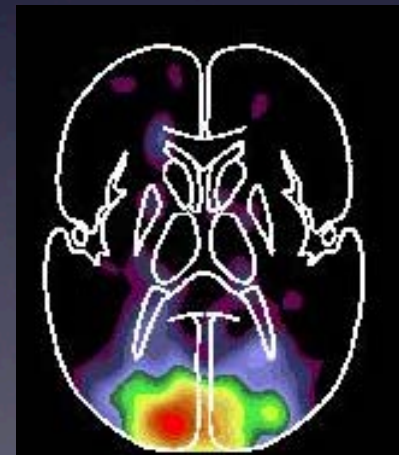
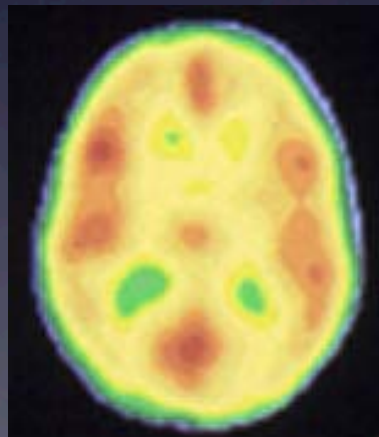
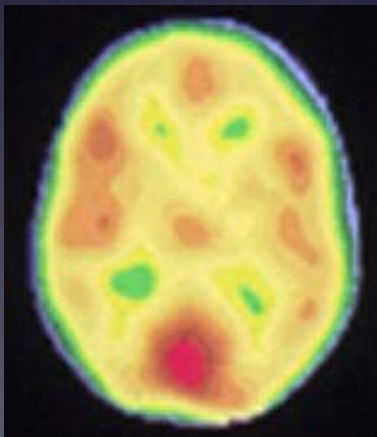
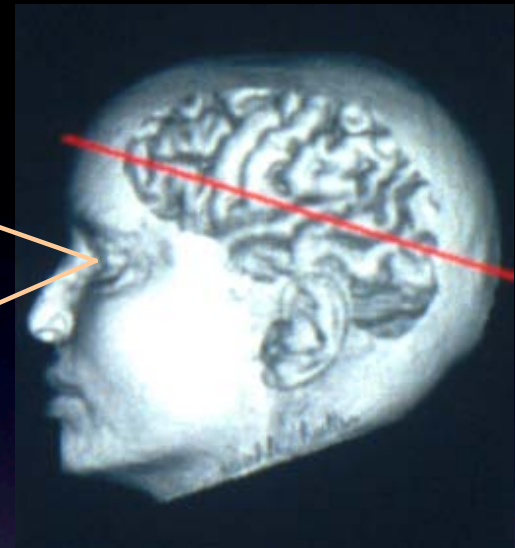
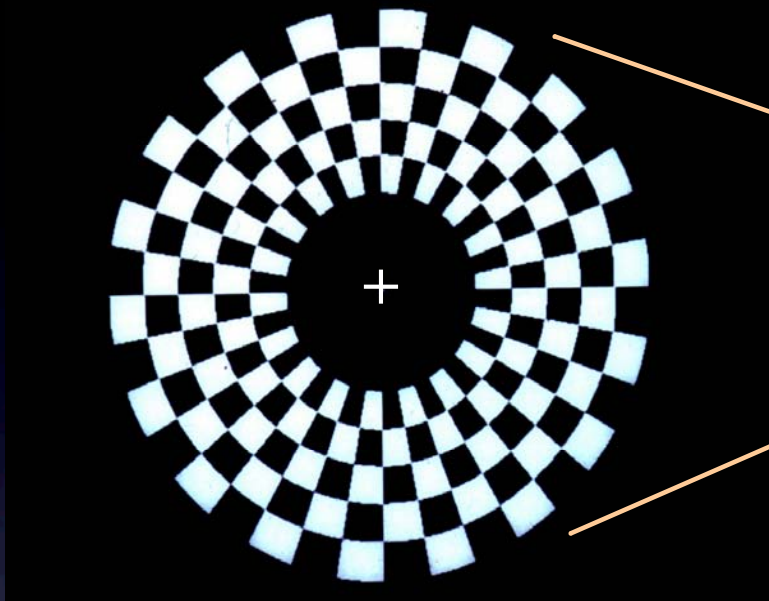


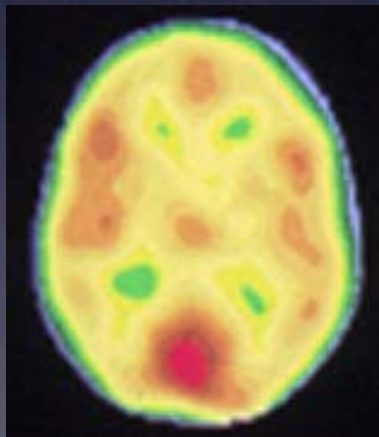
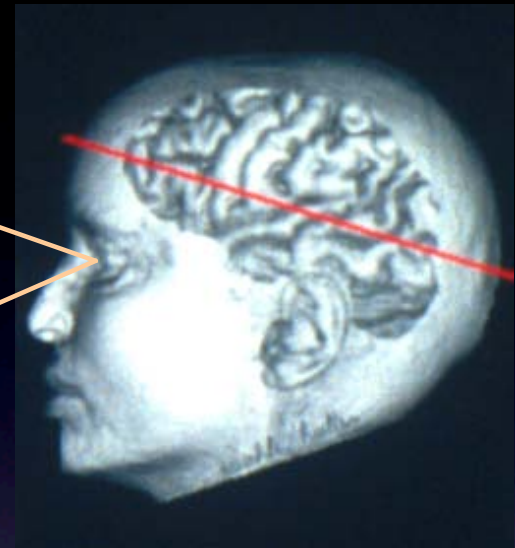
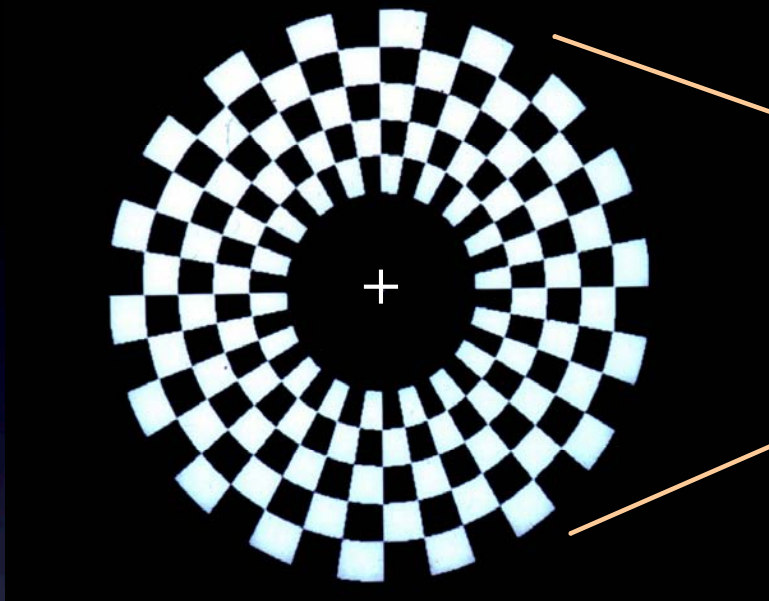
Oxygen
Utilization



Oxygen
Availability
or BOLD

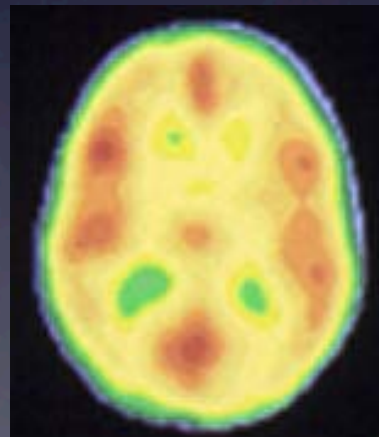
Fox and Raichle, 1986





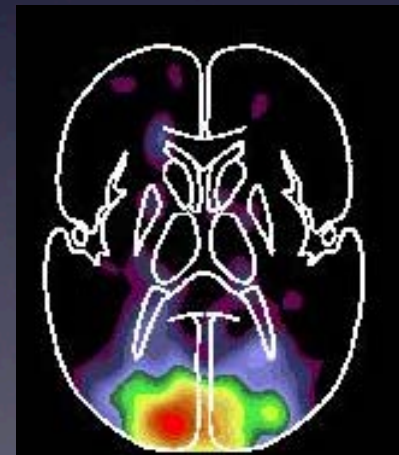
Stimulation

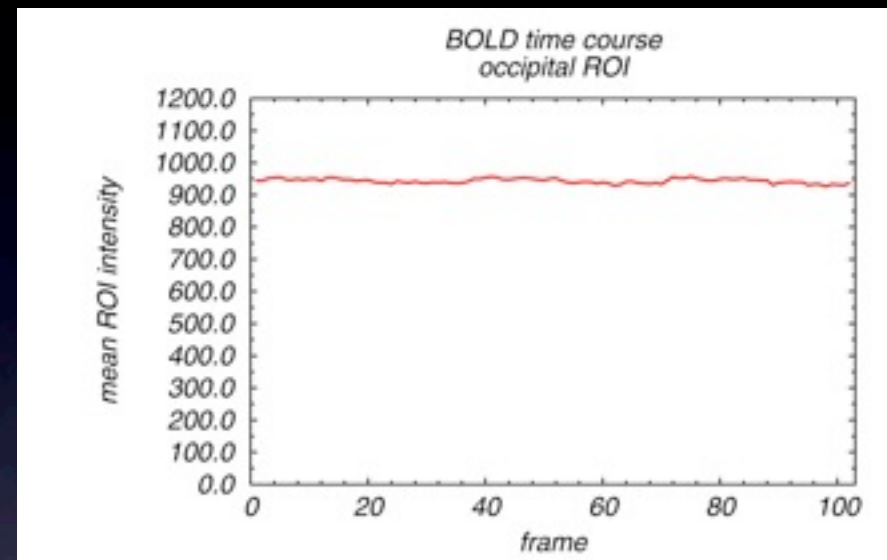
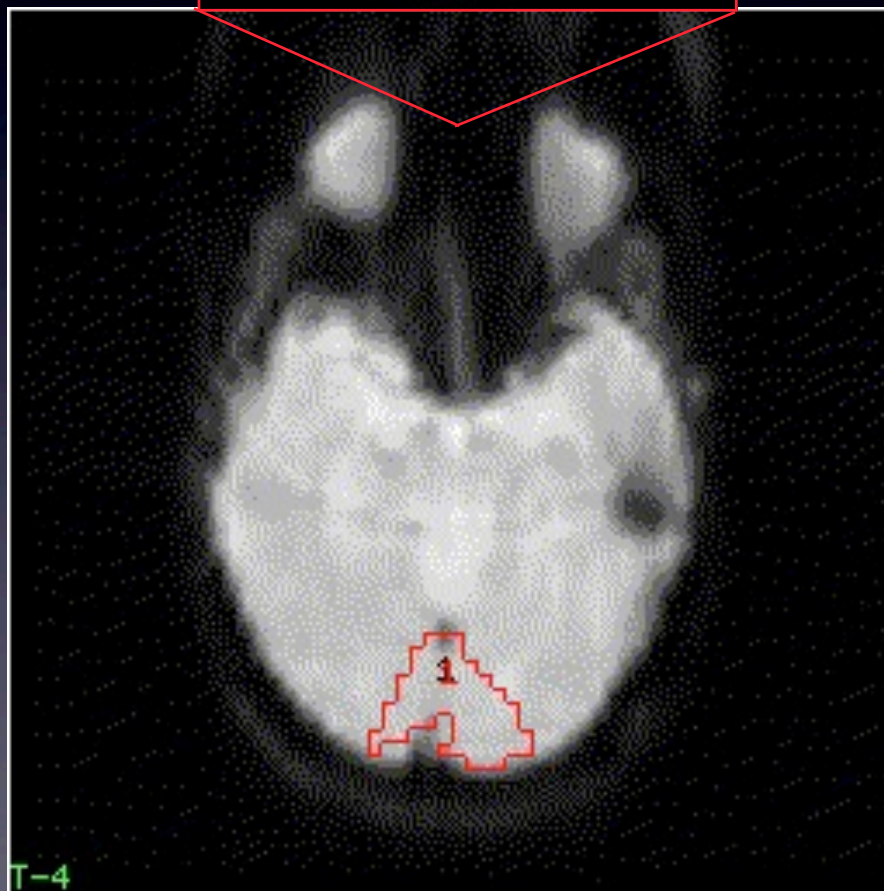
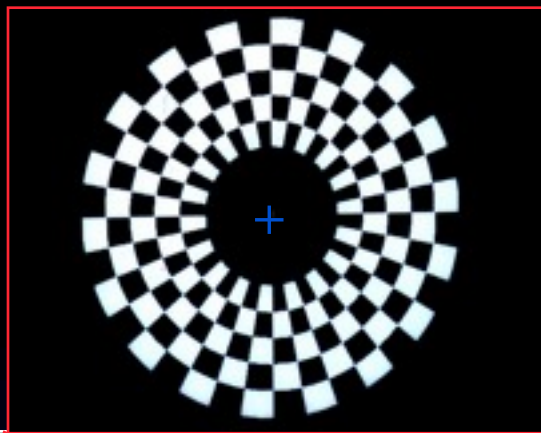
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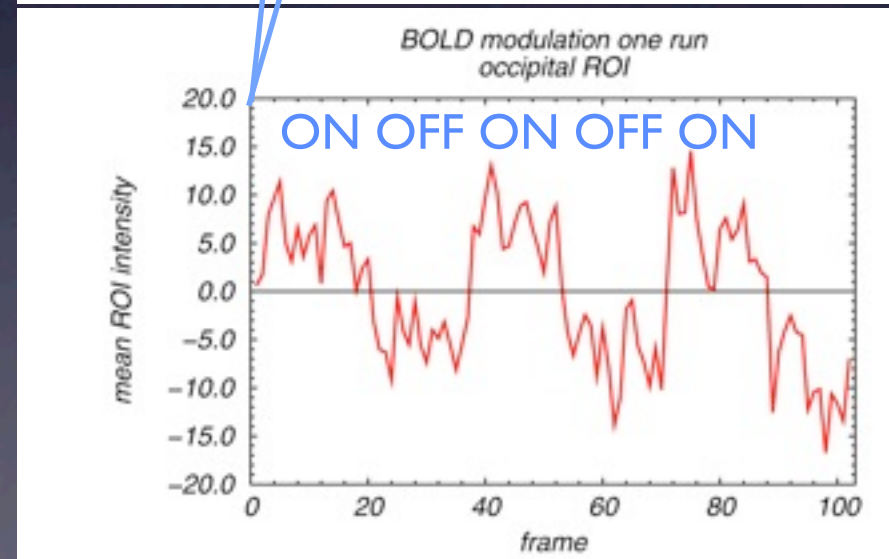
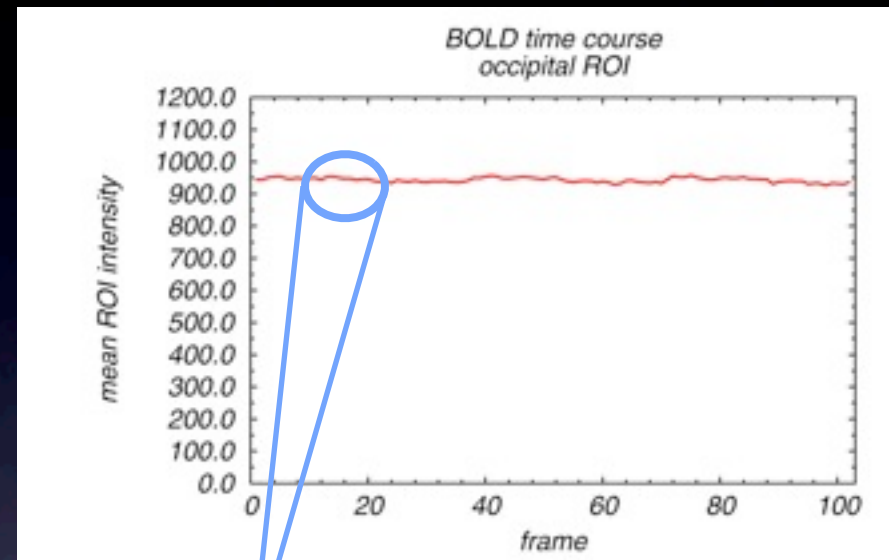
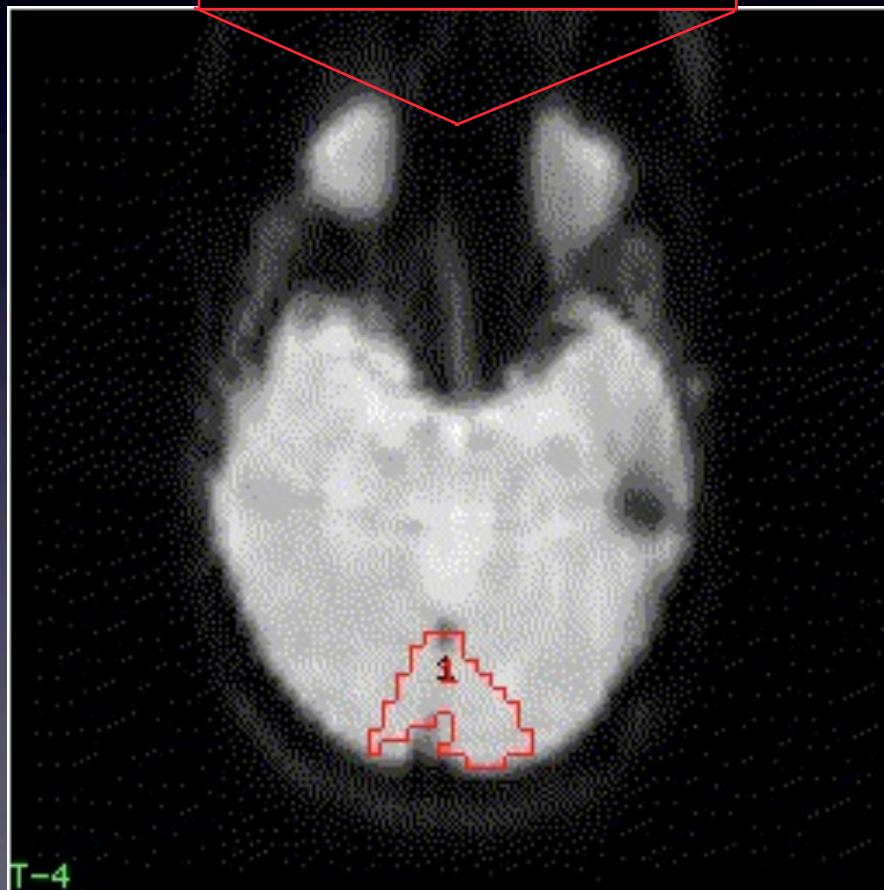
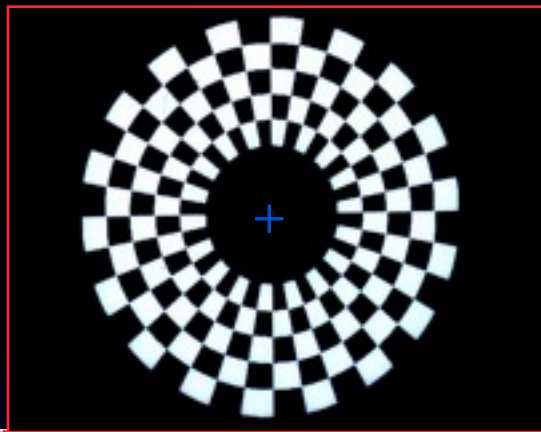


Control

=

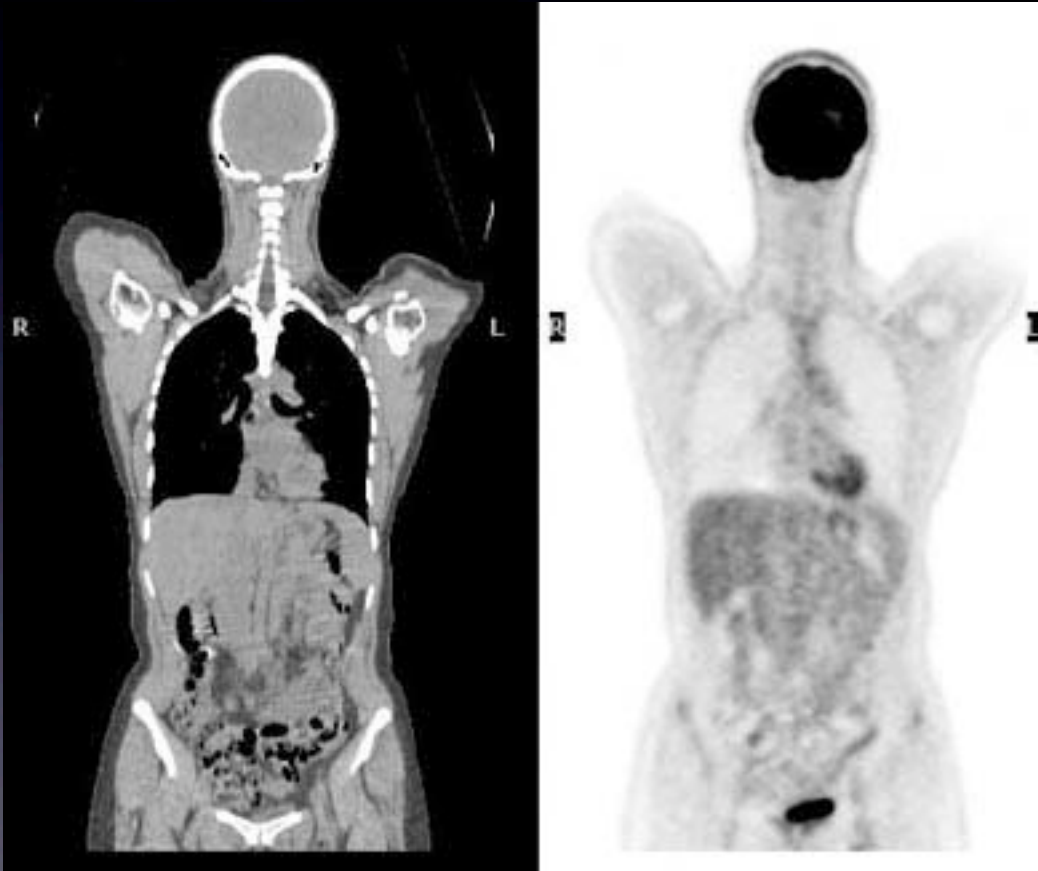






BRAIN

2% body weight
20% body energy



anatomy

function

Sibson et al. 1997, 1998; Shulman et al. 2001, 2004; Ames 2000,
Attwell & Laughlin 2001, Lennie 2003, Wong-Riley 1989

BRAIN

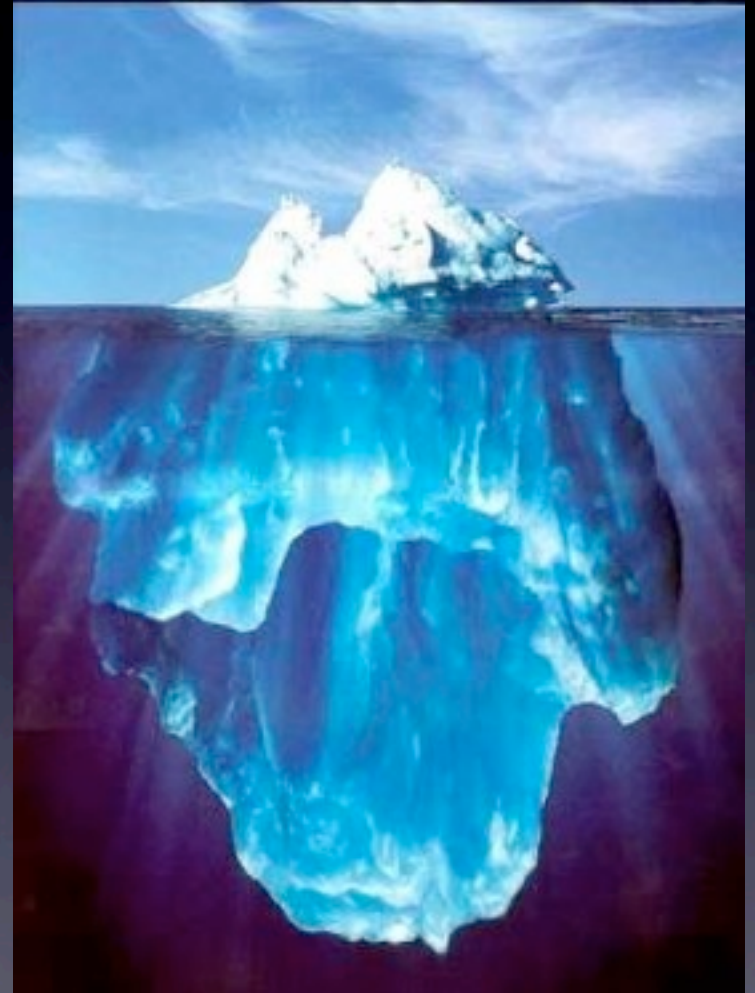
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anatomy



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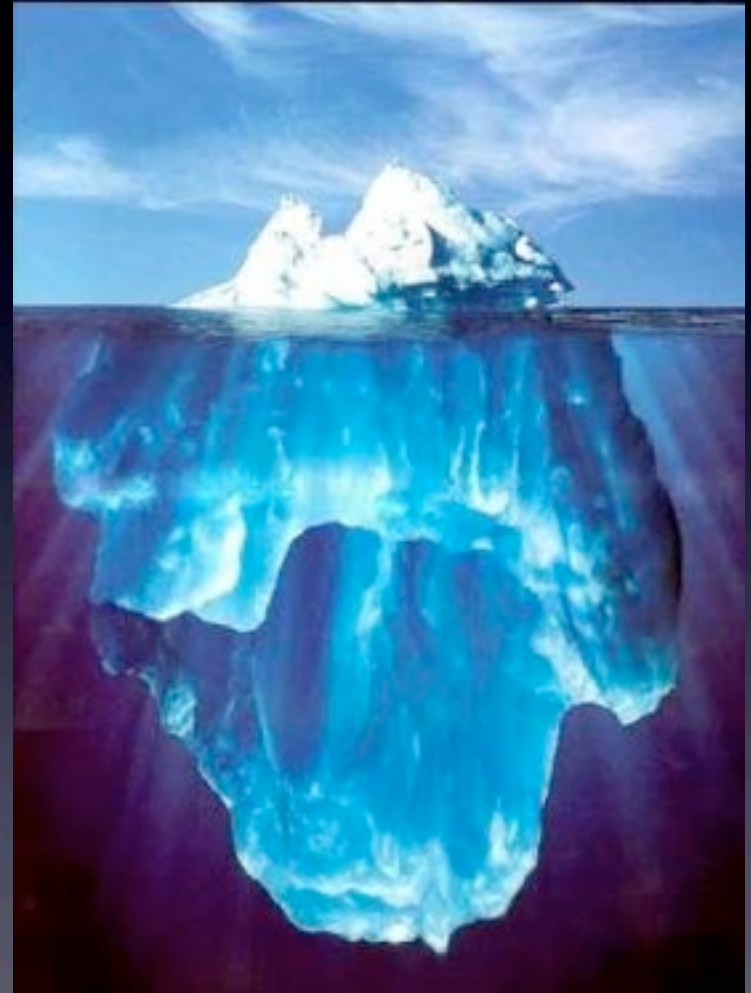


anatomy



function

BRAIN Task-evoked activity



Sibson et al. 1997, 1998; Shulman et al. 2001, 2004; Ames 2000,
Attwell & Laughlin 2001, Lennie 2003, Wong-Riley 1989

BRAIN

2% body weight
20% body energy



anatomy

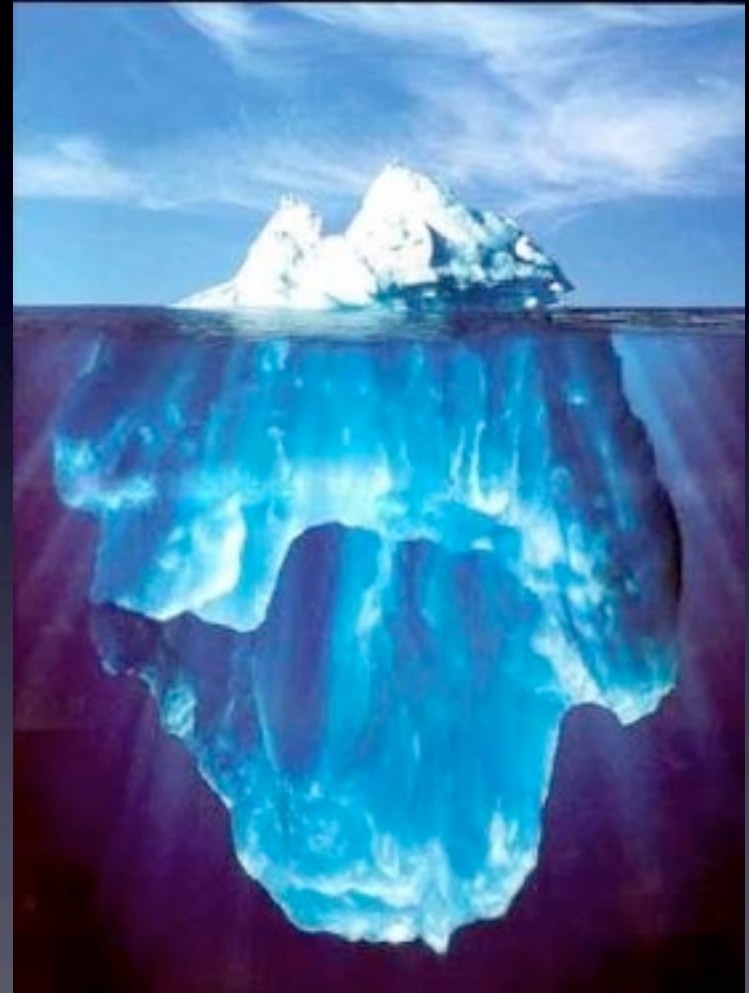


function

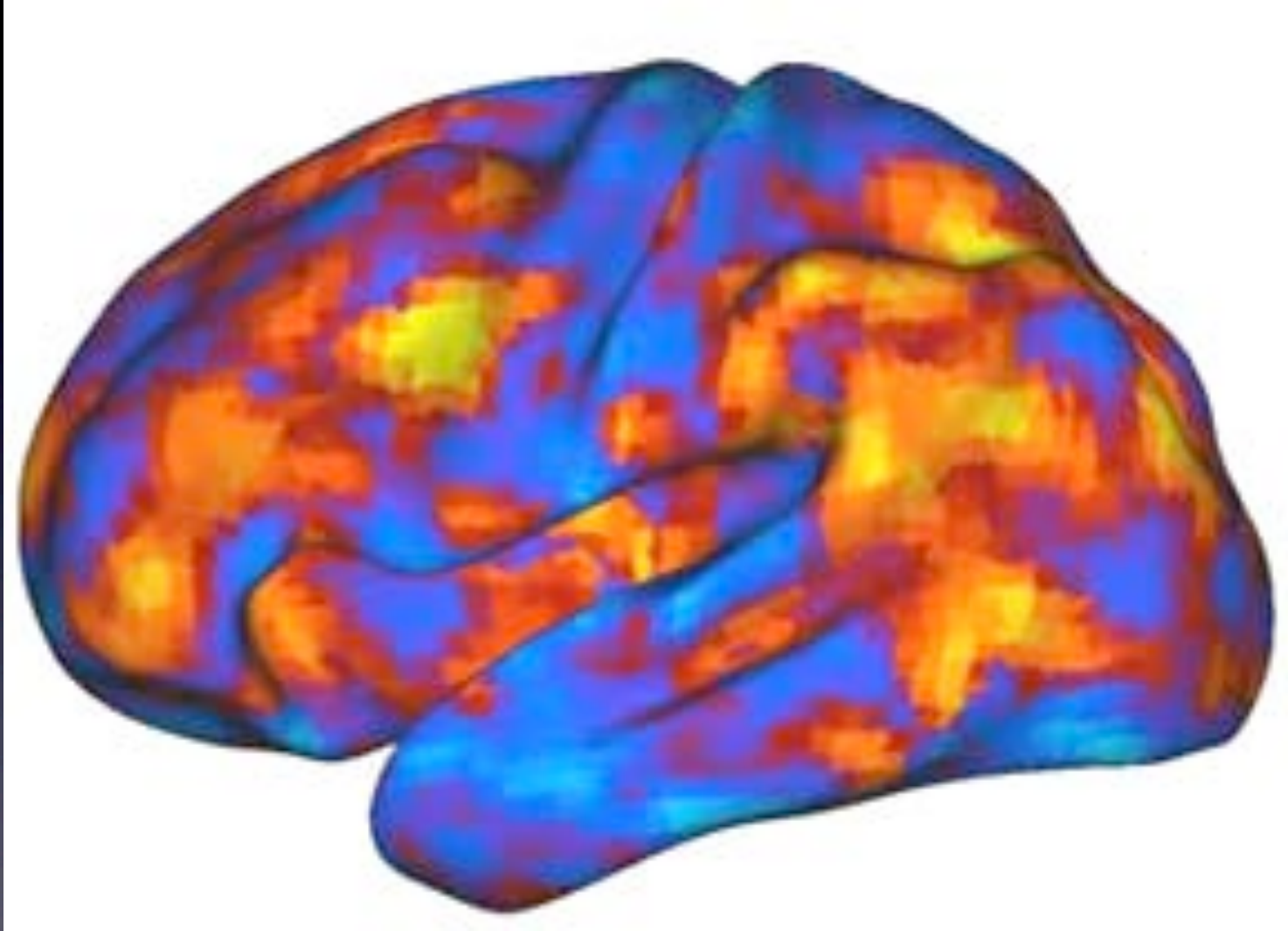
Sibson et al. 1997, 1998; Shulman et al. 2001, 2004; Ames 2000,
Attwell & Laughlin 2001, Lennie 2003, Wong-Riley 1989

BRAIN

Task-evoked activity



Spontaneous activity
70-80% of which 90% signaling



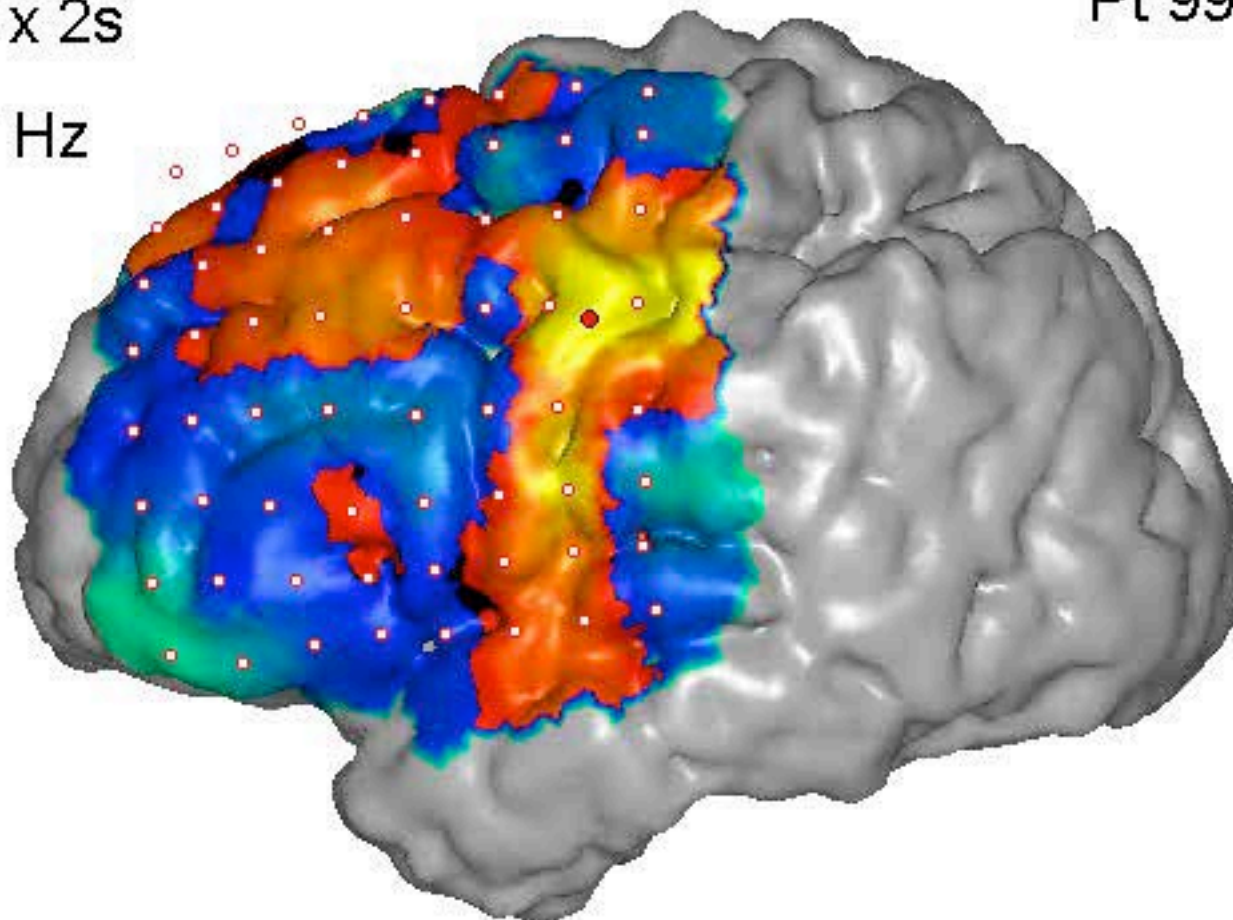
Resting state functional MRI (Washington University, St. Louis)

Tuesday, May 24, 2011

20s x 2s

Pt 99

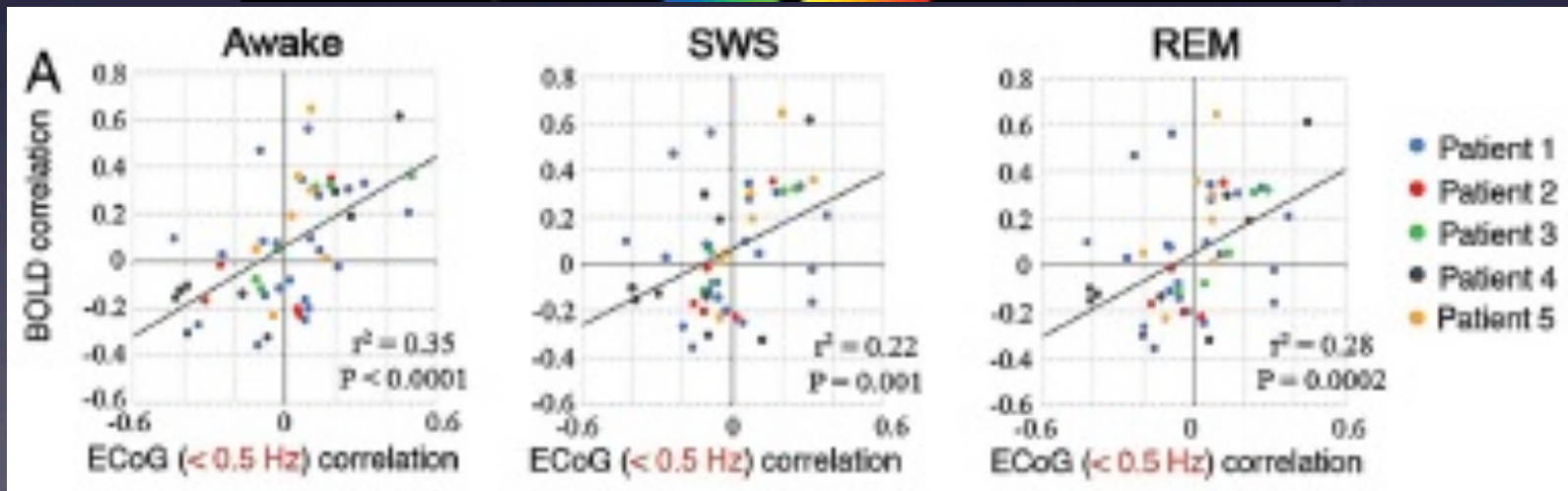
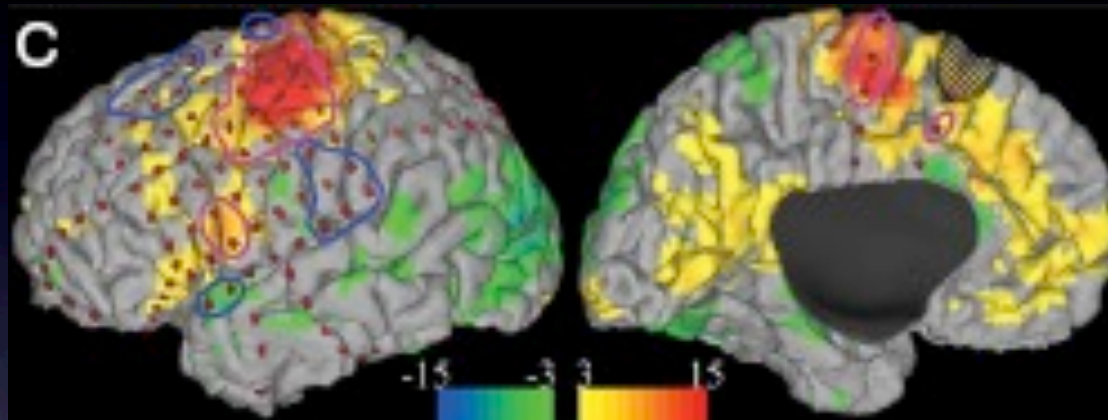
0.7 Hz



00:00:02 / 00:04:44

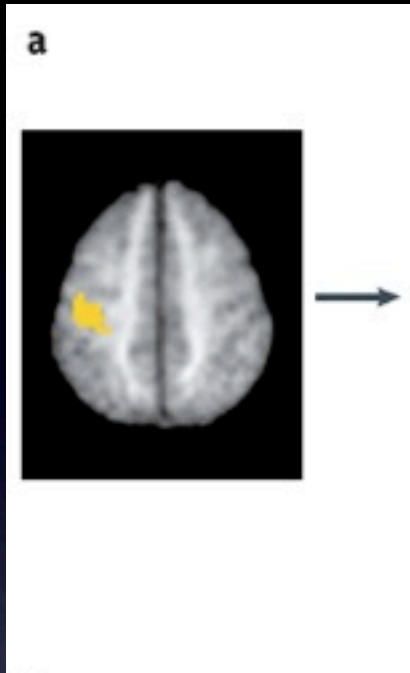
Hacker, Leuthardt, Corbetta unpublished

BOLD functional connectivity
may correlate with slow cortical potentials (<0.5 Hz) and
low frequency fluctuations of gamma band limited power



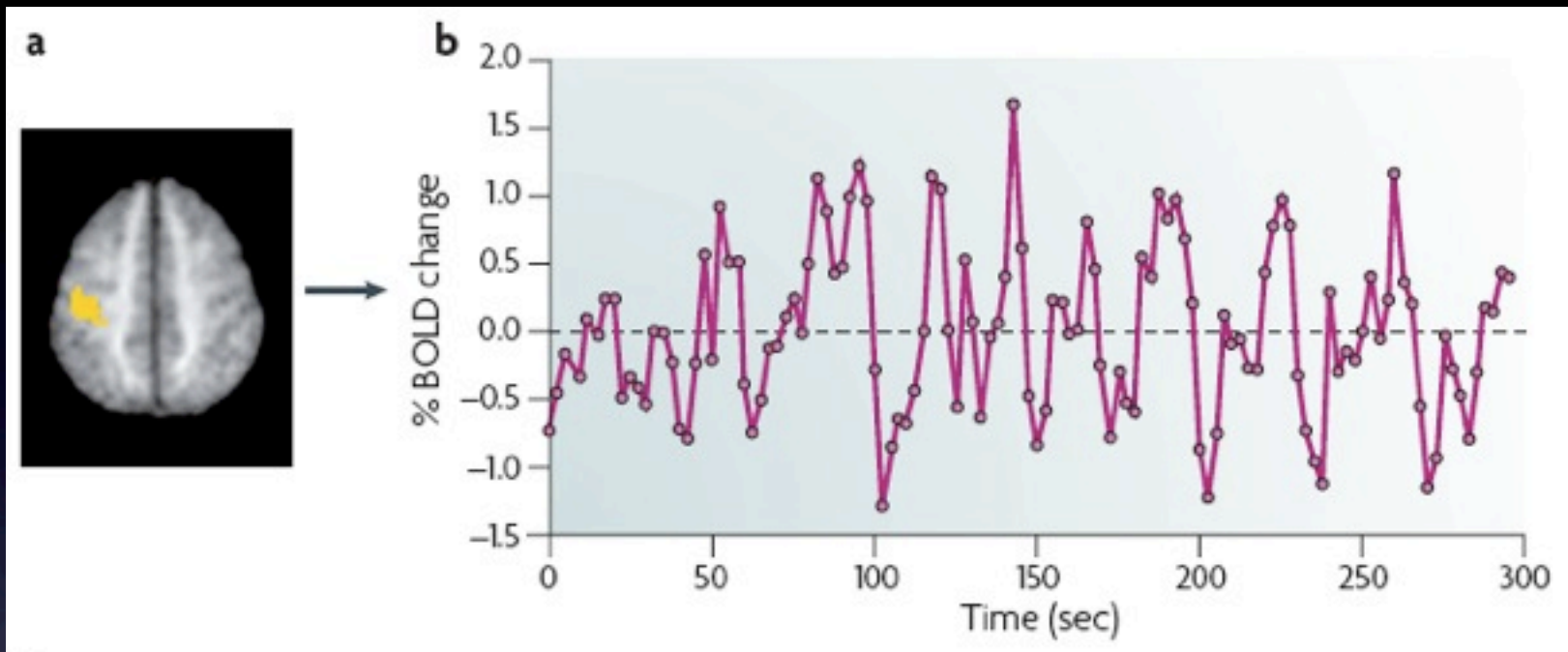
He et al., *PNAS* 2008

fMRI temporal correlation (functional connectivity) in the motor network



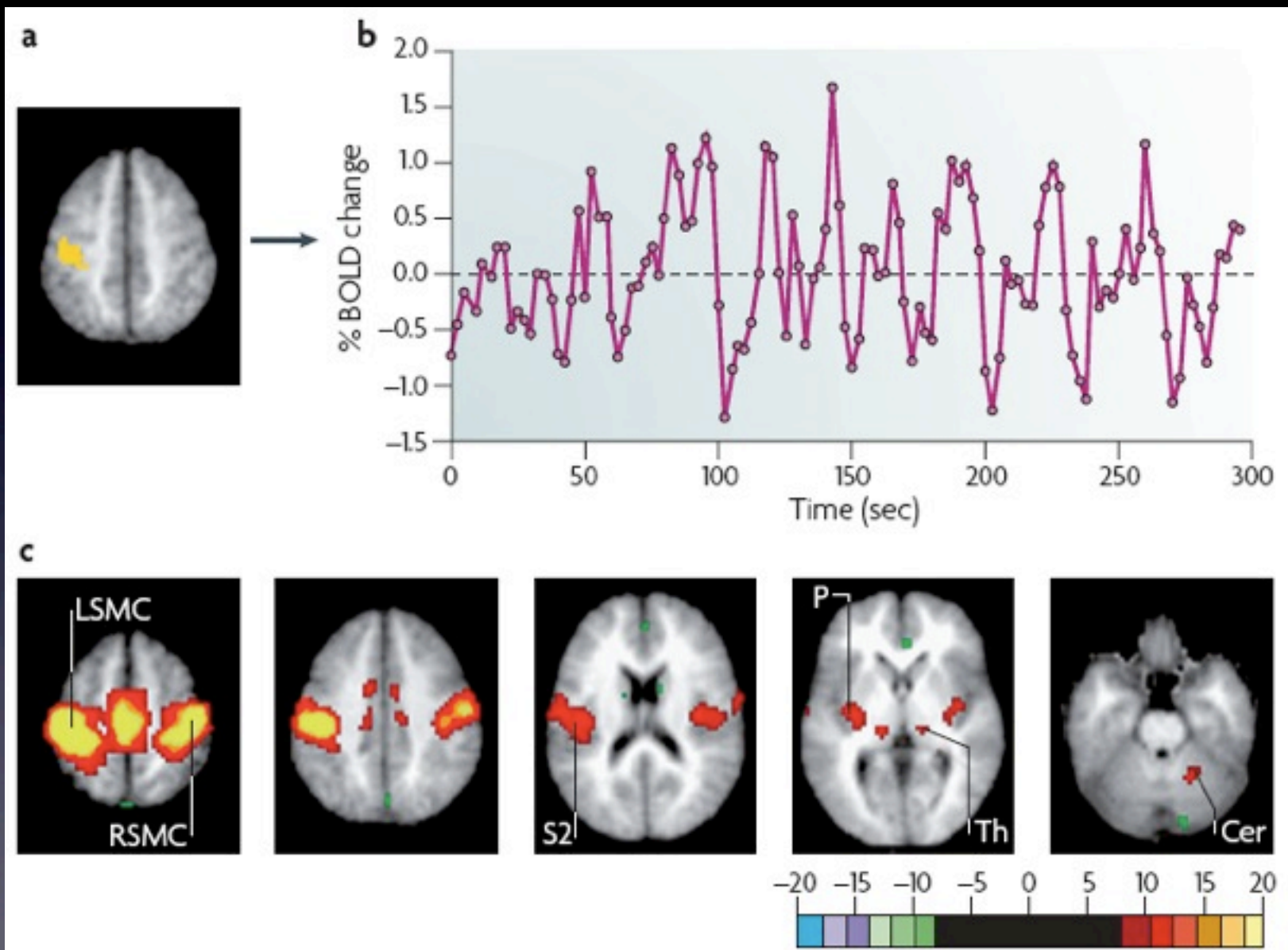
Biswal, *Magn.Res.Imag.Medicine*, 1996

fMRI temporal correlation (functional connectivity) in the motor network



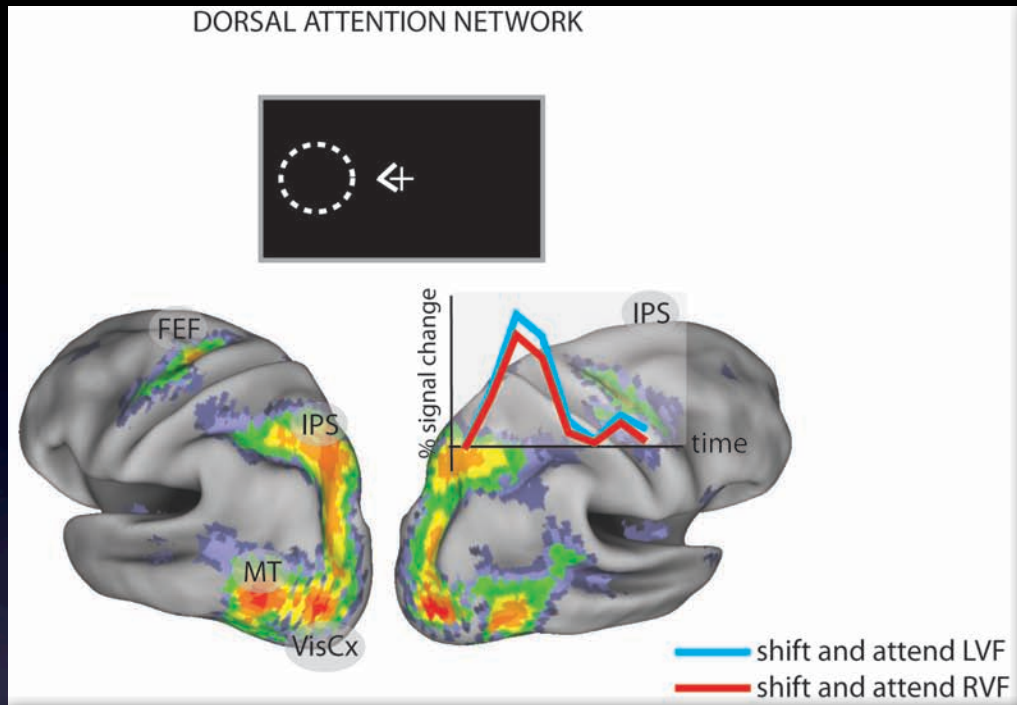
Biswal, *Magn.Res.Imag.Medicine*, 1996

fMRI temporal correlation (functional connectivity) in the motor network



Biswal, *Magn.Res.Imag.Medicine*, 1996

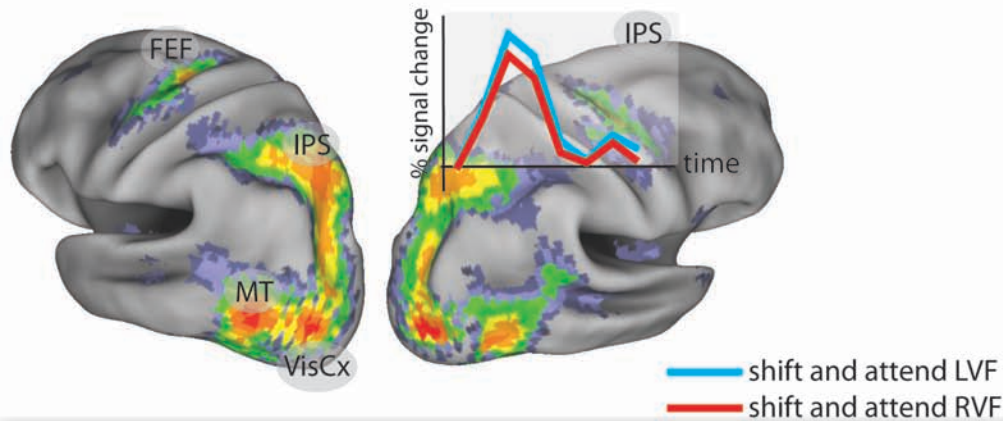
Dorsal and Ventral Attention Networks



Corbetta & Shulman, *Ann.Rev.Neurosci.* 2011

Dorsal and Ventral Attention Networks

DORSAL ATTENTION NETWORK



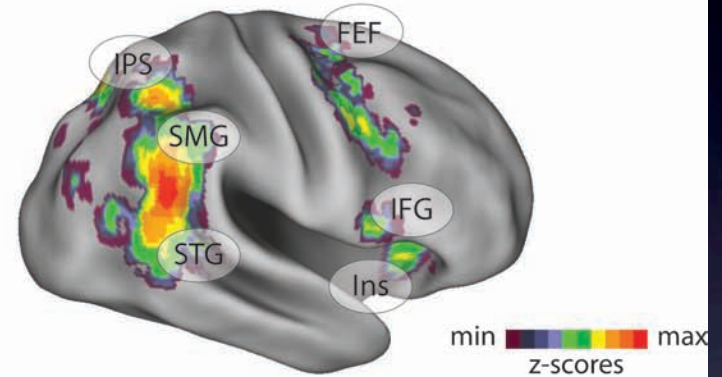
VENTRAL ATTENTION NETWORK



Invalidly cued target



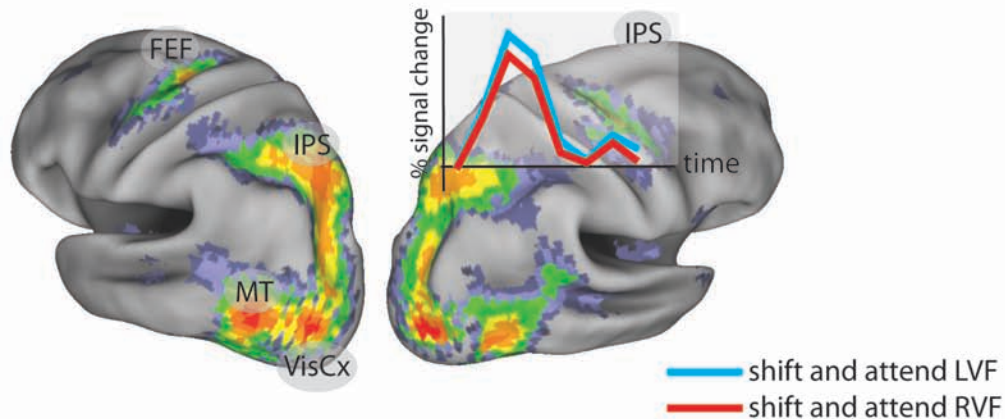
Validly cued target



Corbetta & Shulman, *Ann.Rev.Neurosci.* 2011

Dorsal and Ventral Attention Networks

DORSAL ATTENTION NETWORK



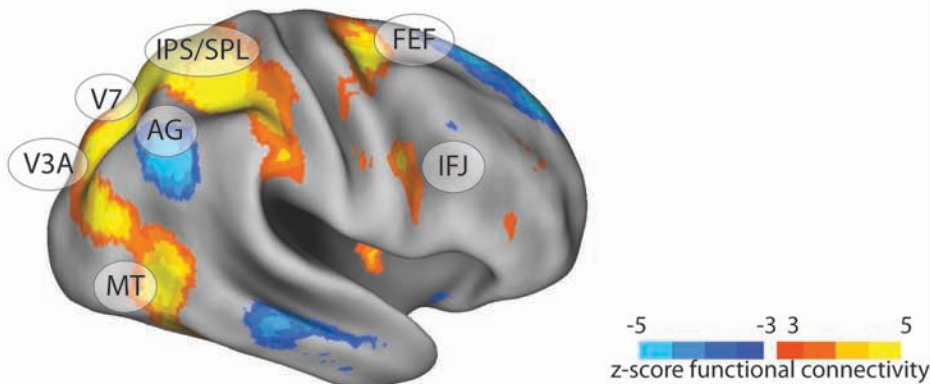
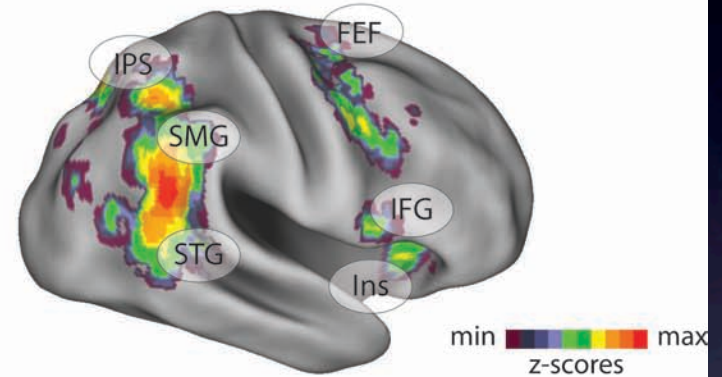
VENTRAL ATTENTION NETWORK



Invalidly cued target



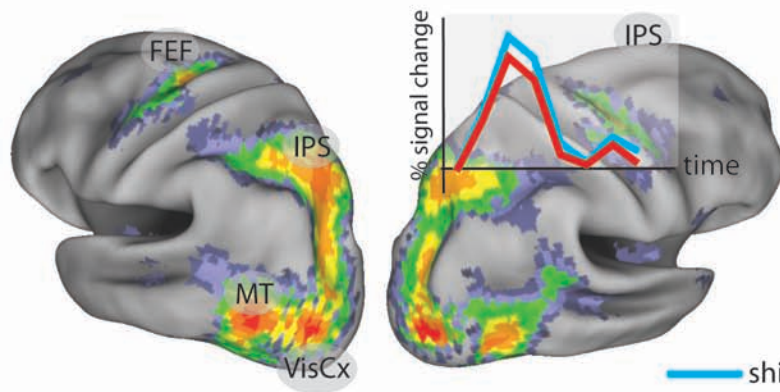
Validly cued target



Corbetta & Shulman, *Ann.Rev.Neurosci.* 2011

Dorsal and Ventral Attention Networks

DORSAL ATTENTION NETWORK



— shift and attend LVF
— shift and attend RVF

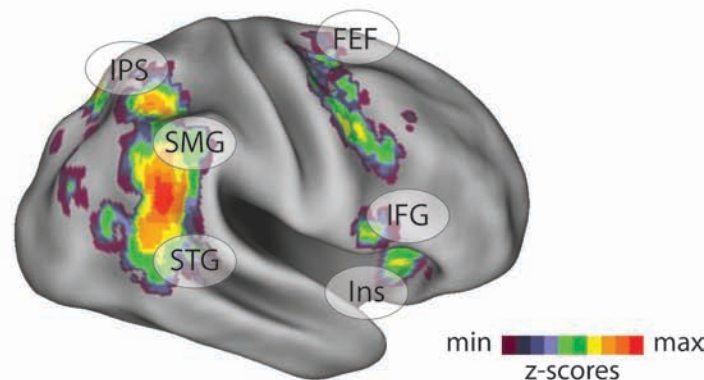
VENTRAL ATTENTION NETWORK



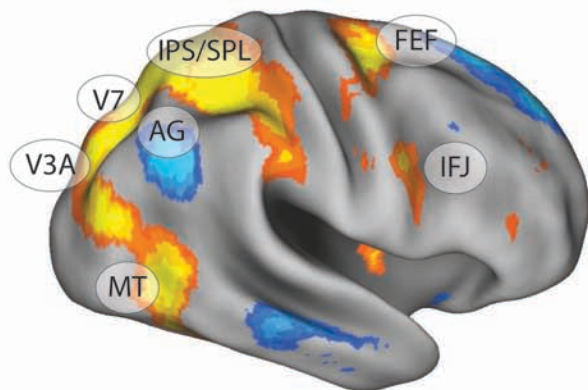
Invalidly cued target



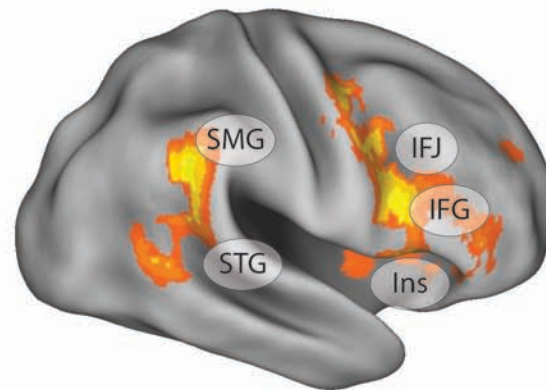
Validly cued target



min z-scores max



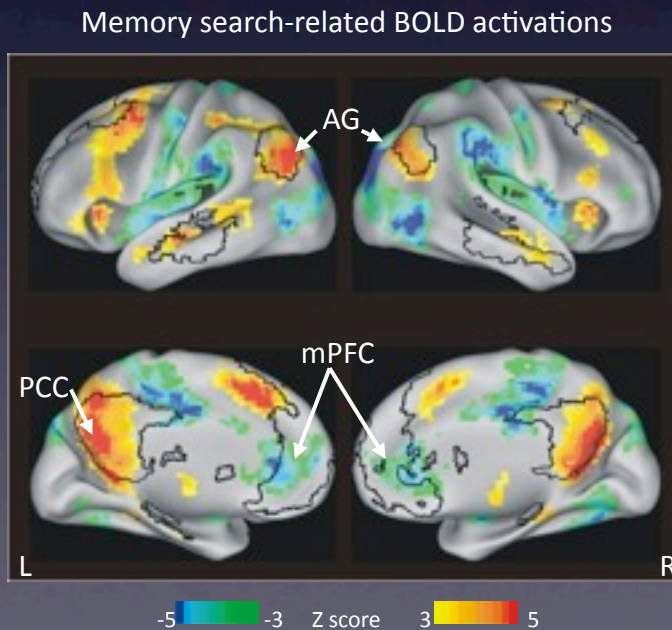
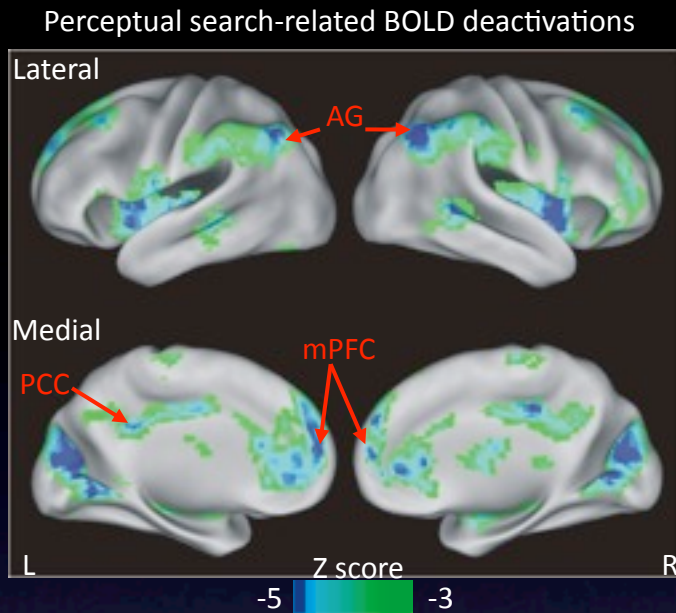
-5 -3 3 5
z-score functional connectivity



Corbetta & Shulman, *Ann.Rev.Neurosci.* 2011

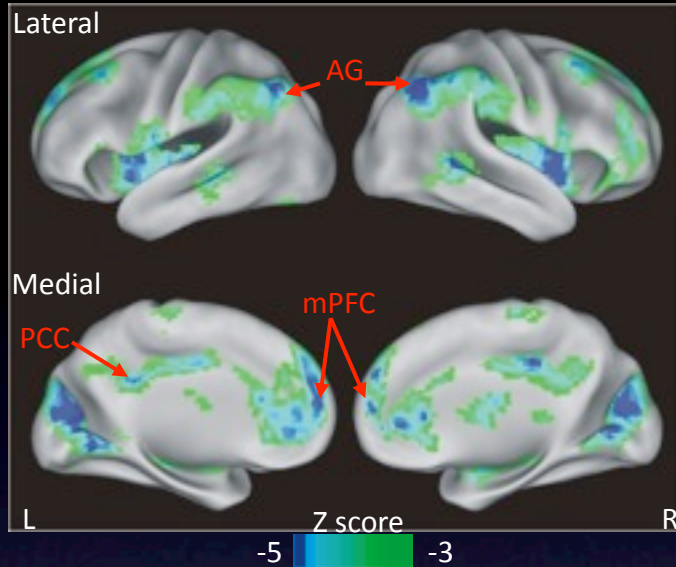
Default-mode network

Episodic memory

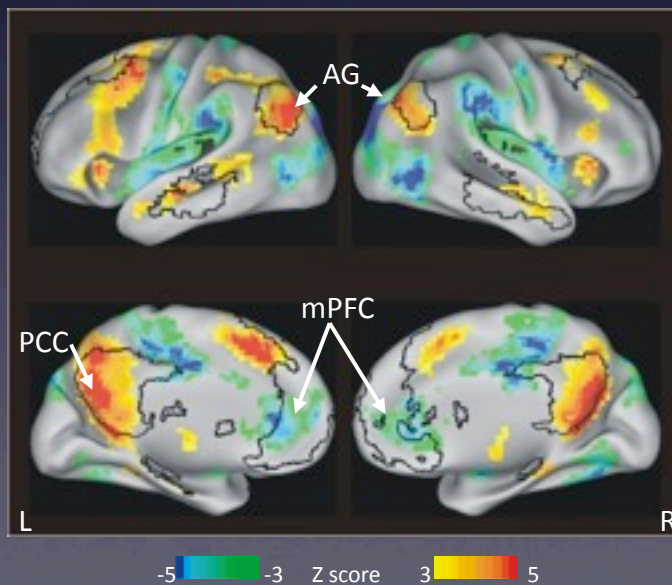


Fox, et al. (2005) Proc. Natl. Acad. Sci. USA 102, 9673-9678
Sestieri, et al. (2011) J.Neurosci.

Perceptual search-related BOLD deactivations

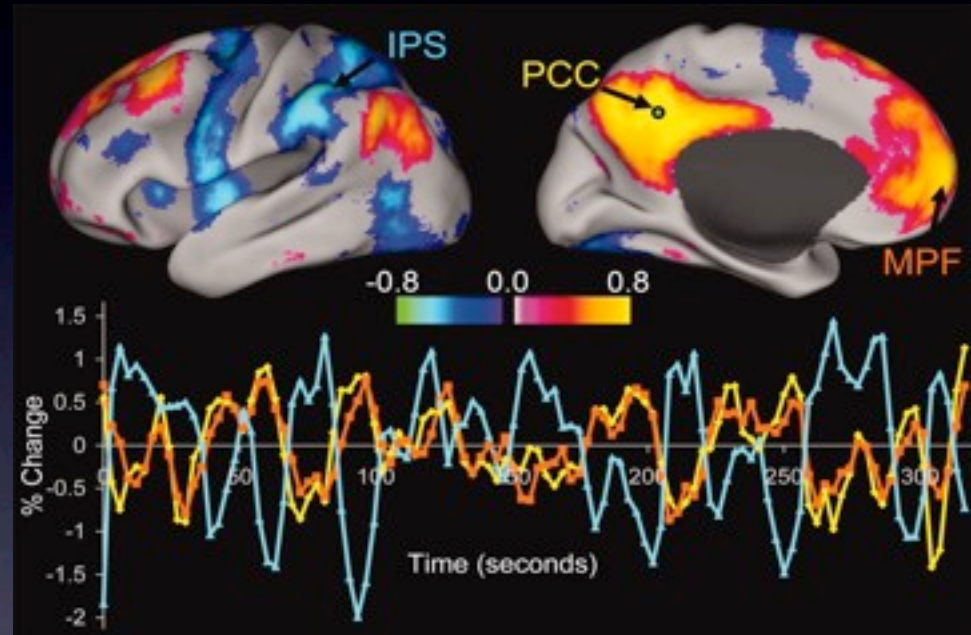


Memory search-related BOLD activations



Default-mode network

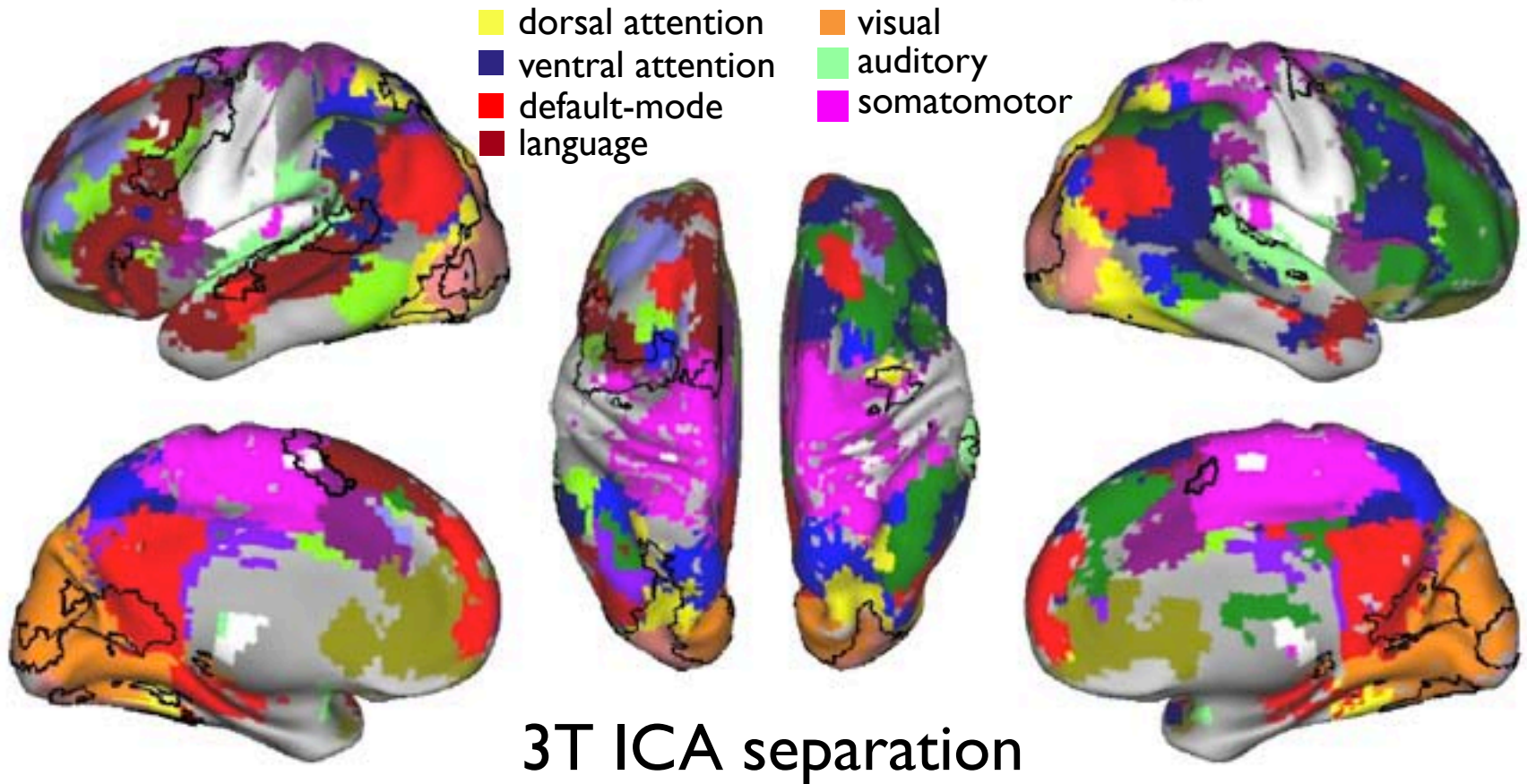
Episodic memory



Fox, et al. (2005) Proc. Natl. Acad. Sci. USA 102, 9673-9678

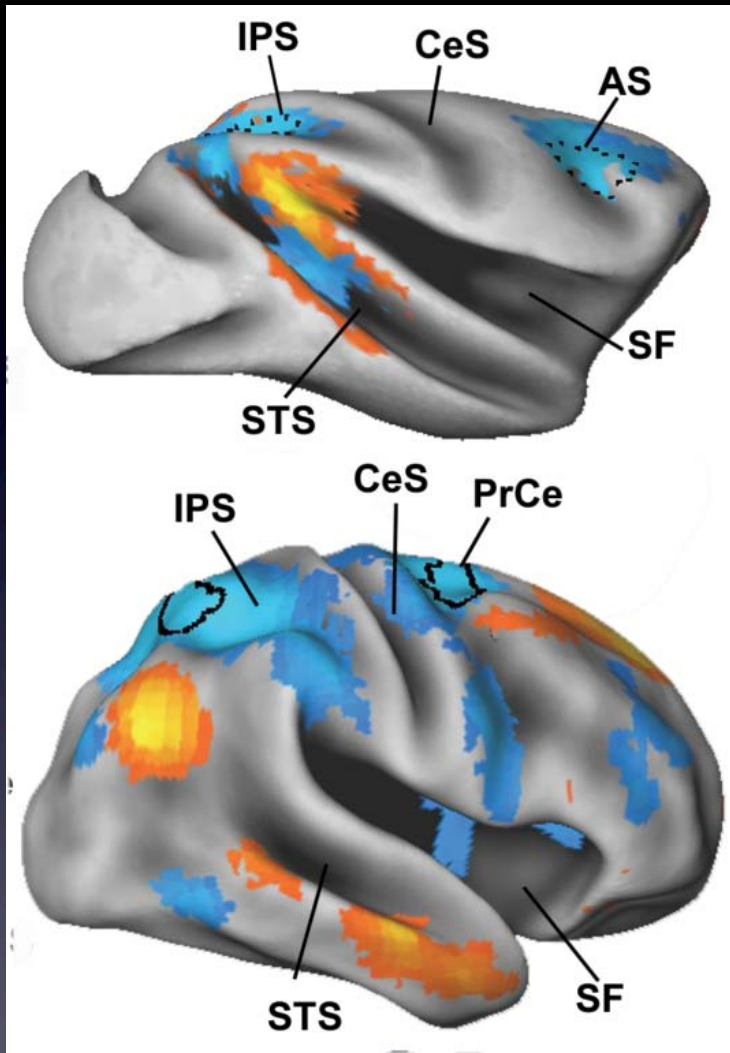
Sestieri, et al. (2011) J.Neurosci.

About 90% cerebral cortex is organized in networks of spontaneous activity



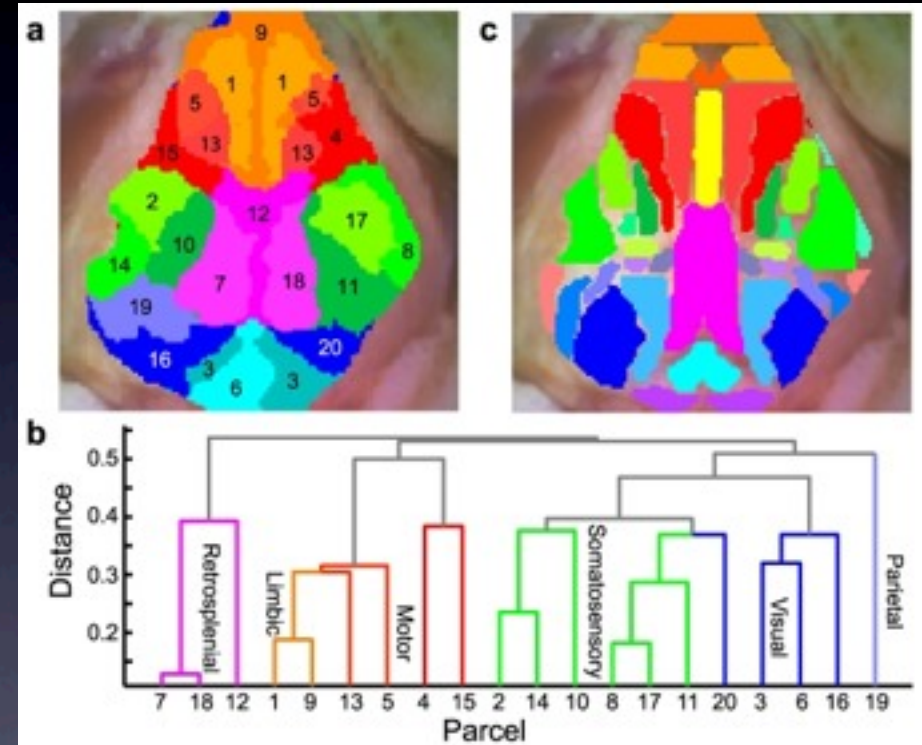
Mantini & Corbetta, unpublished

Functional connectivity in macaque and mouse



■ dorsal attention ■ default

Vincent et al. *Nature* 2007



Culver et al. *PLOS* 2011

Summary

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Spontaneous activity is organized in large-scale spatiotemporal patterns (or functional connectivity) that resemble functional networks recruited during tasks.

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Functional connectivity is a higher probability state to which the cortex goes back at rest.

Origin of spontaneous activity correlation patterns?

Summary

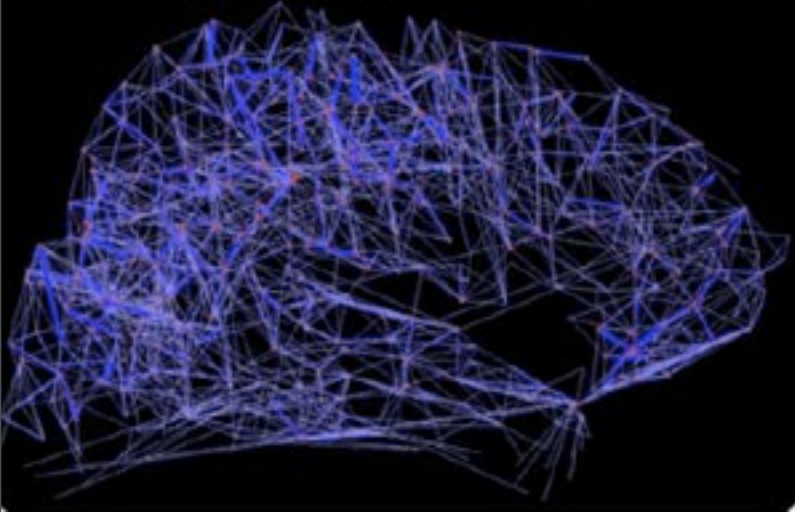
Spontaneous activity is organized in large-scale spatiotemporal patterns (or functional connectivity) that resemble functional networks recruited during tasks.

Functional connectivity is a higher probability state to which the cortex goes back at rest.

Origin of spontaneous activity correlation patterns?
Anatomy vs. Function?

BOLD functional connectivity: a physiological index of anatomical connectivity?

Whole brain structural
connection network

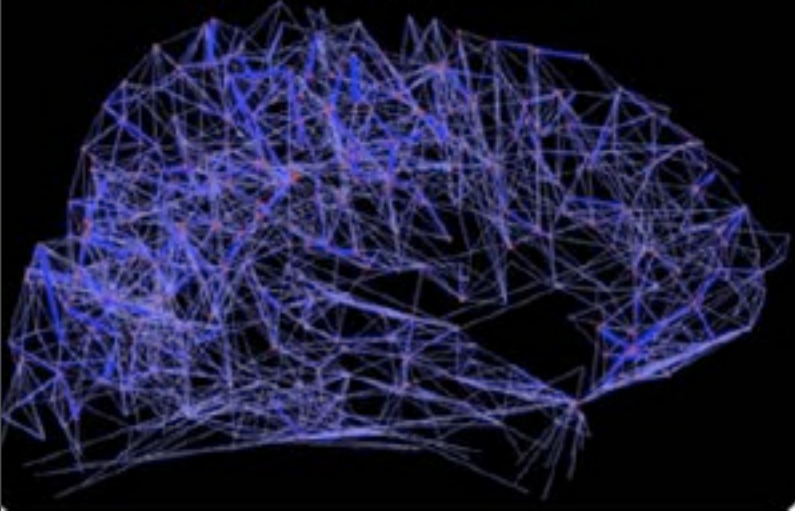


Hagman et al. *PLOS* 2008

Honey et al PNAS 2009

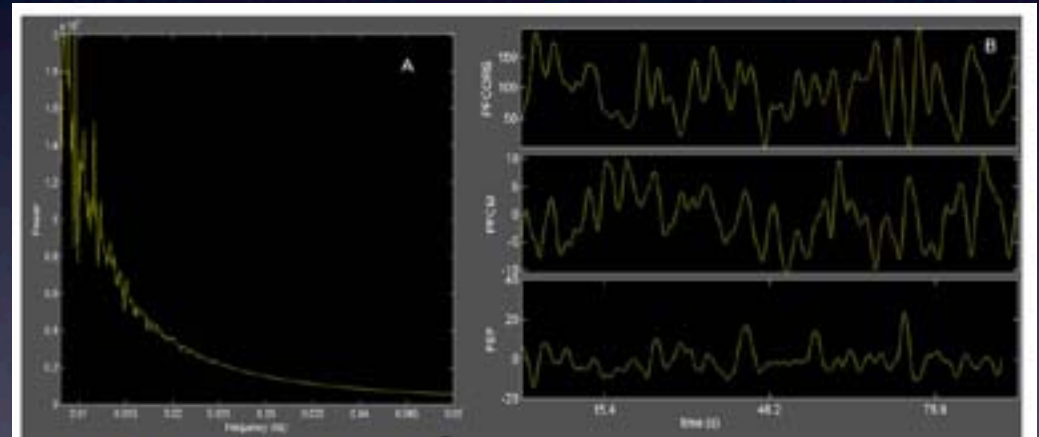
BOLD functional connectivity: a physiological index of anatomical connectivity?

Whole brain structural
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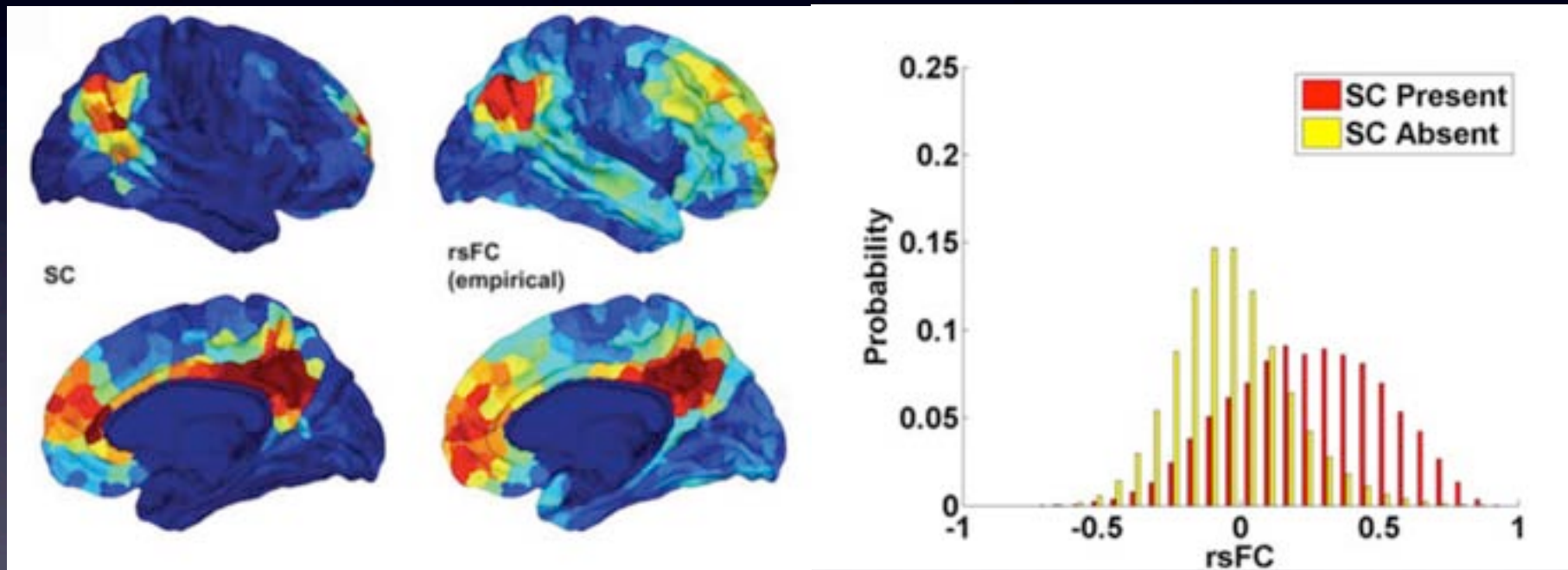
Hagman et al. *PLOS* 2008
Honey et al *PNAS* 2009

Connectome + delays generates
spontaneous fluctuations



Gosh et al. *PLOS* 2008; Jirsa et al. *JNeurosci* 2009;
Deco et al *PNAS* 2010; McIntosh & Deco, *Nature
Rev.Neurosci.* 2011

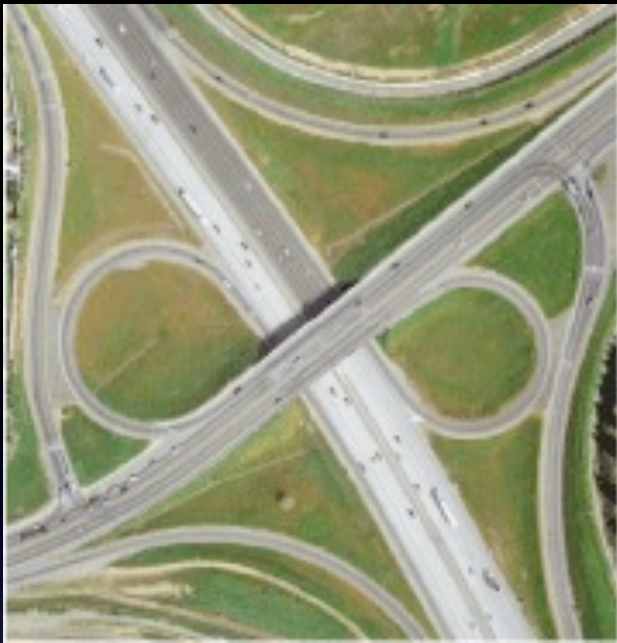
Structural connectivity (SC) does not predict resting state functional connectivity (rsFC)



Honey et al. *PNAS* 2009



Anatomical Connectivity



Anatomical Connectivity



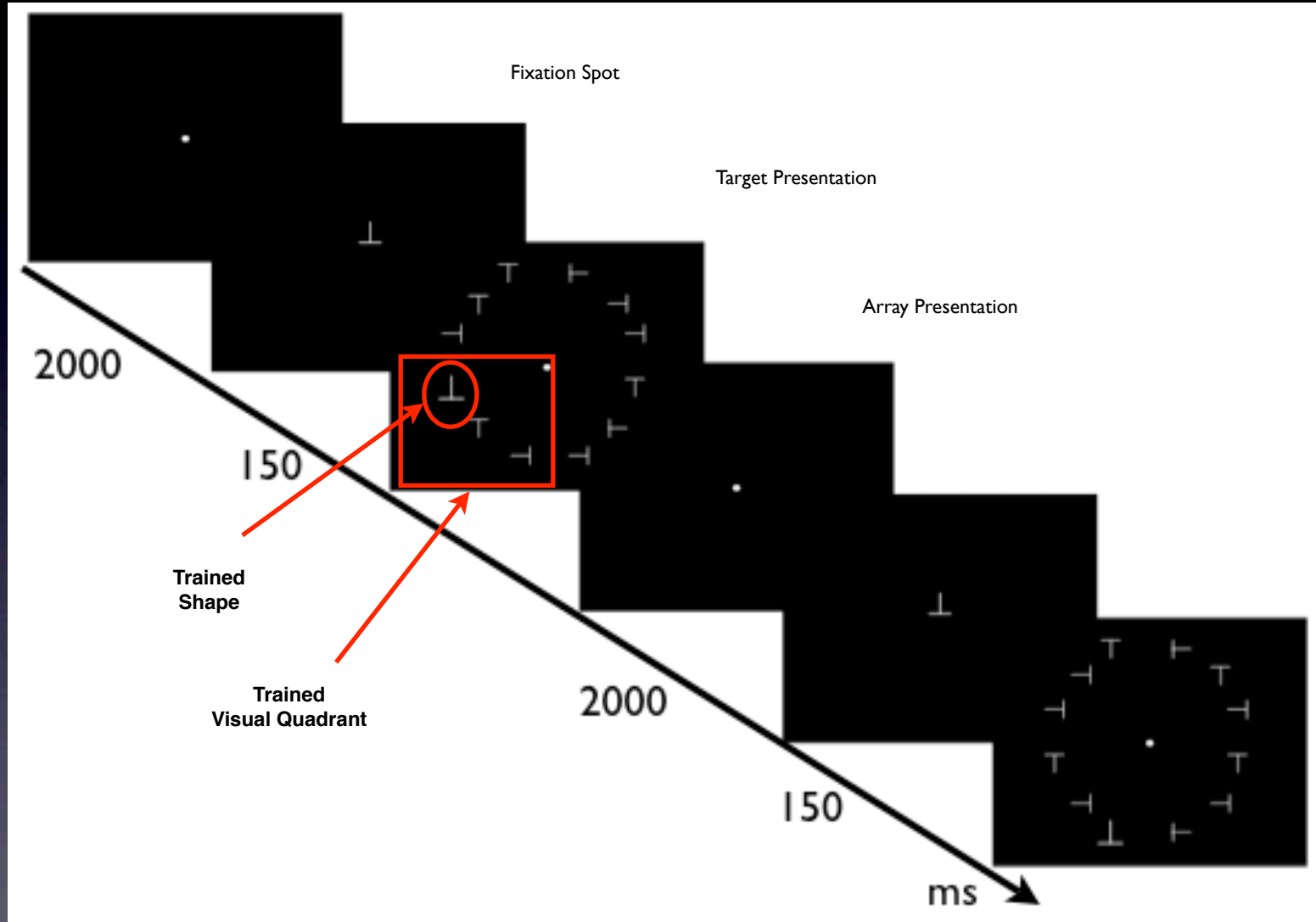
Functional Connectivity



If functional connectivity networks are not simply hard-wired, but partly reflect the history of prior activation (fire-wire), then training should ‘*sculpt*’ the functional architecture at rest

- New patterns of covariance reflecting prior experience
- Strength of covariance change related to behavioral performance
- Functional connectivity as a potential correlate of predisposition and individual variability

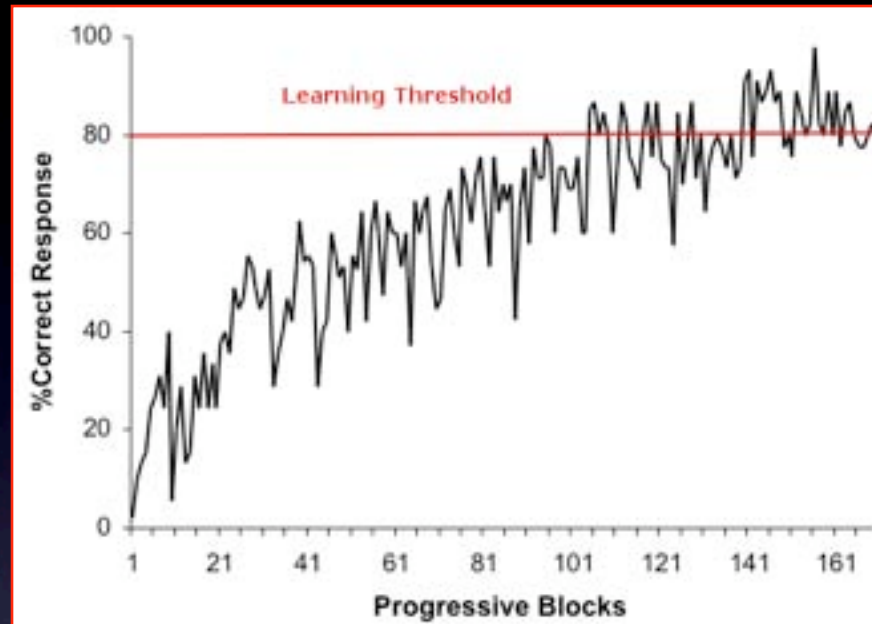
Paradigm and behavior



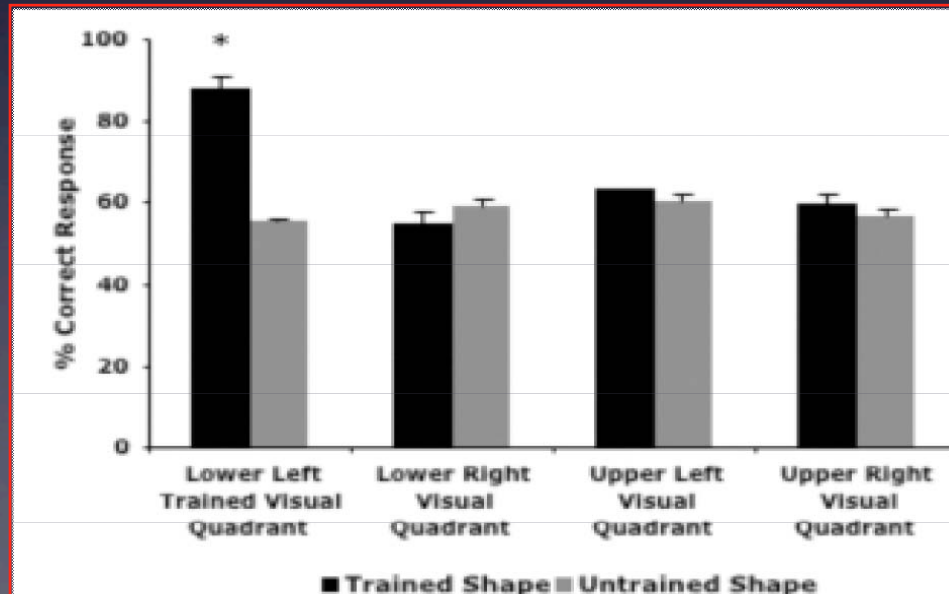
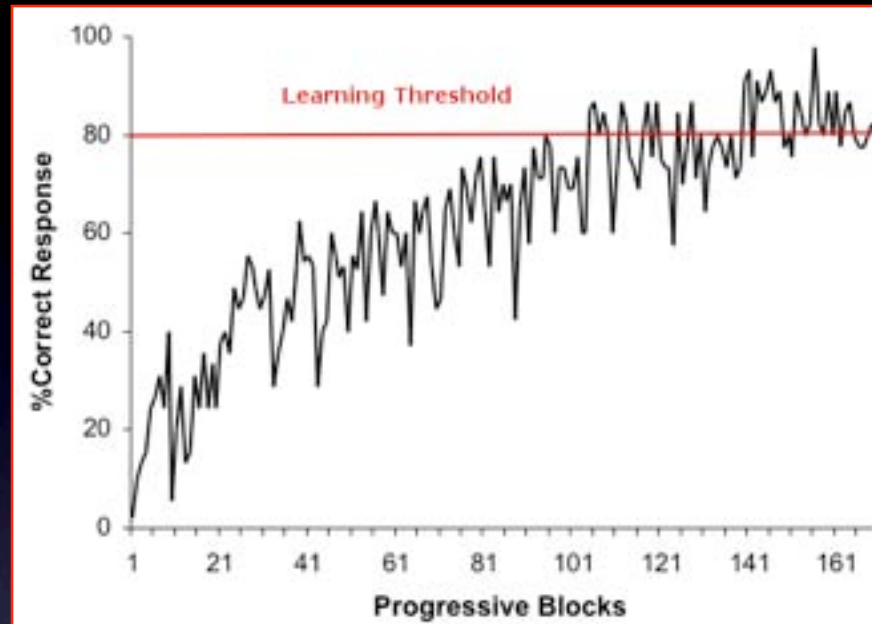
Lewis et al. *PNAS* 2009

Training specific for the location and target shape

Training specific for the location and target shape



Training specific for the location and target shape



Design



Design



Visual cortex



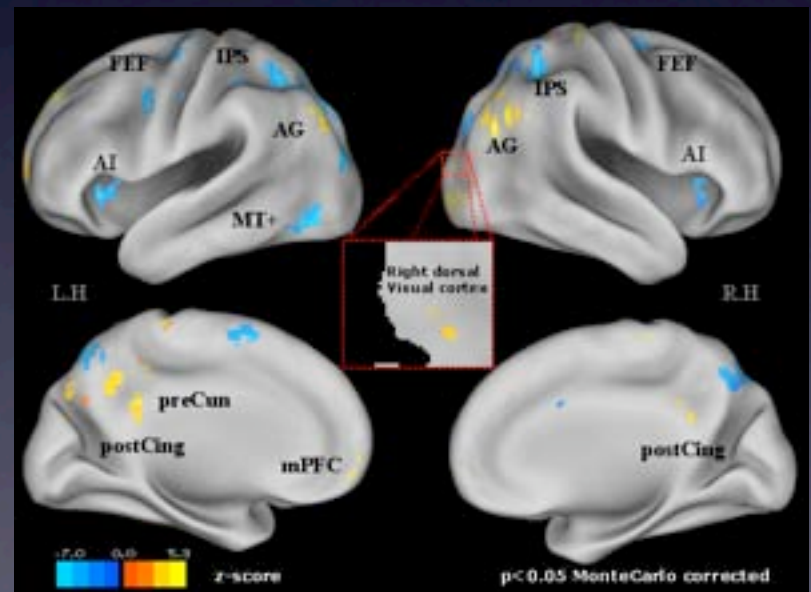
Design



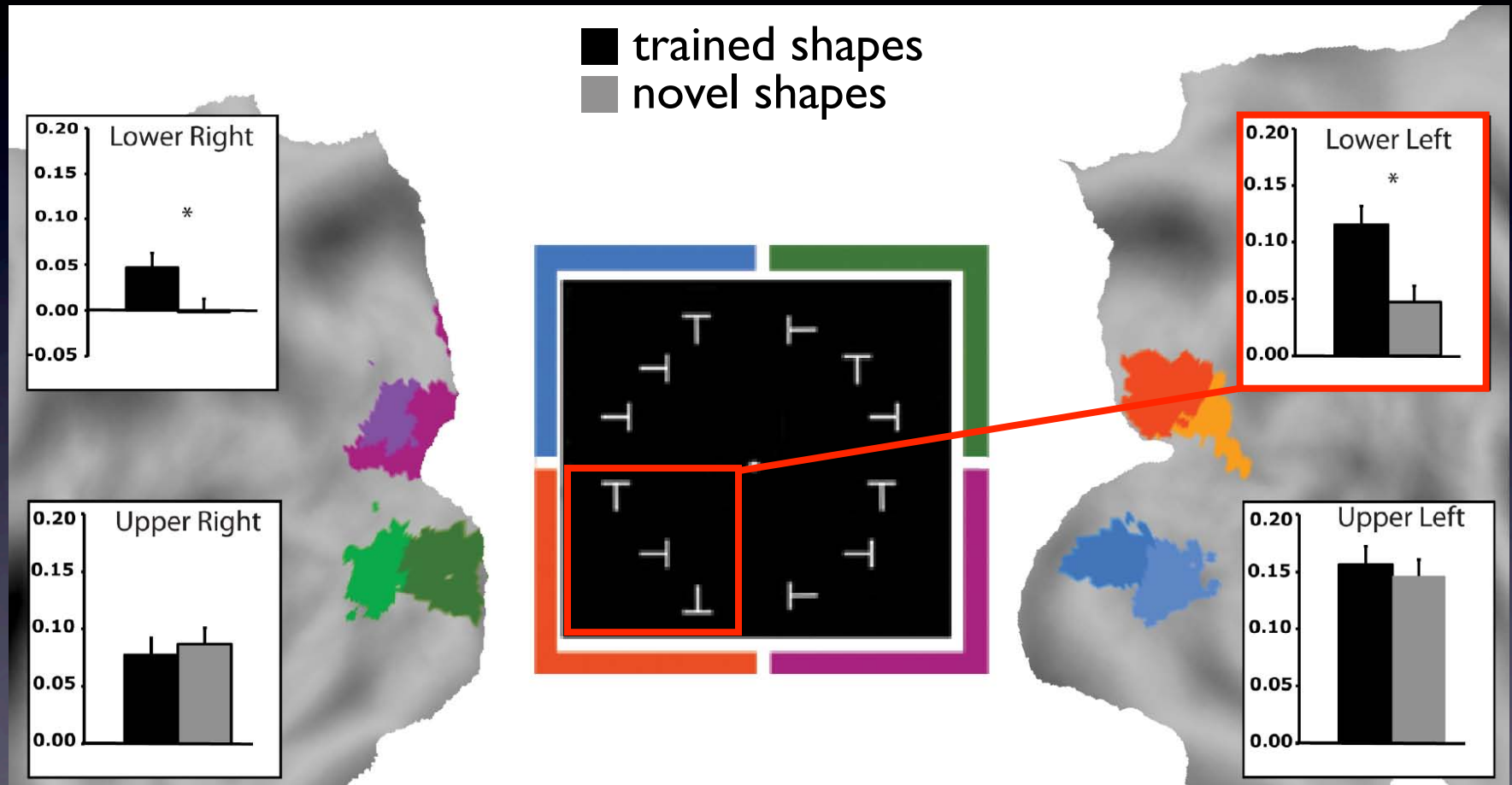
Visual cortex



Trained-novel shapes

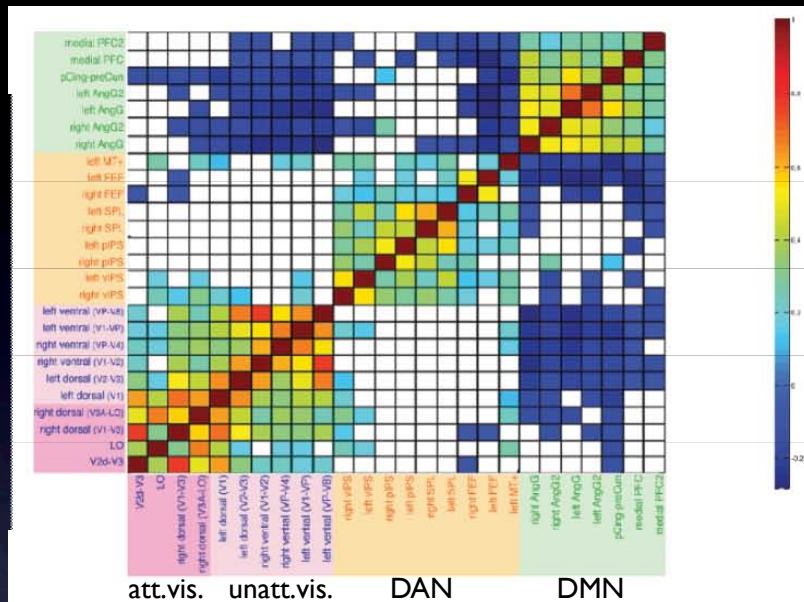


Task-evoked activity: learning enhances retinotopic activity for trained over novel target

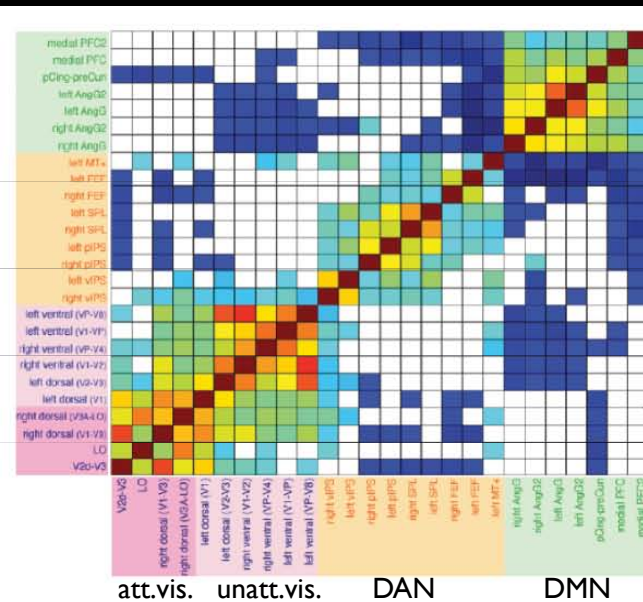


Lewis et al. *PNAS* 2009

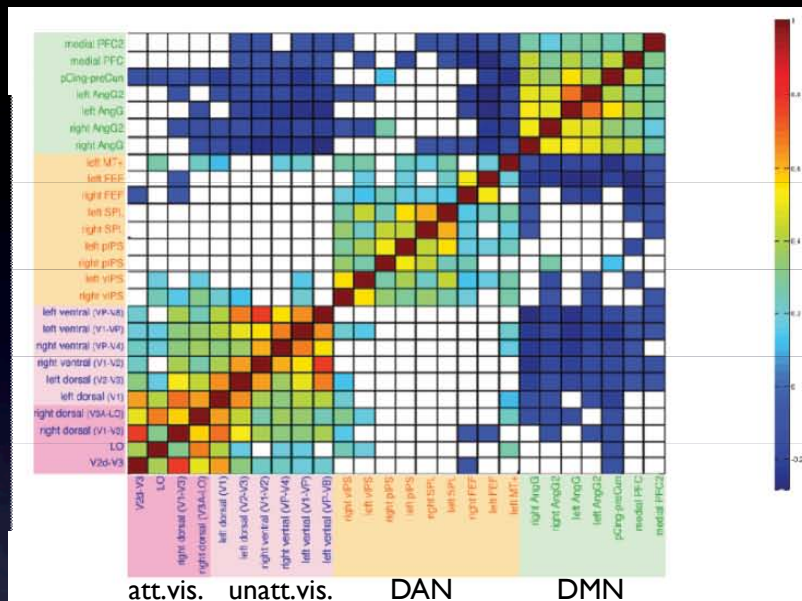
Pre-learning



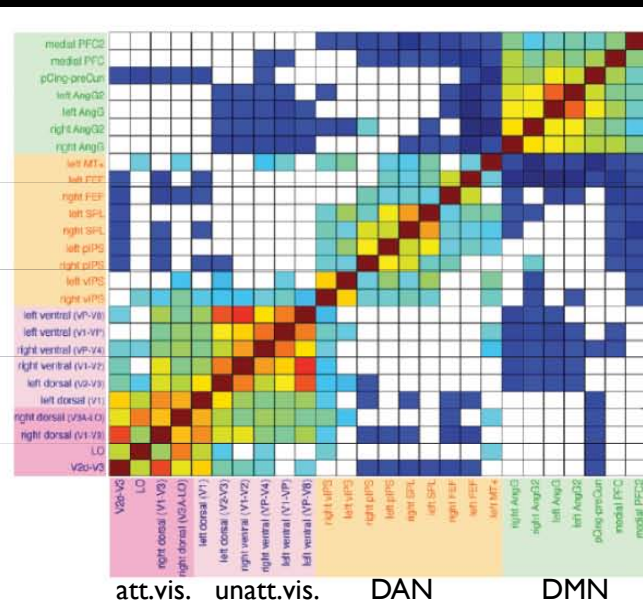
Post-learning



Pre-learning

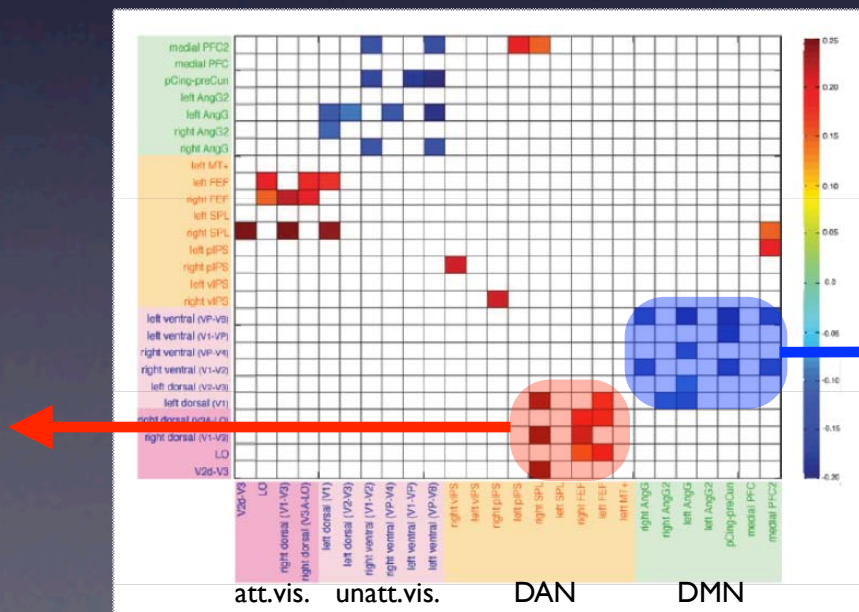


Post-learning

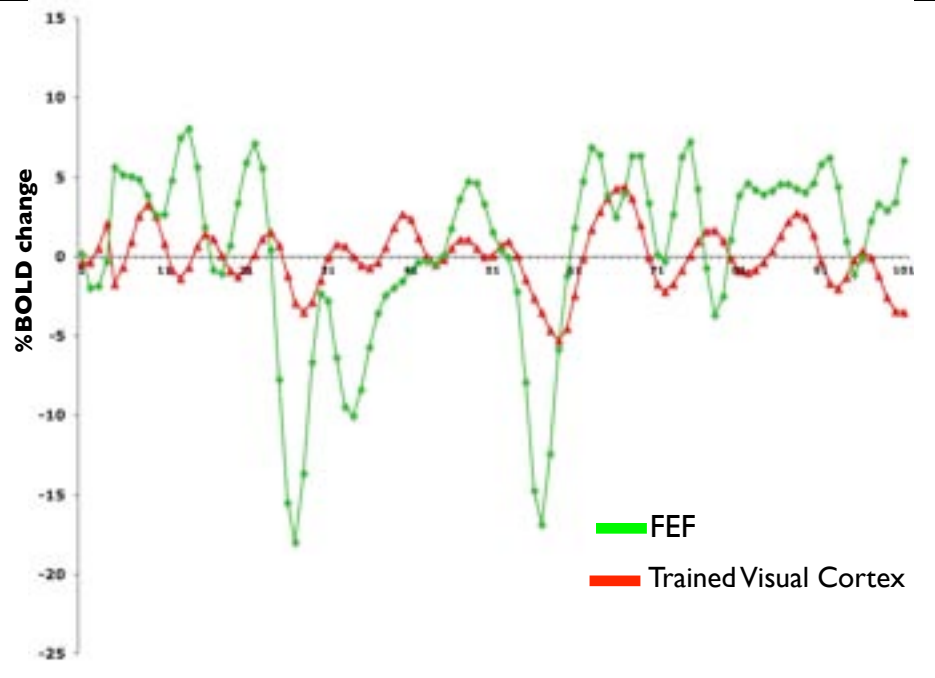


Pre-Post

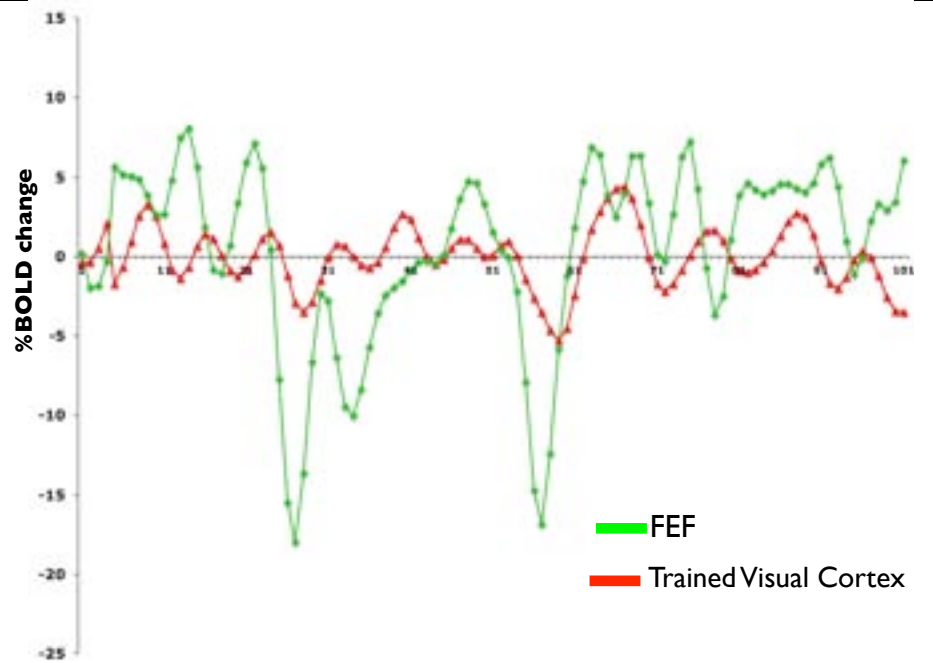
DAN & attended Vis.Cx



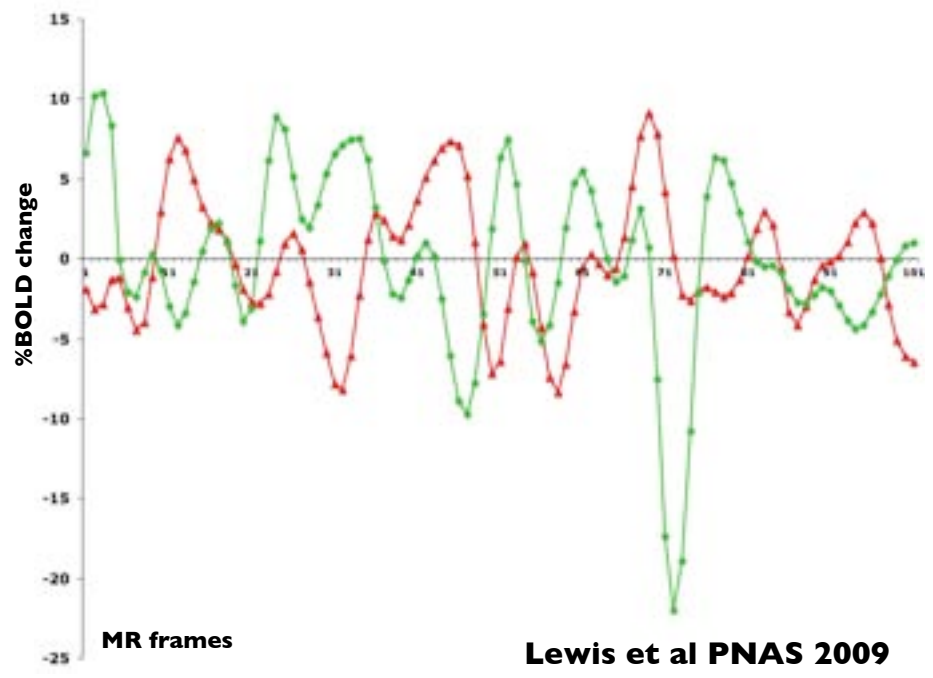
DMN & unattended Vis.Cx



PRE-LEARNING
no correlation



PRE-LEARNING
no correlation

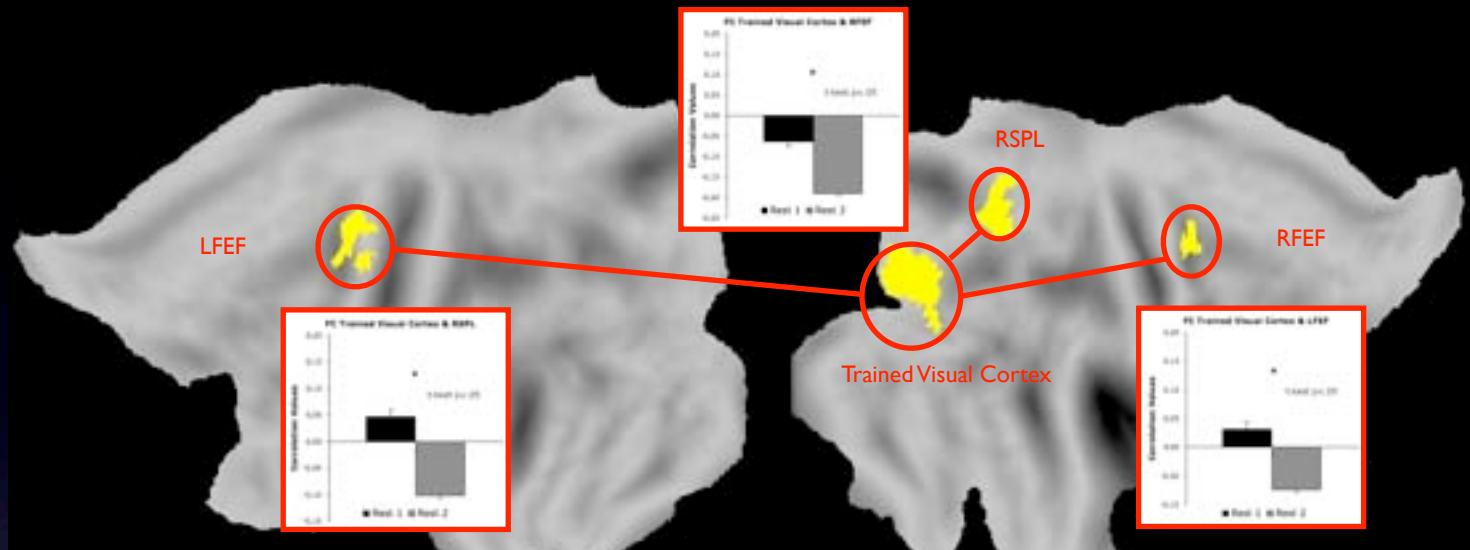


POST-LEARNING
negative correlation

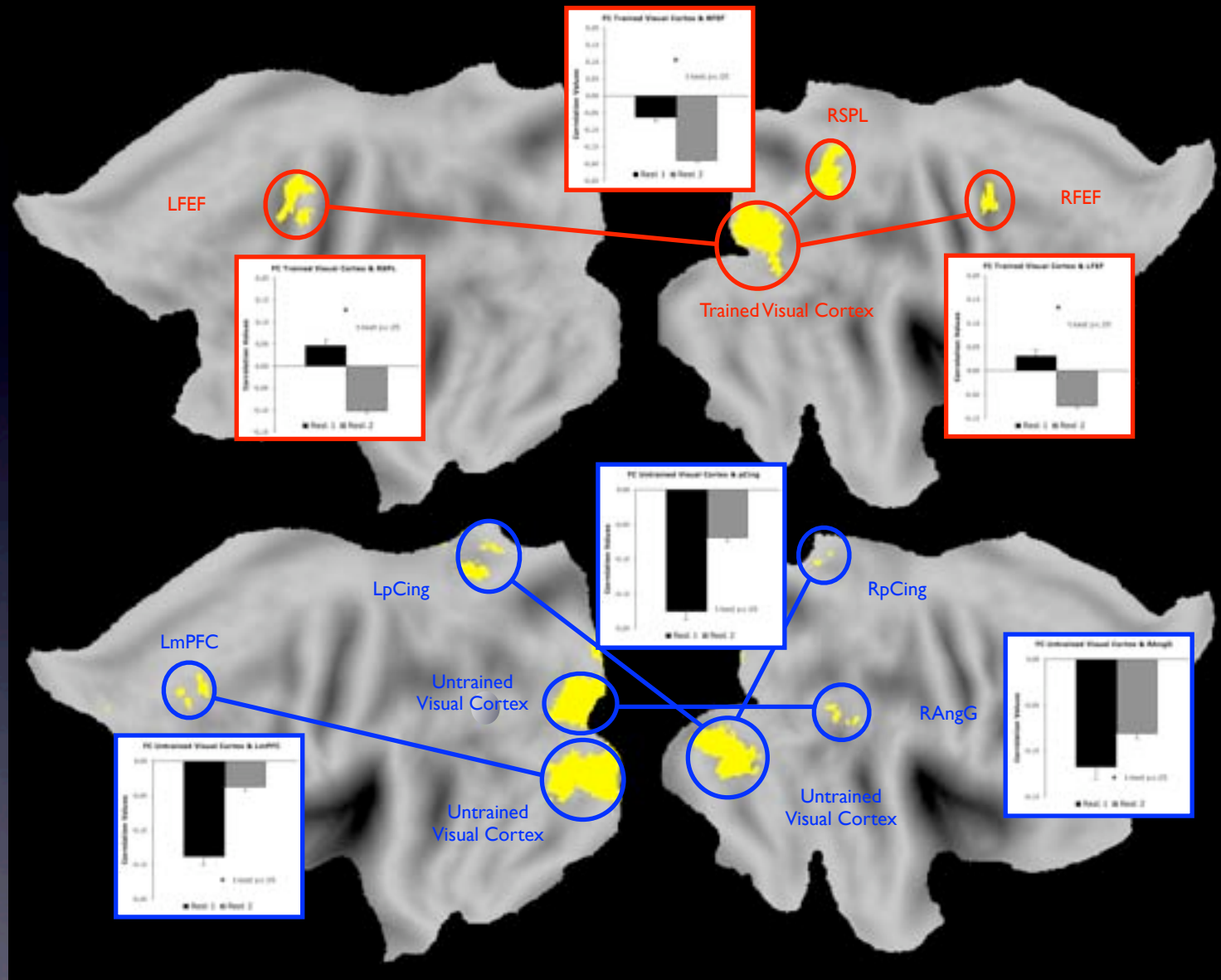
MR frames

Lewis et al PNAS 2009

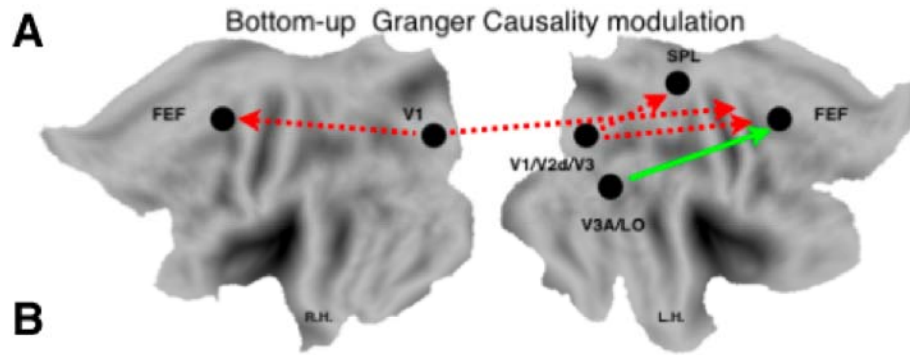
Learning-dependent changes in functional connectivity





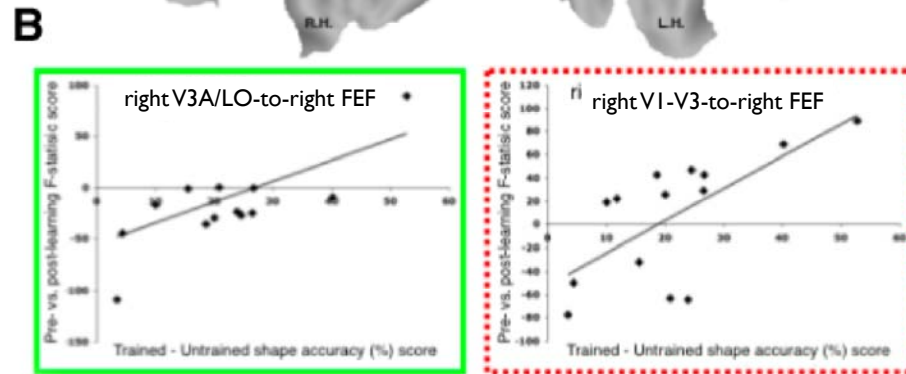
Learning-dependent changes in functional connectivity



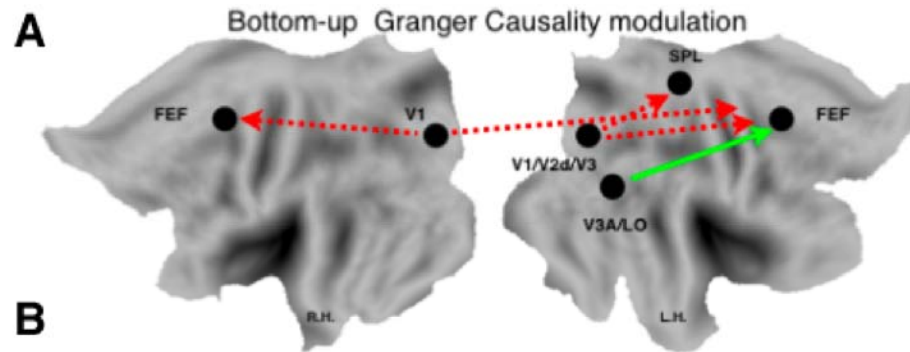
Bottom-up:
decreased V1/V2>FEF
increased V3A/LO>FEF



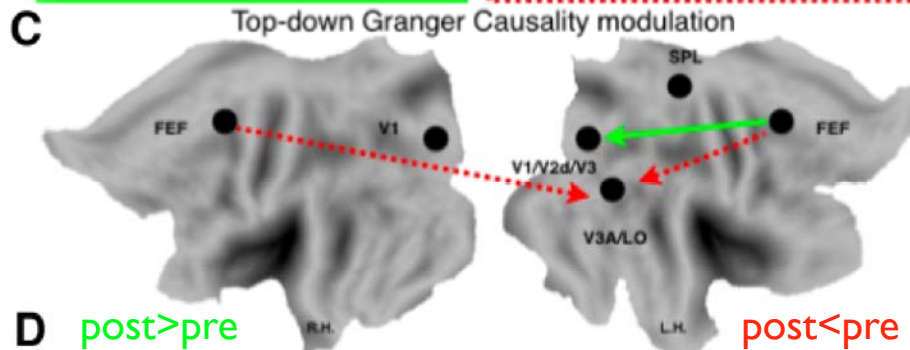
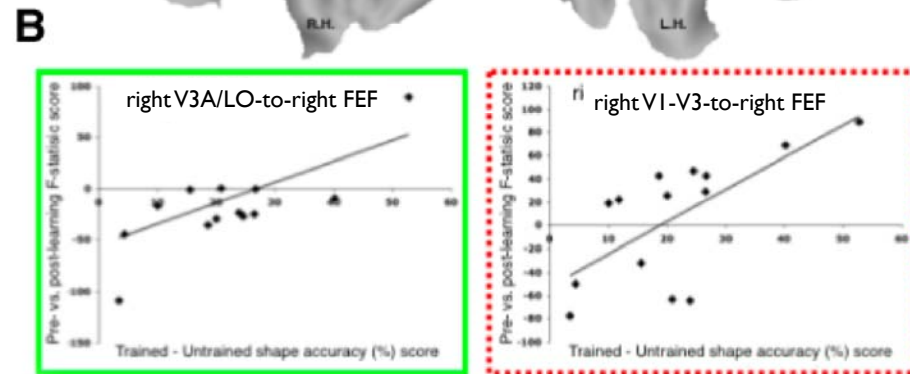
post-learning
 decrease GC
 increase GC



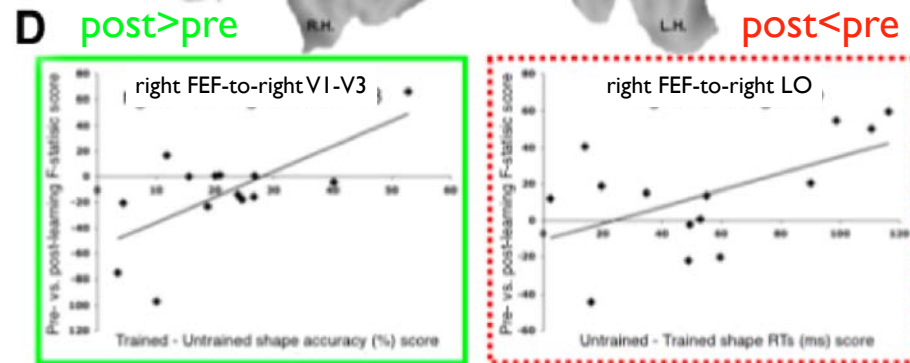
Bottom-up:
decreased V1/V2>FEF
increased V3A/LO>FEF



post-learning
→ decrease GC
→ increase GC



post-learning
→ decrease GC
→ increase GC



Summary

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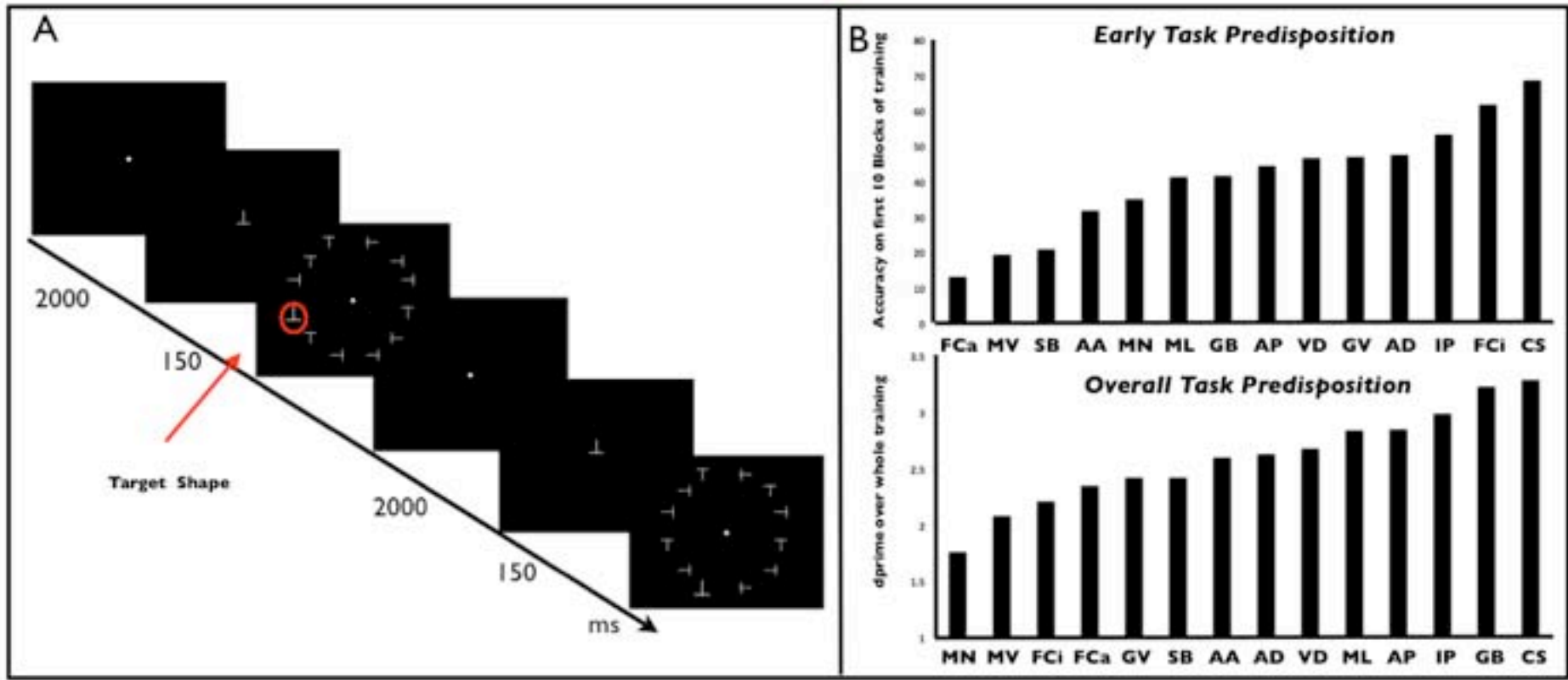
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Learning-dependent changes in functional connectivity may underlie a systems level memory of task activation (Perception: Lewis et al, 2009; Motor: Albert et al 2009; Memory: Tambini et al 2010).

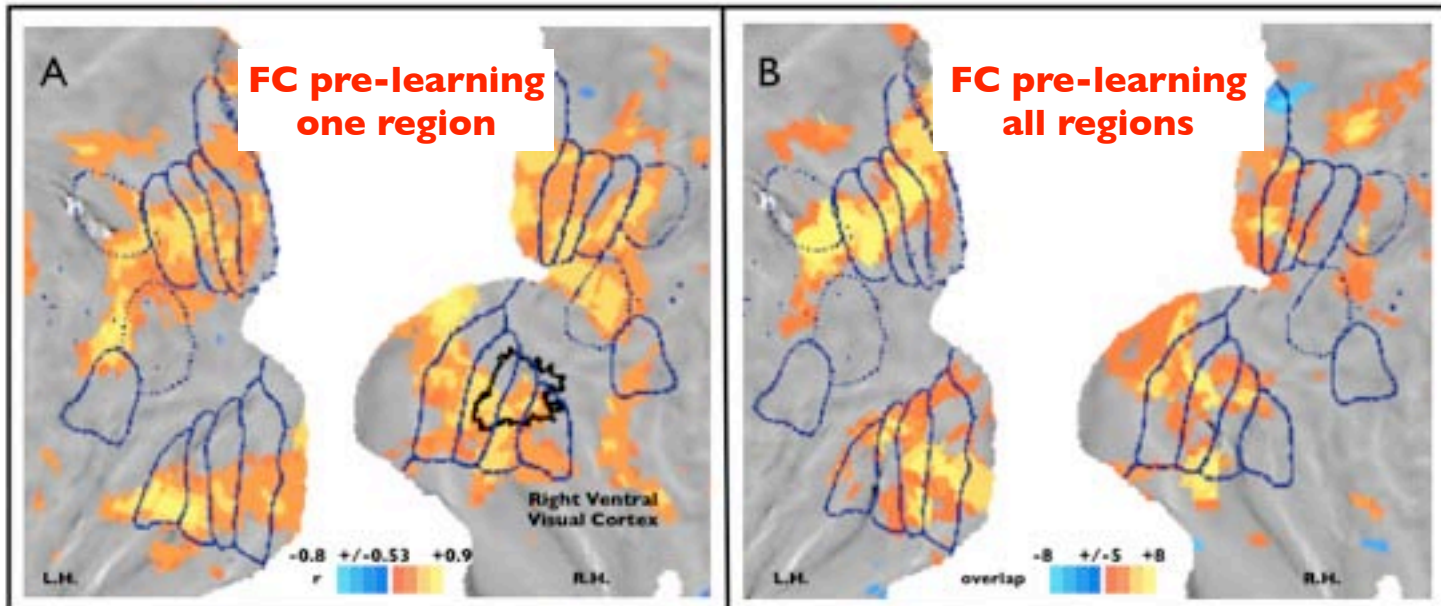
Functional connectivity and individual predisposition

Fig 1

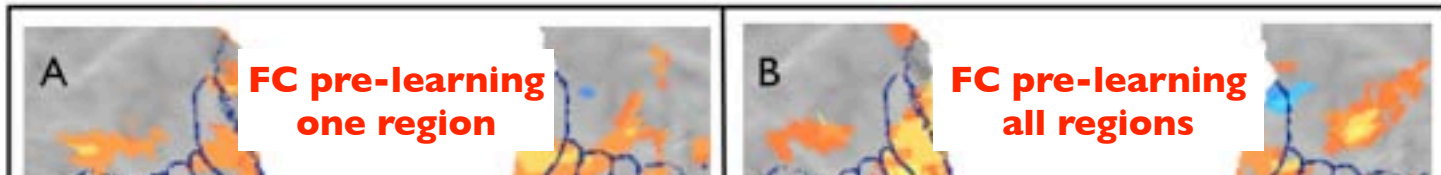


Baldassare et al *Current Biology* in press

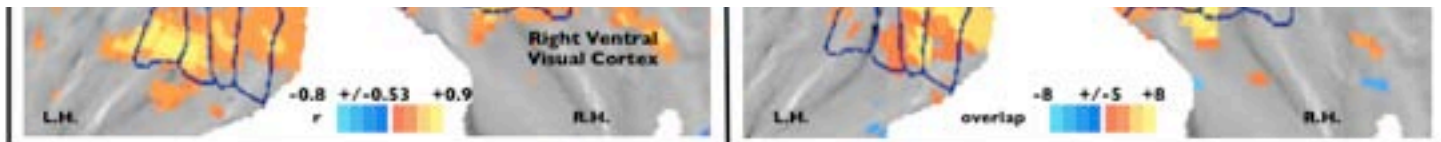
Functional connectivity (FC) & Early Accuracy



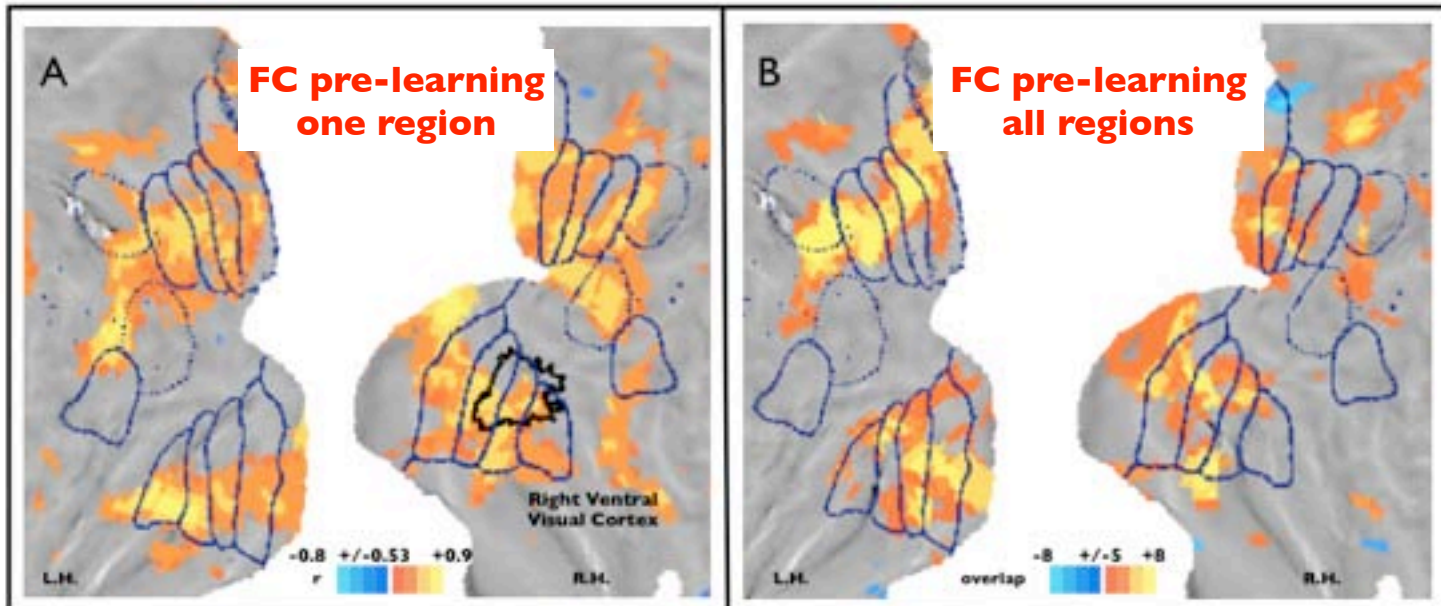
Functional connectivity (FC) & Early Accuracy



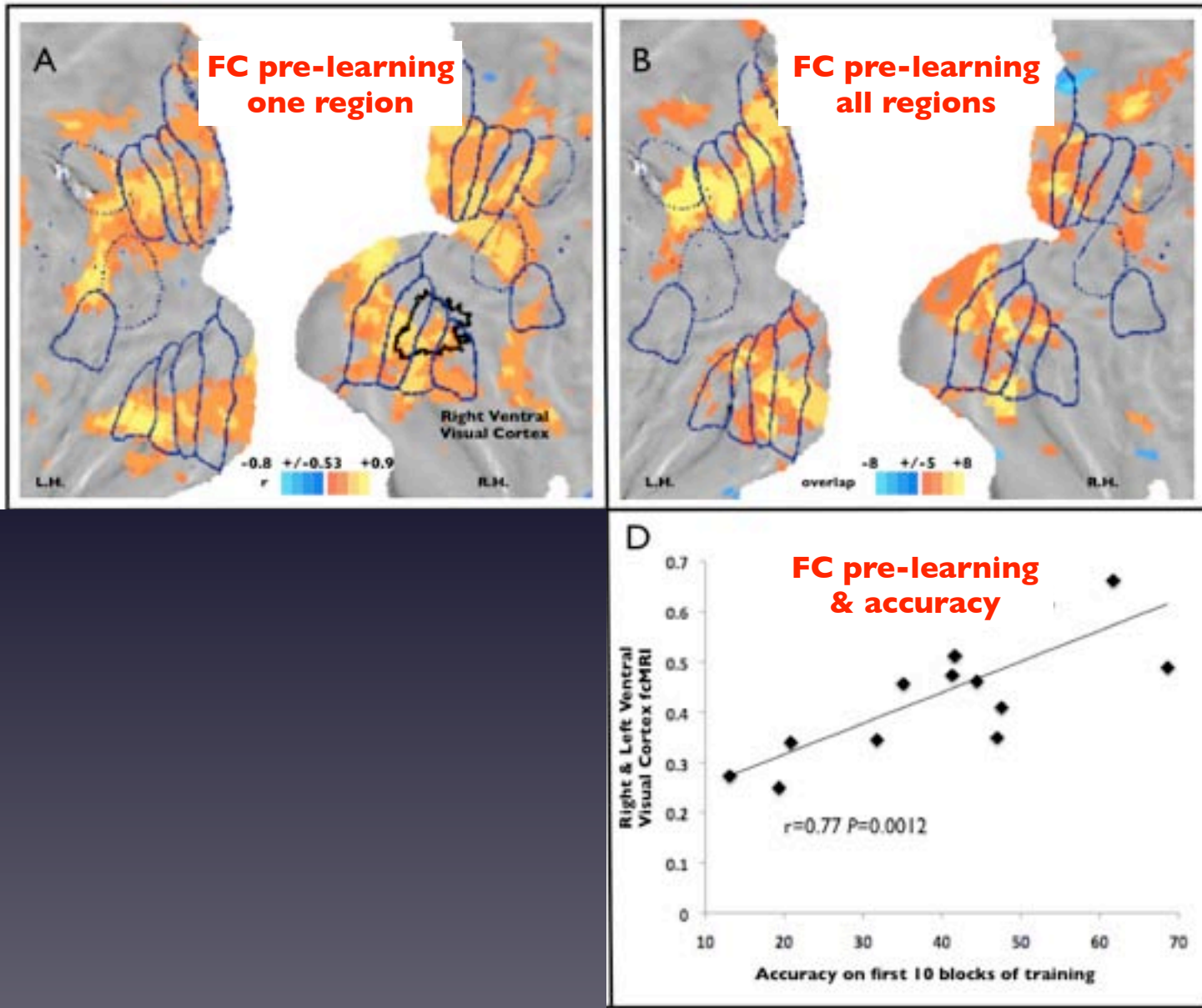
$$r = \frac{1}{n-1} \sum_{i=1}^n \left[\left(\frac{X_i - \bar{X}}{\sigma_X} \right) \left(\frac{Y_i - \bar{Y}}{\sigma_Y} \right) \right]$$



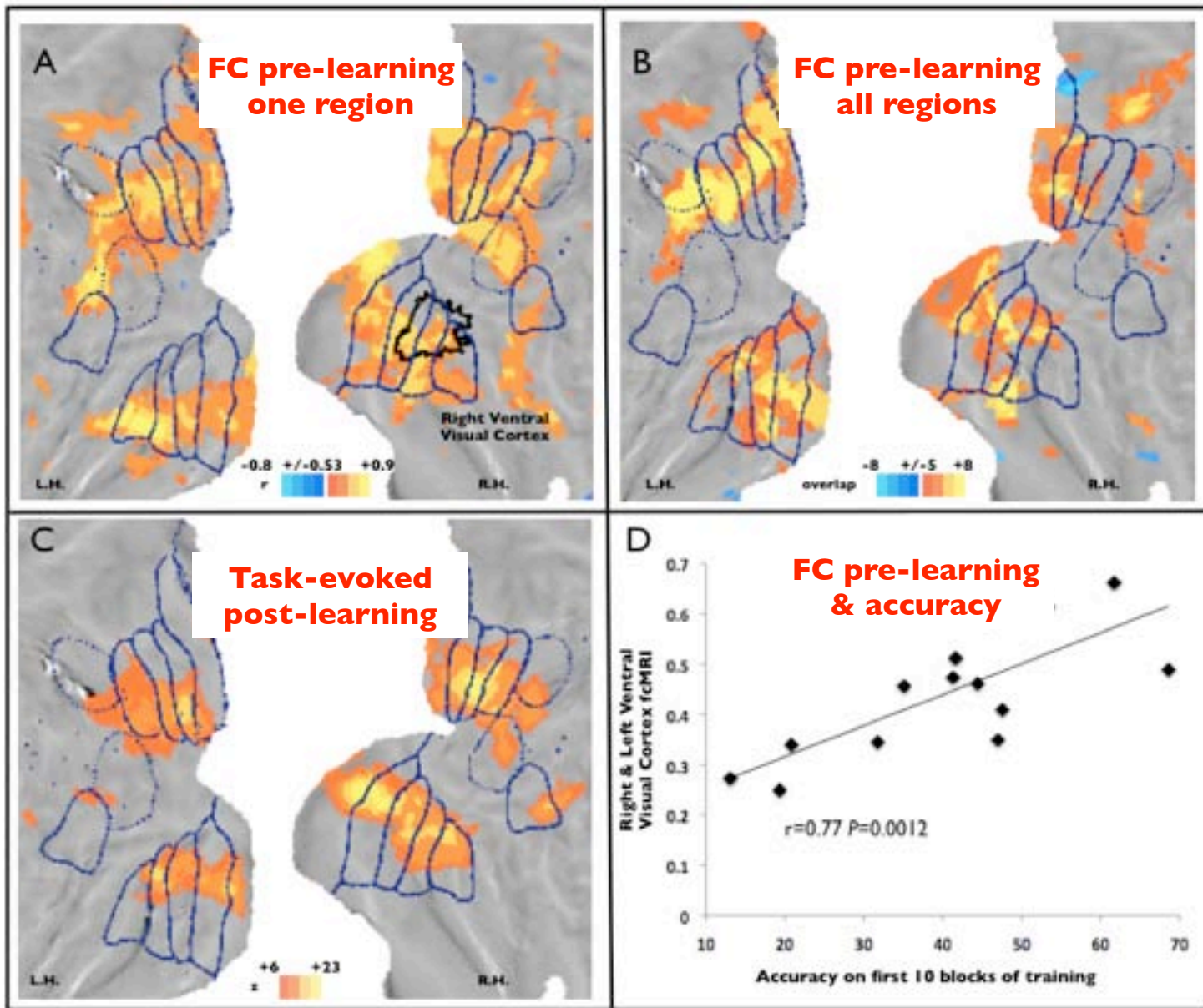
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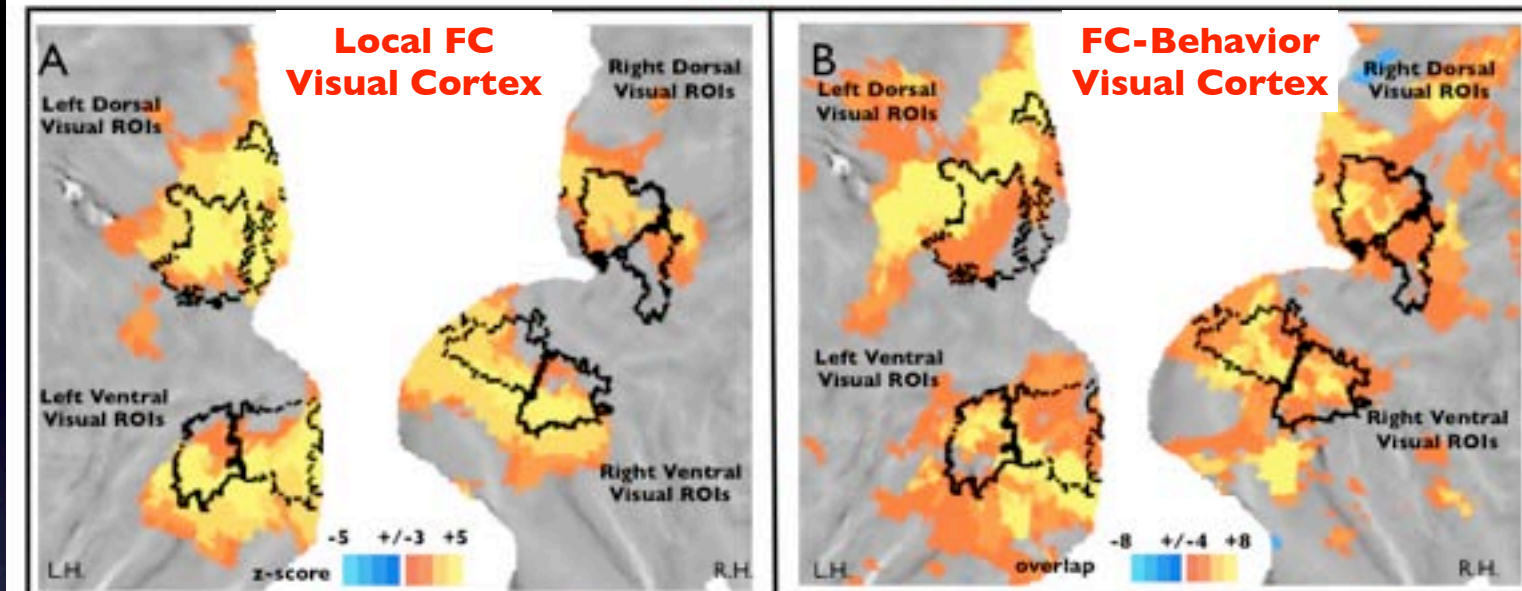
Functional connectivity (FC) & Early Accuracy



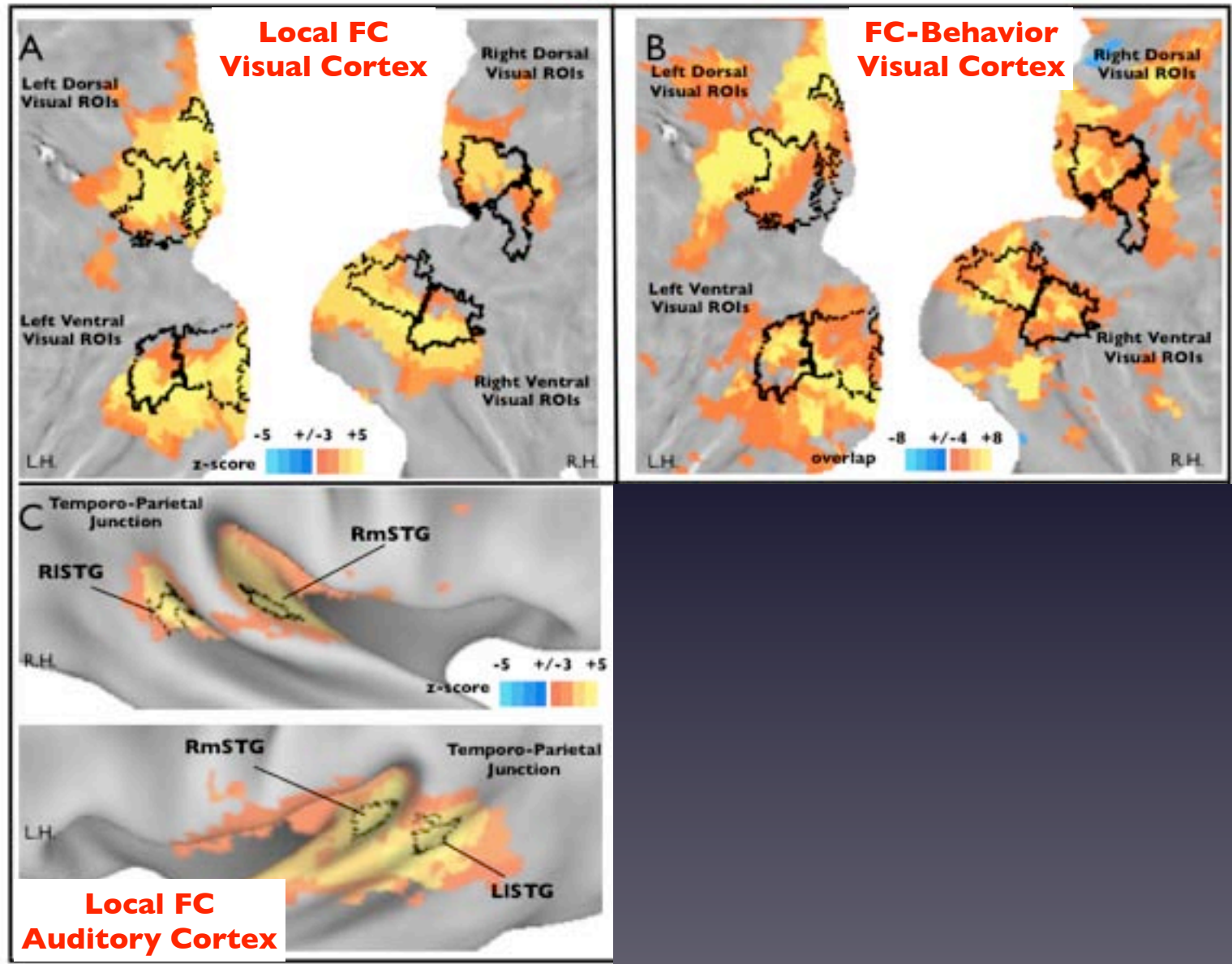
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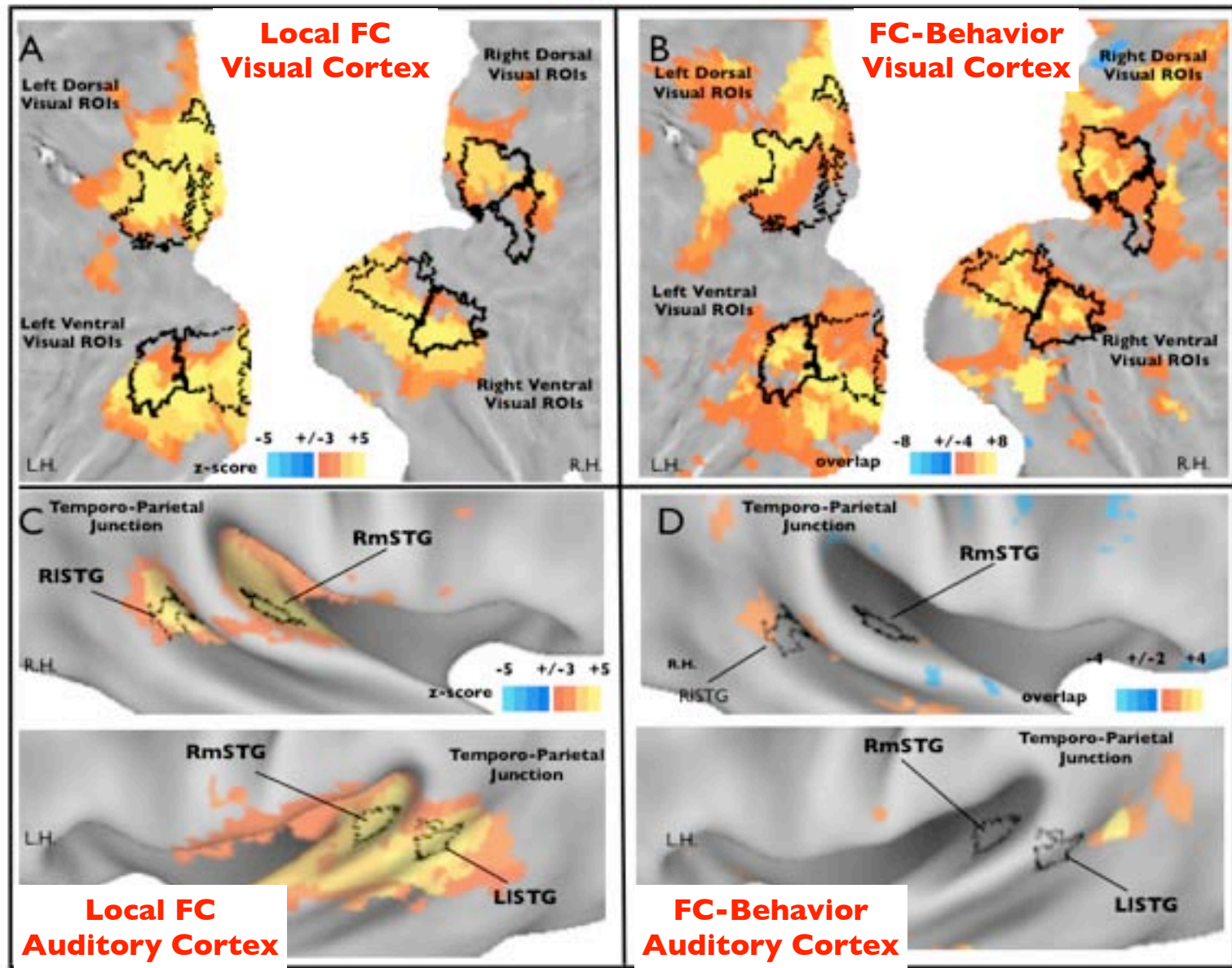
Local vs. behaviorally relevant functional connectivity (FC)



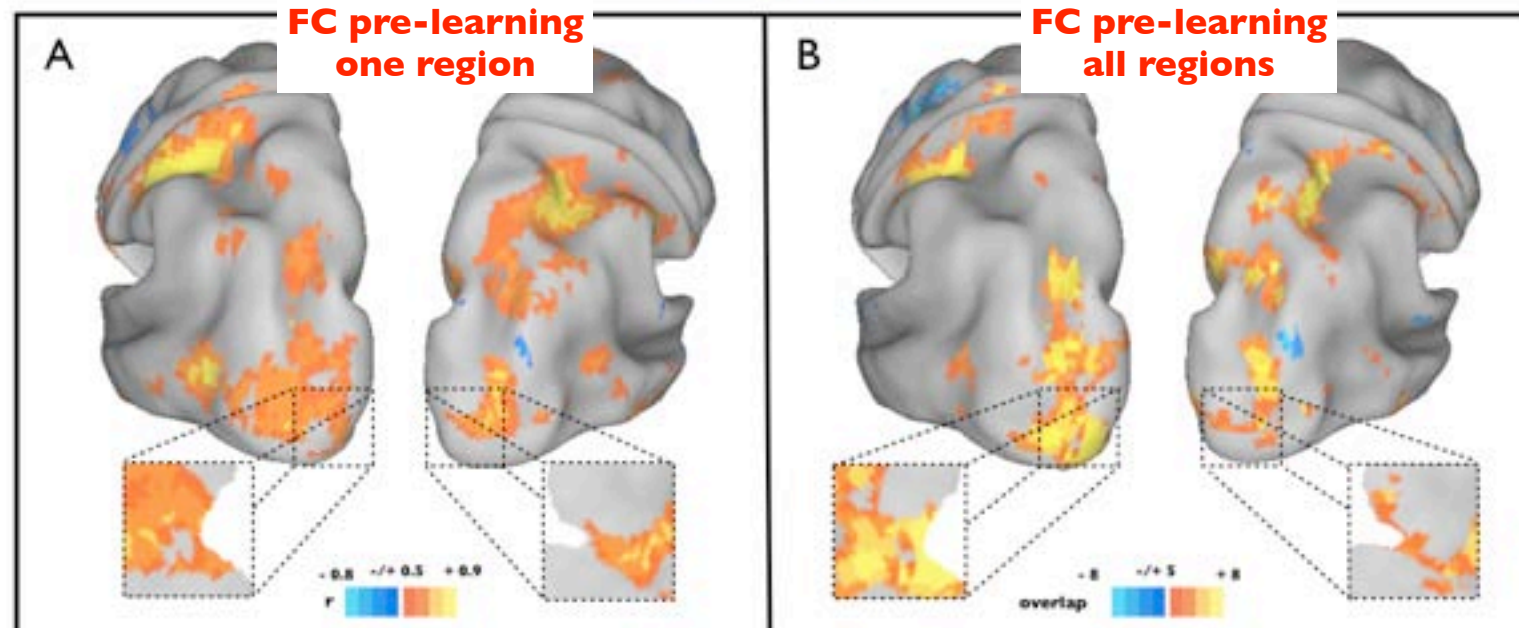
Local vs. behaviorally relevant functional connectivity (FC)



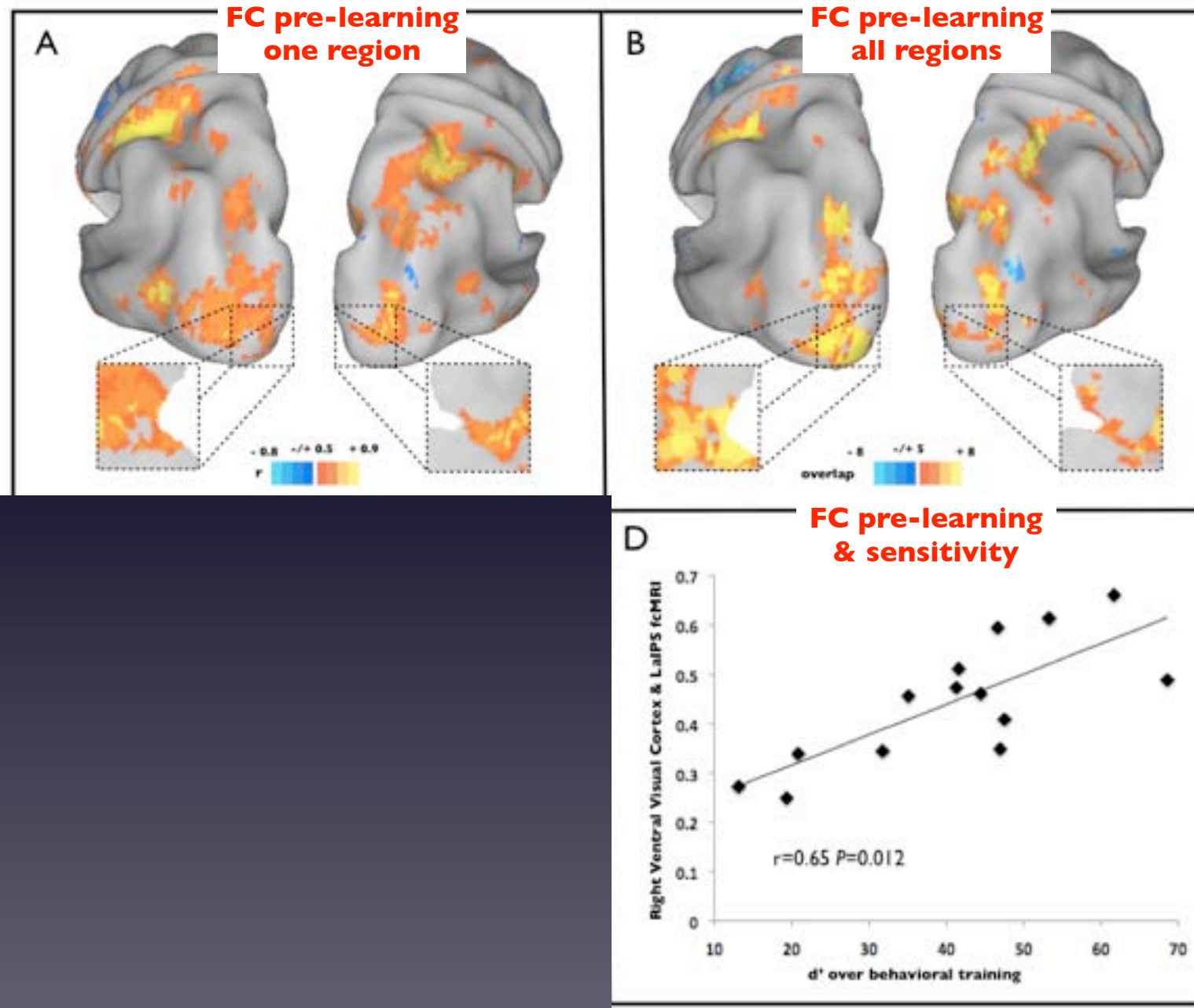
Local vs. behaviorally relevant functional connectivity (FC)



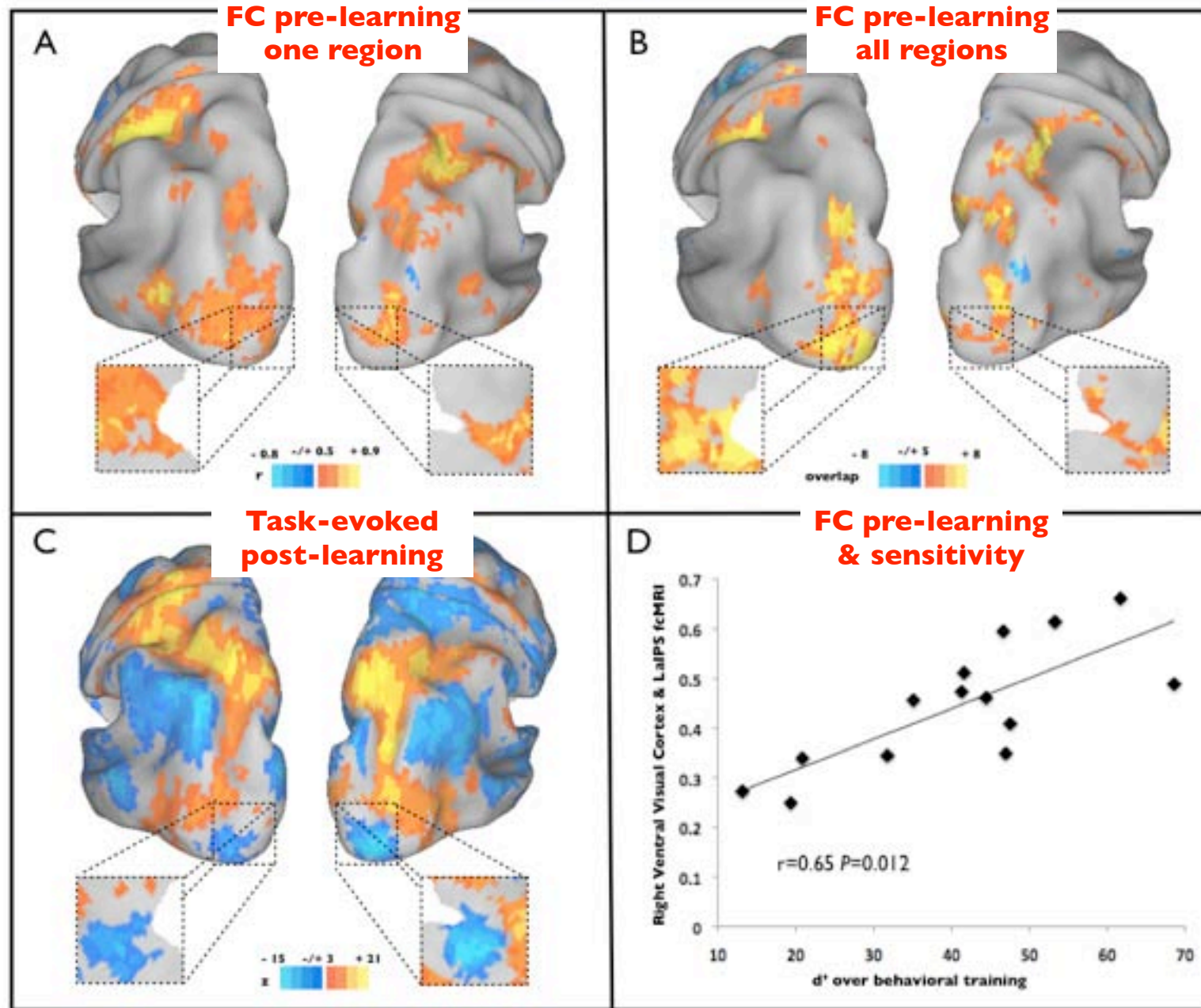
Functional connectivity (FC) & Overall Sensitivity



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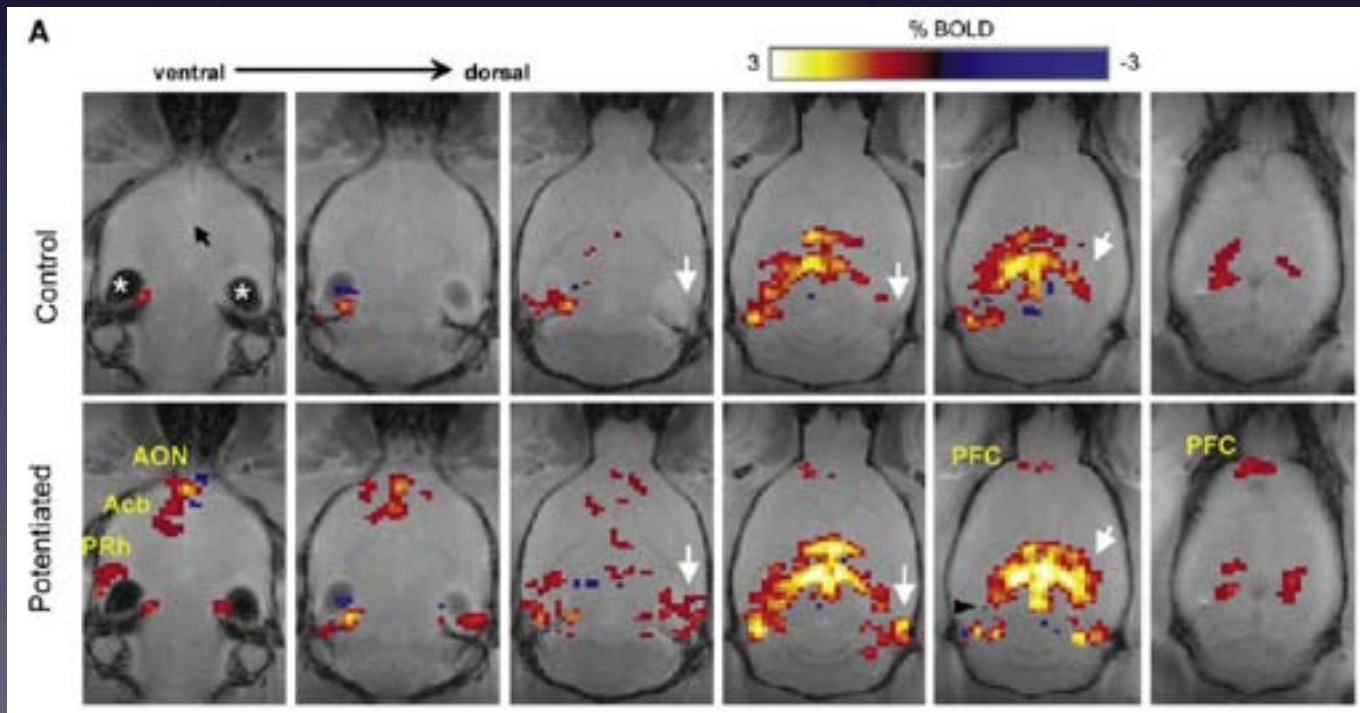
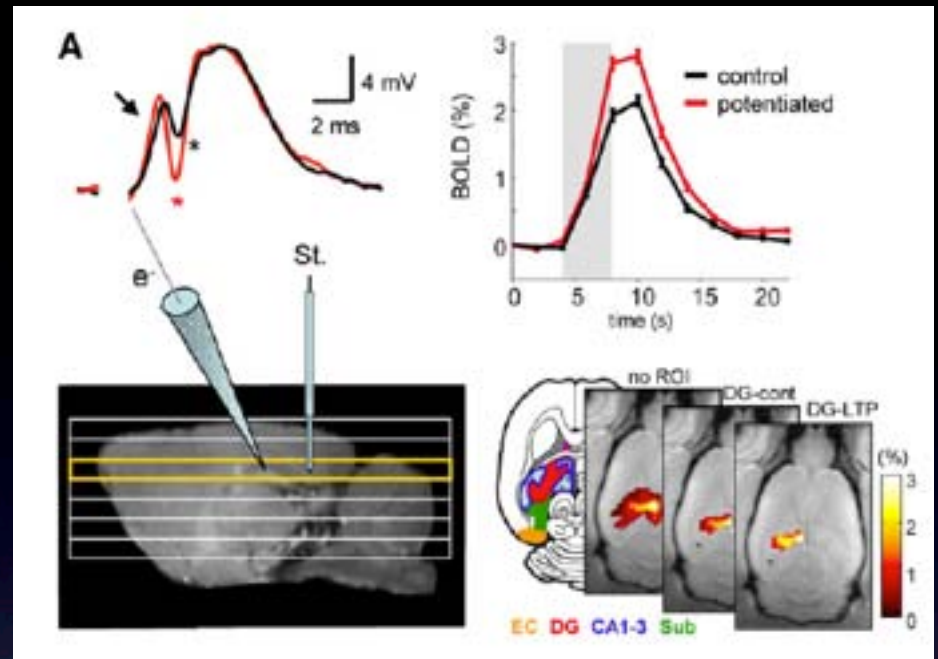
- positive correlation between cognitive functions (language, memory, saliency, intelligence)(Hampson et al. 2006, 2007; Kelley et al 2008).

The relationship with learning or predisposition indicates a potential link with synaptic mechanisms of plasticity.

Functional MRI Evidence for LTP-Induced Neural Network Reorganization

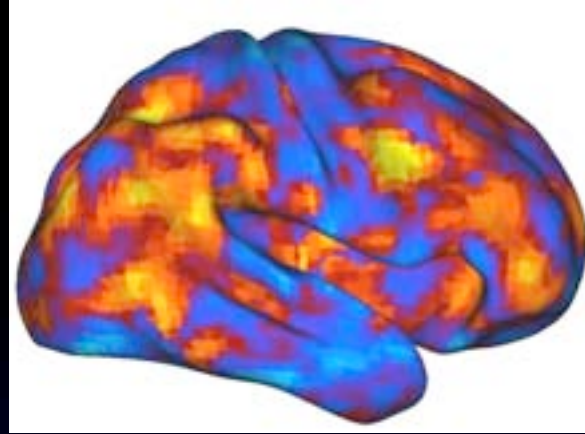
Santiago Canals,^{1,4,*} Michael Beyerlein,¹ Hellmut Merkle,³ and Nikos K. Logothetis^{1,2}

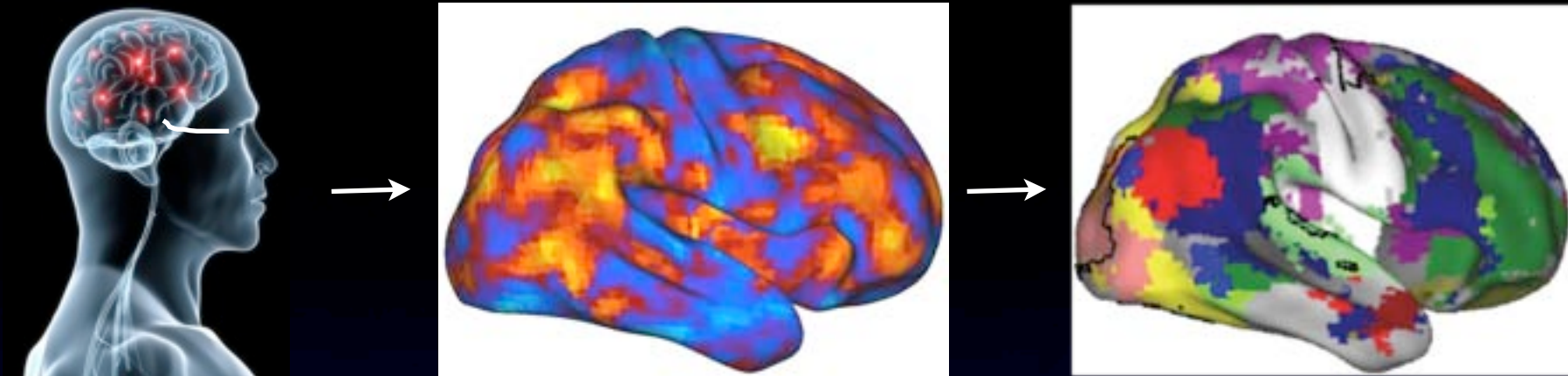
Current Biology, 2009

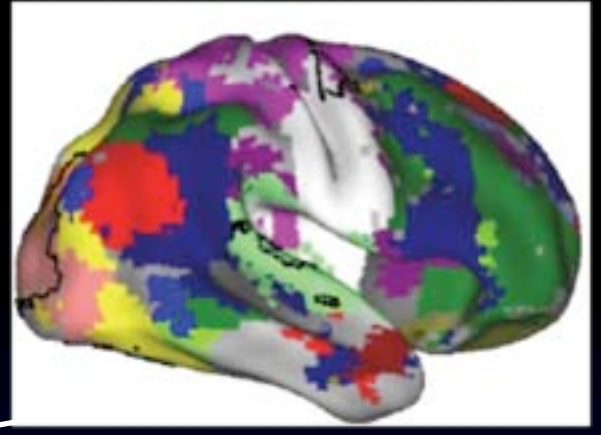


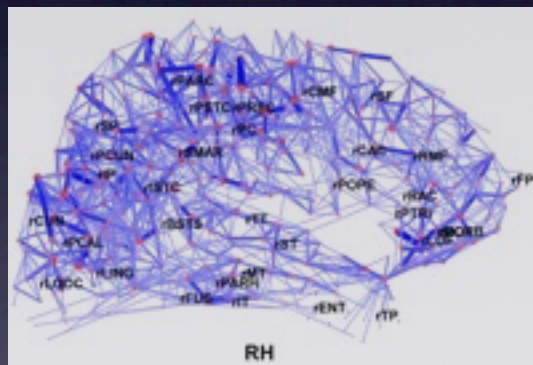
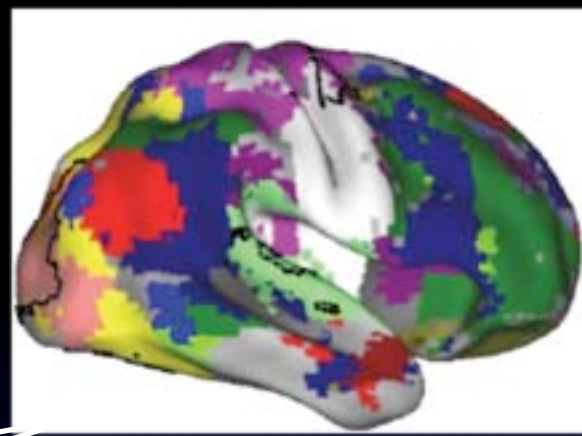
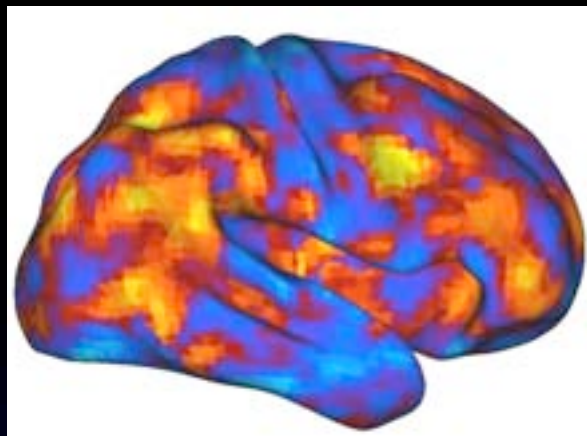


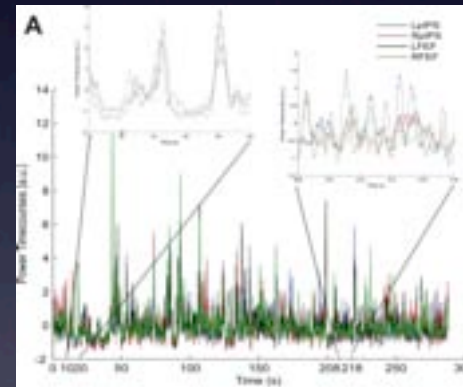
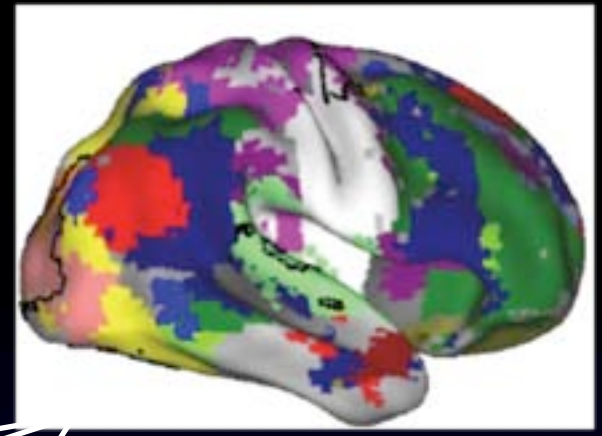


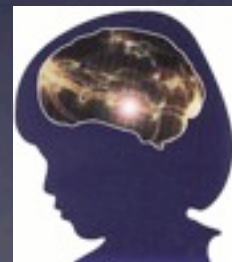
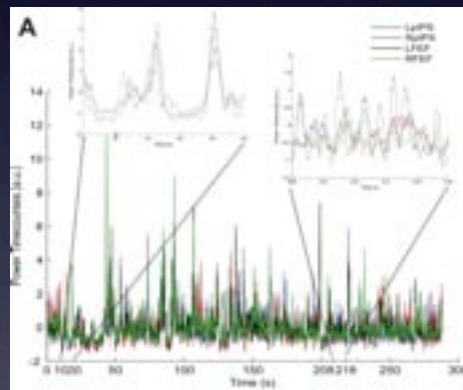
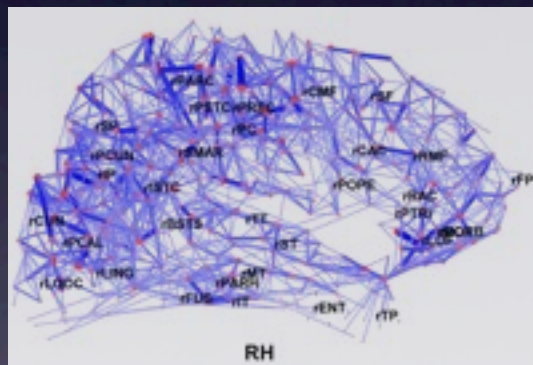
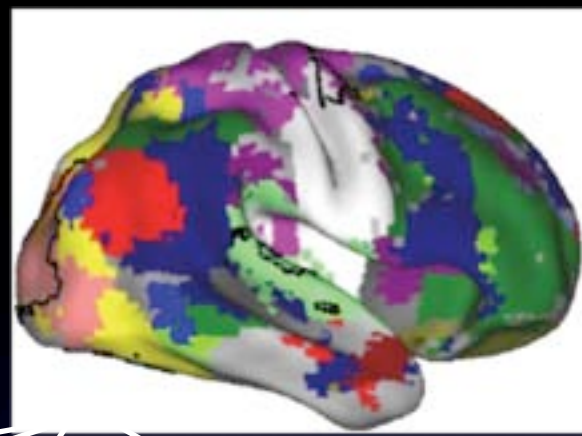
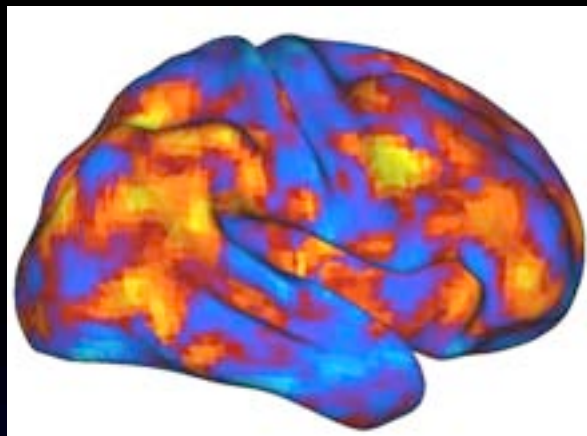












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Gian Luca Romani
Cosimo Del Gratta
Claudio Babiloni

Chieti

fMRI-EEG

Dante Mantini
Gianni Perrucci

FcMRI Learning

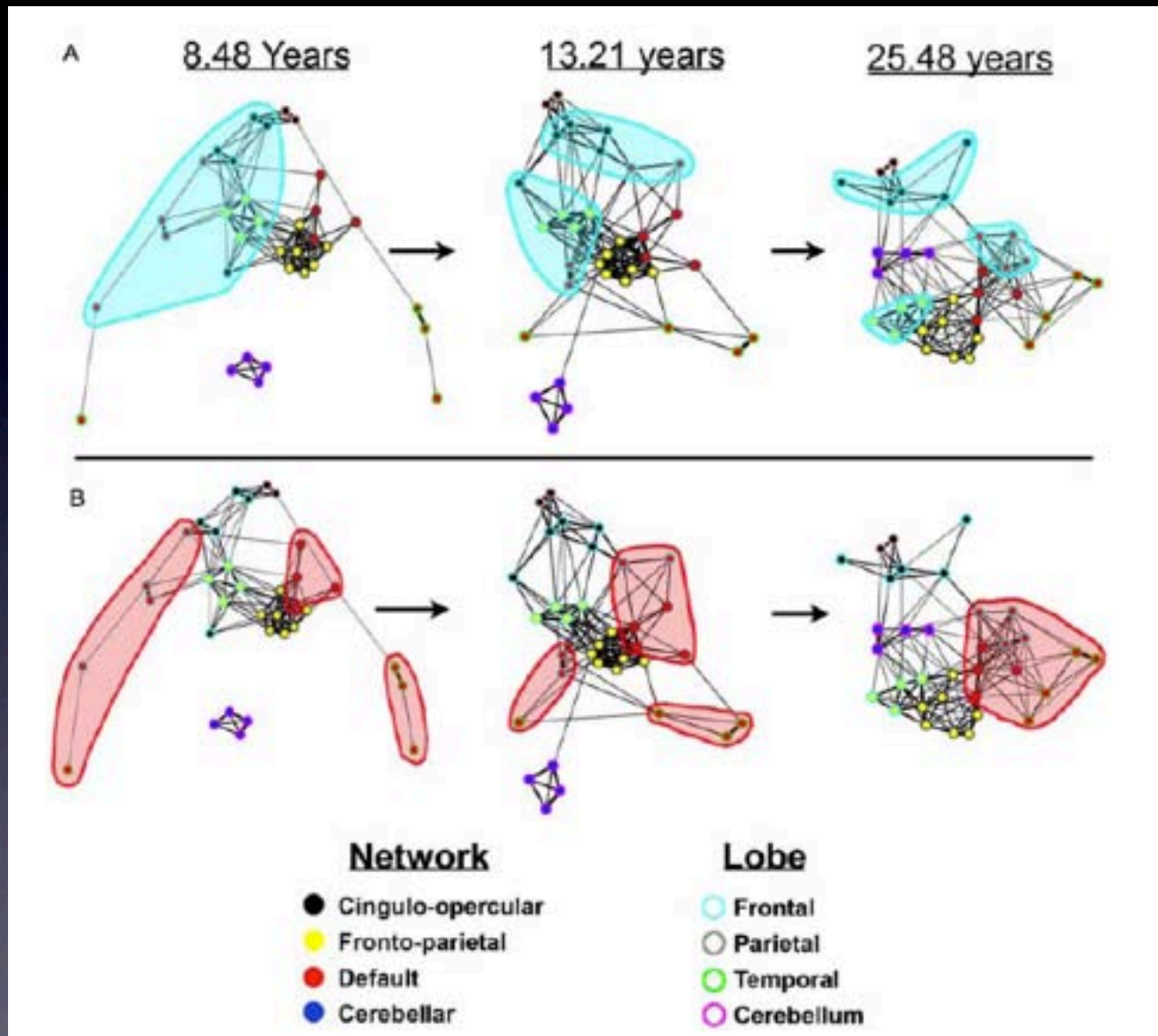
Chris Lewis
Antonello Baldassare

TMS-EEG

Paolo Capotosto

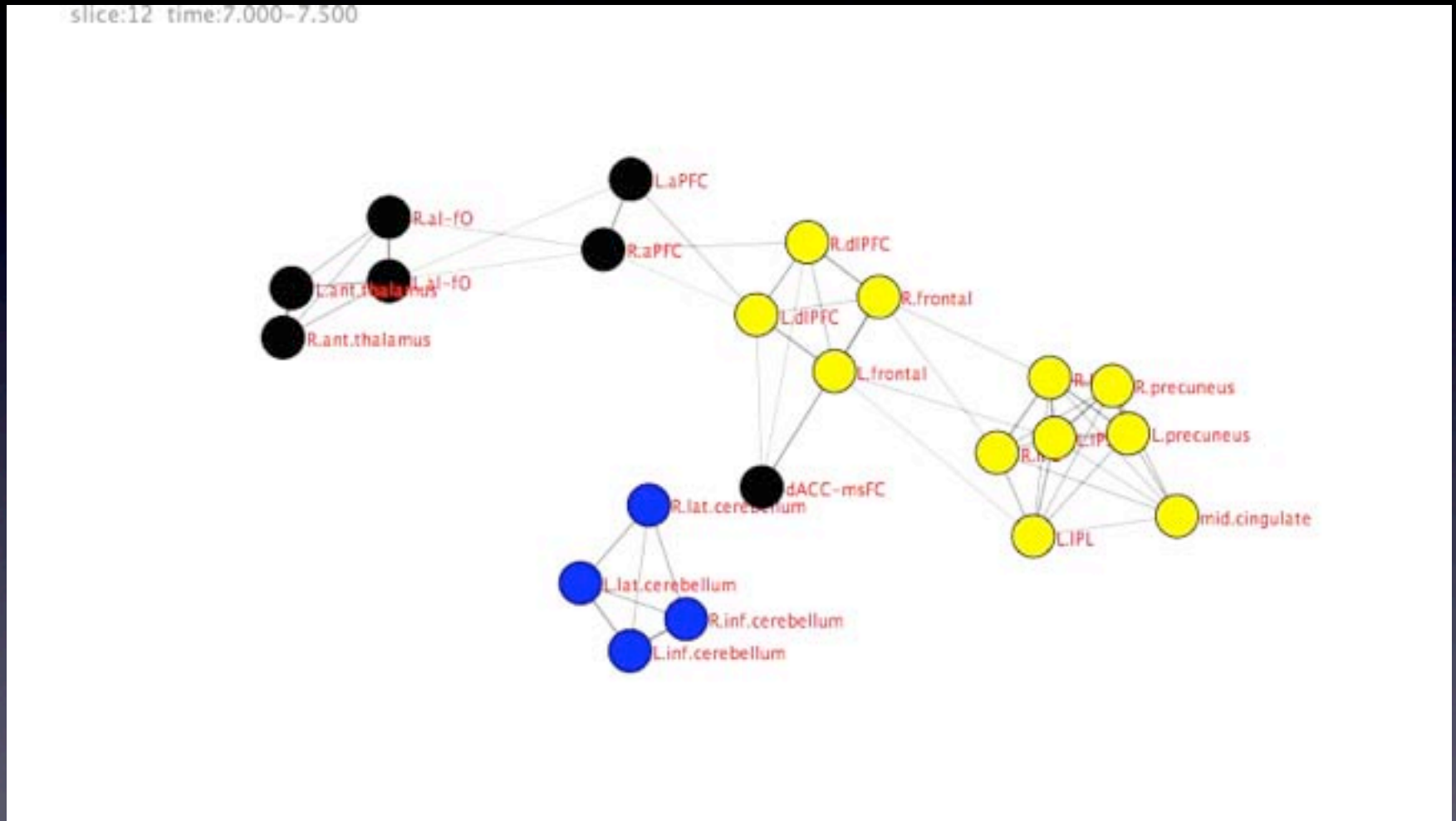
NINDS, NIMH, McDonnell Foundation
EU Marie Curie Chair @ ITAB University of Chieti Italy

Functional connectivity & development



Fair et al PLOS 2009

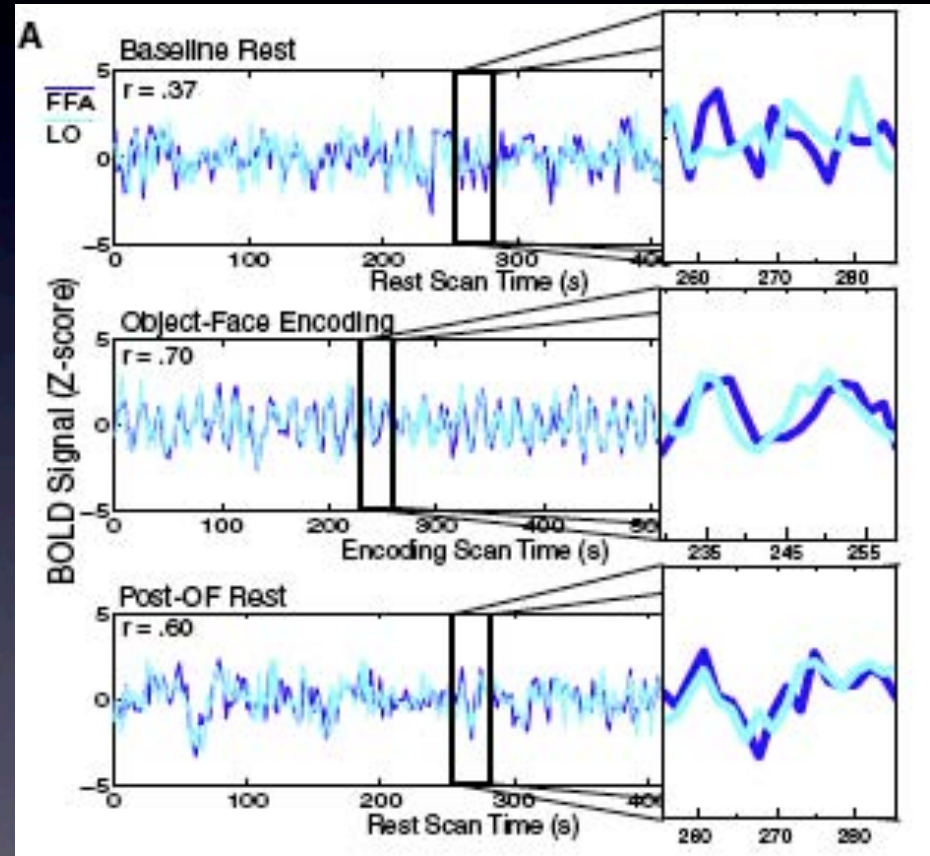
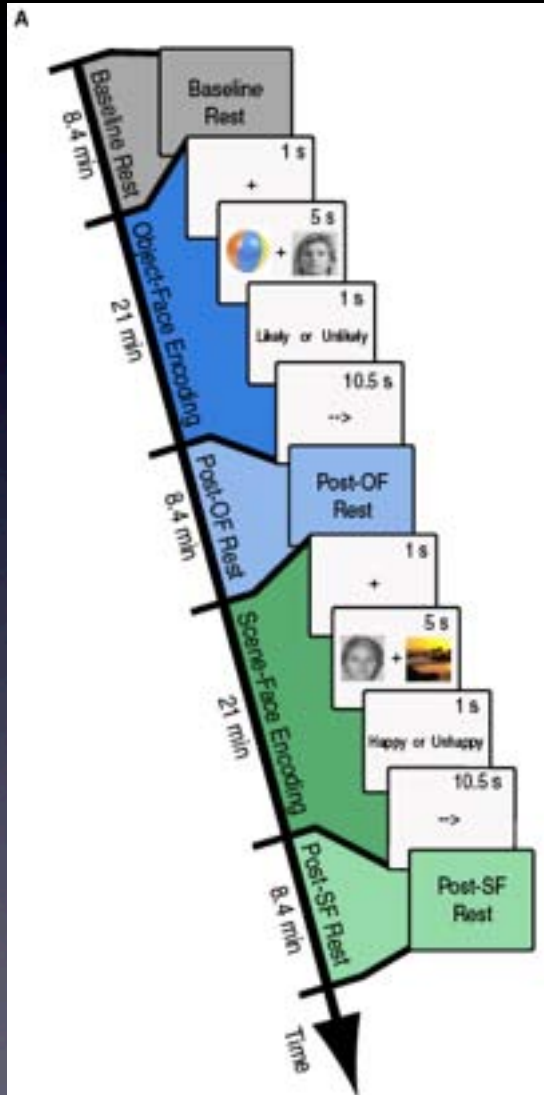
Development of core task set and dorsal attention network (age 7-27)



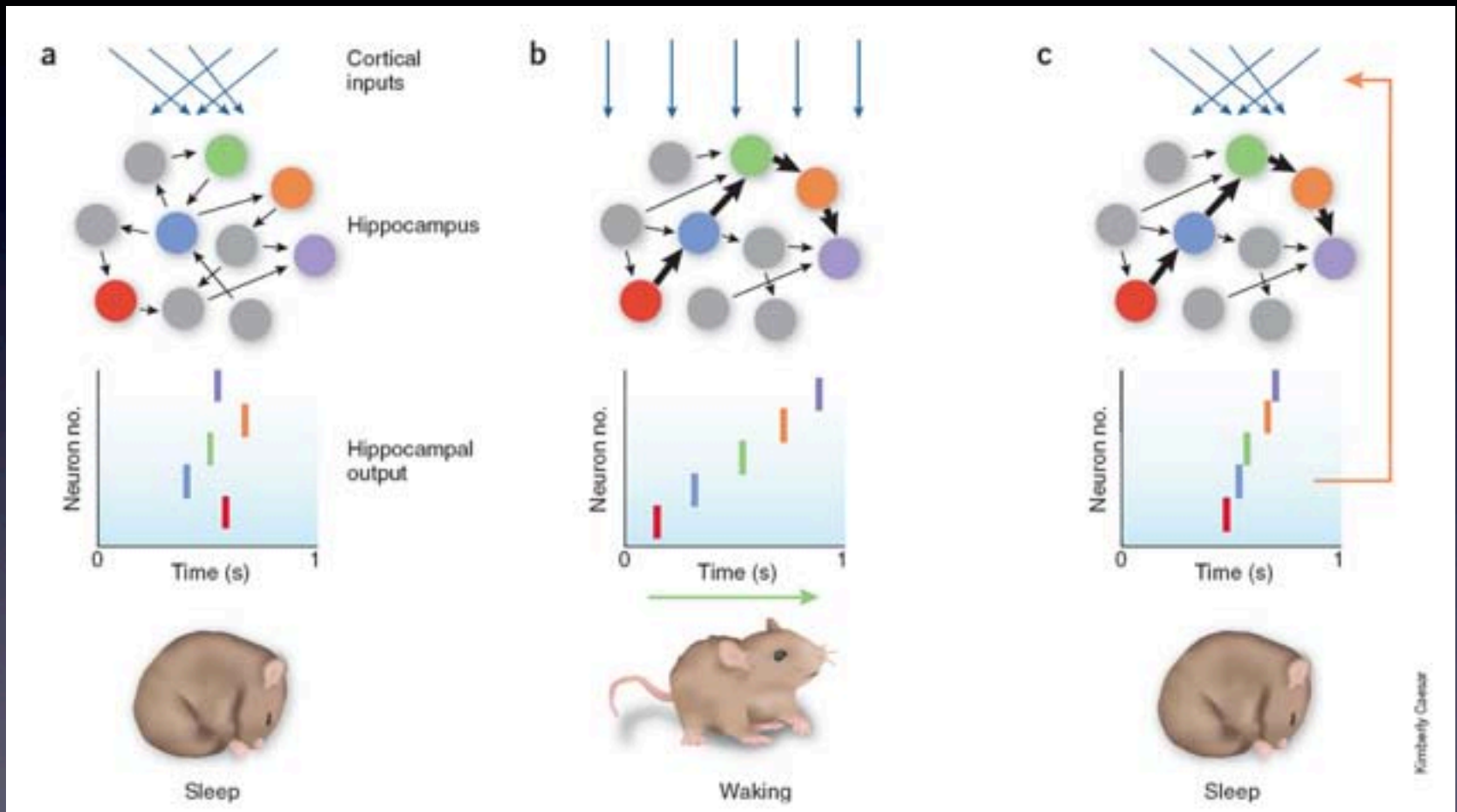
Fair et al., PNAS, 2007

Enhanced Brain Correlations during Rest Are Related to Memory for Recent Experiences

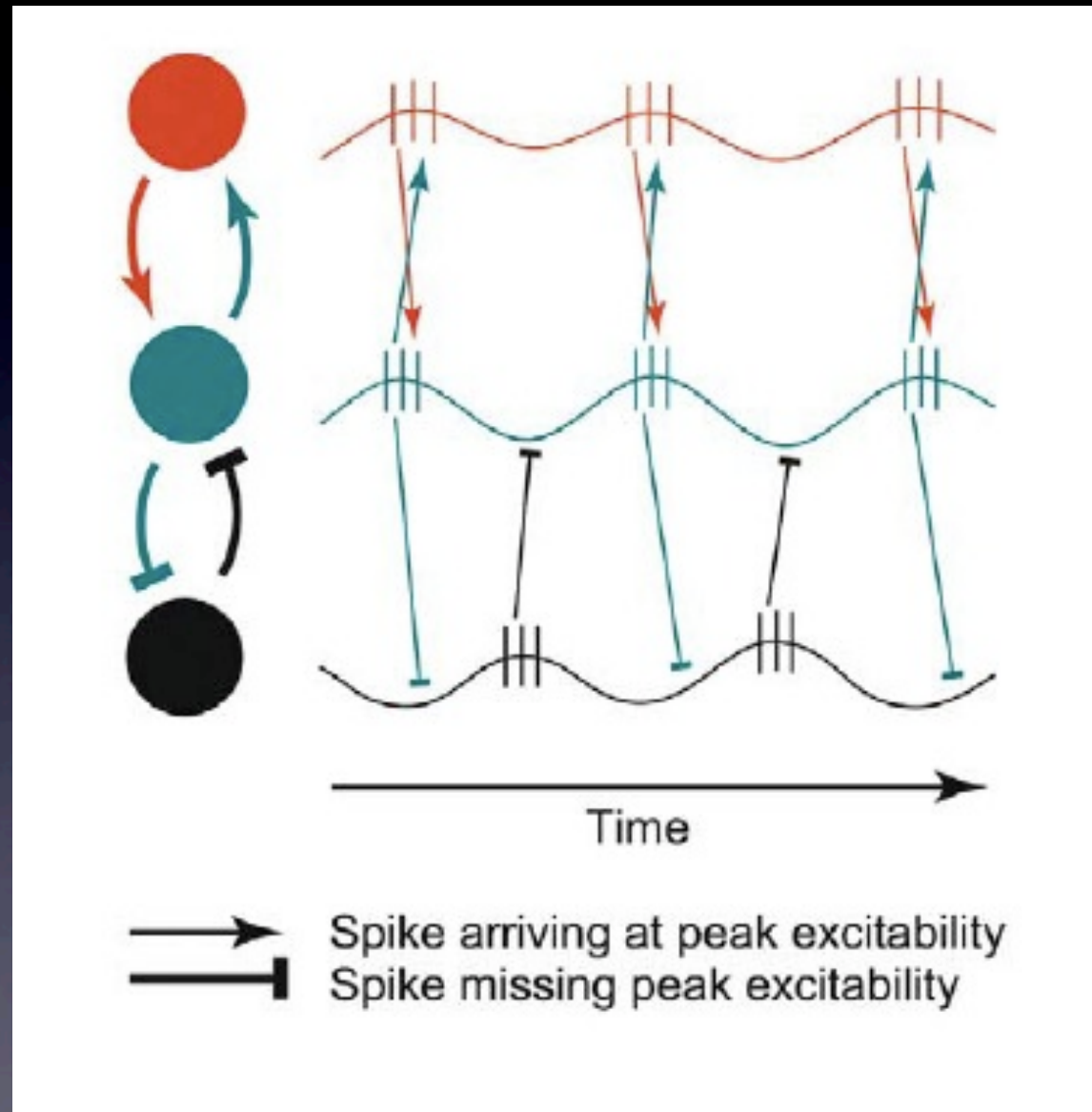
Arielle Tambini,¹ Nicholas Ketz,² and Lila Davachi^{1,2,*}



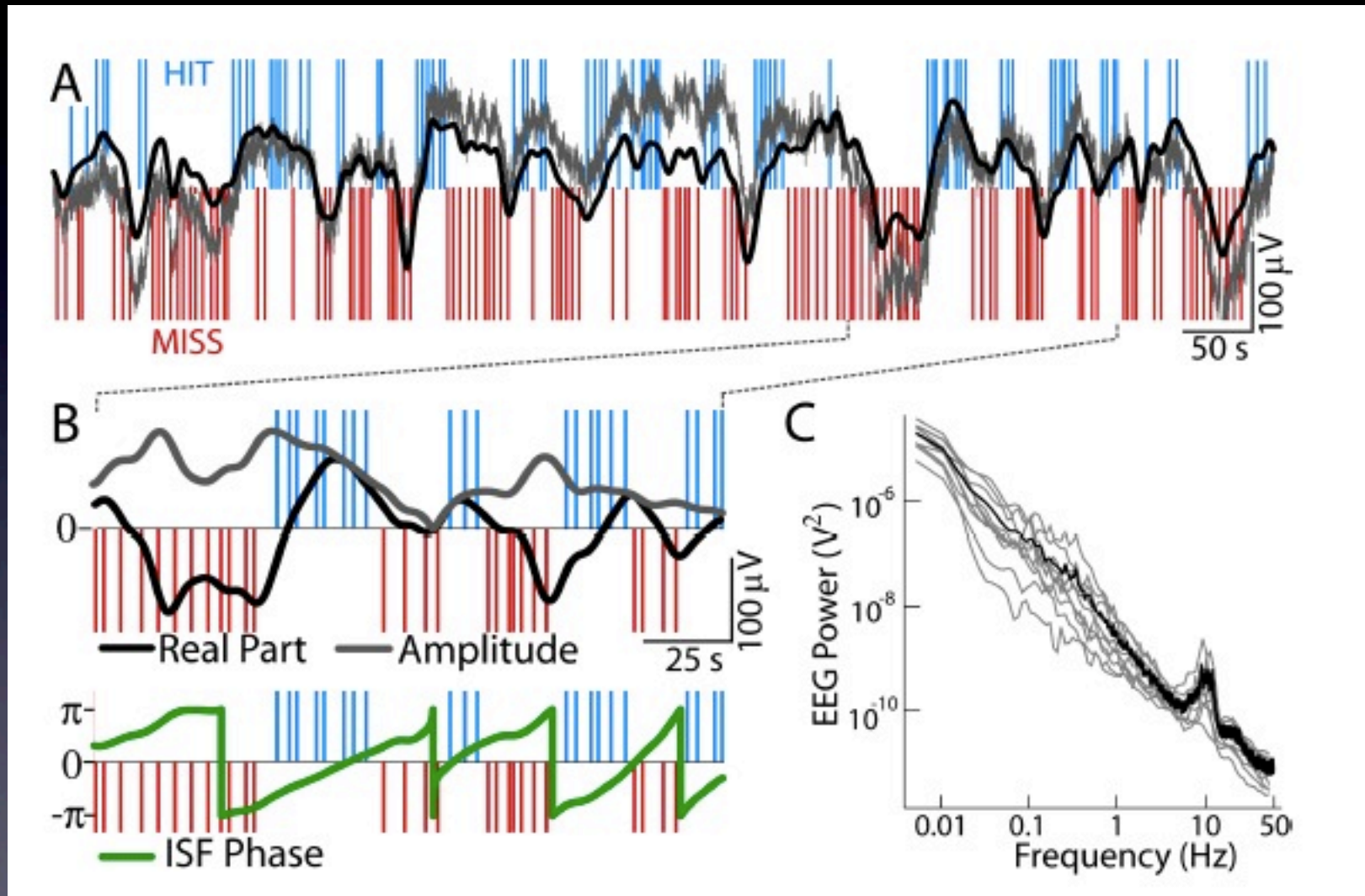
Hippocampal replay



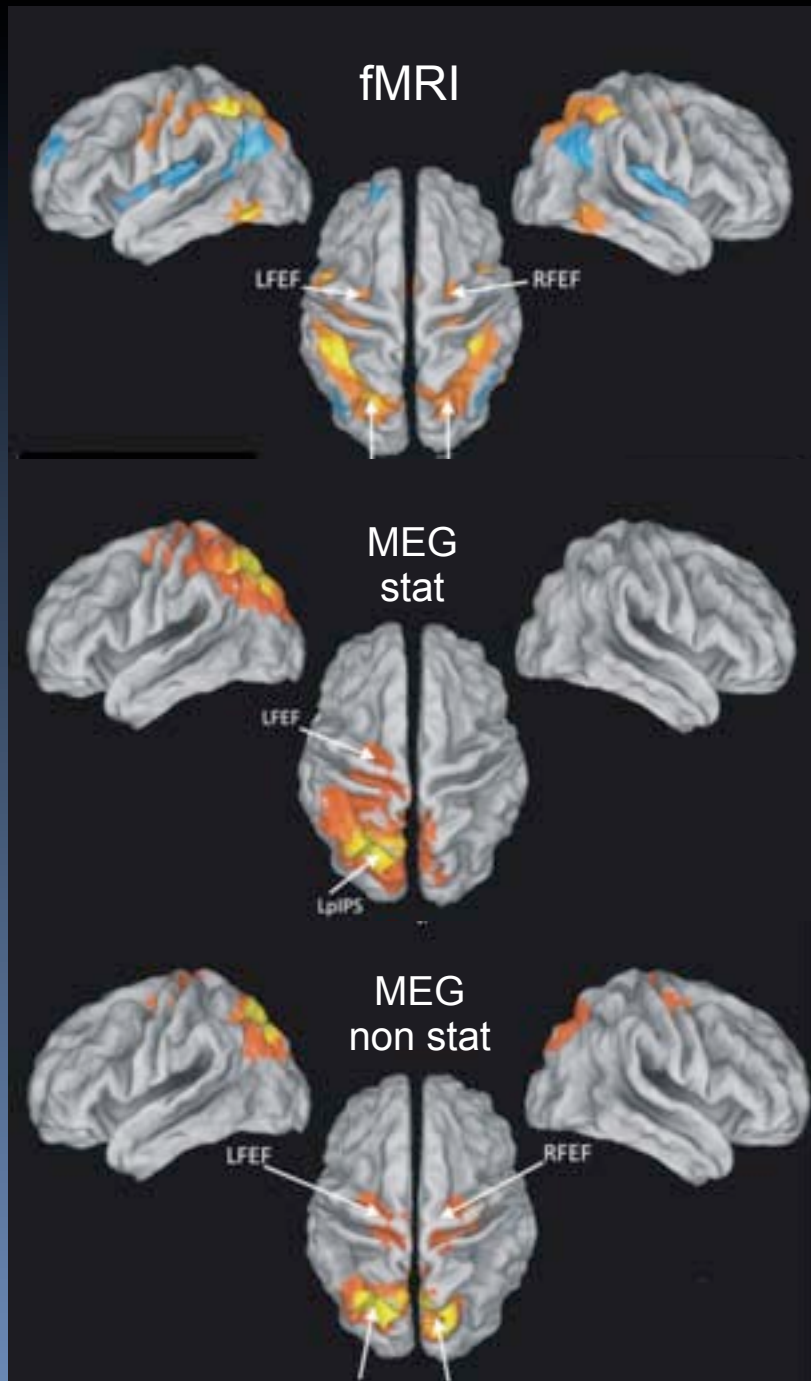
III. Facilitation of neural communication



Behavioral performance follows phase of infra-slow EEG

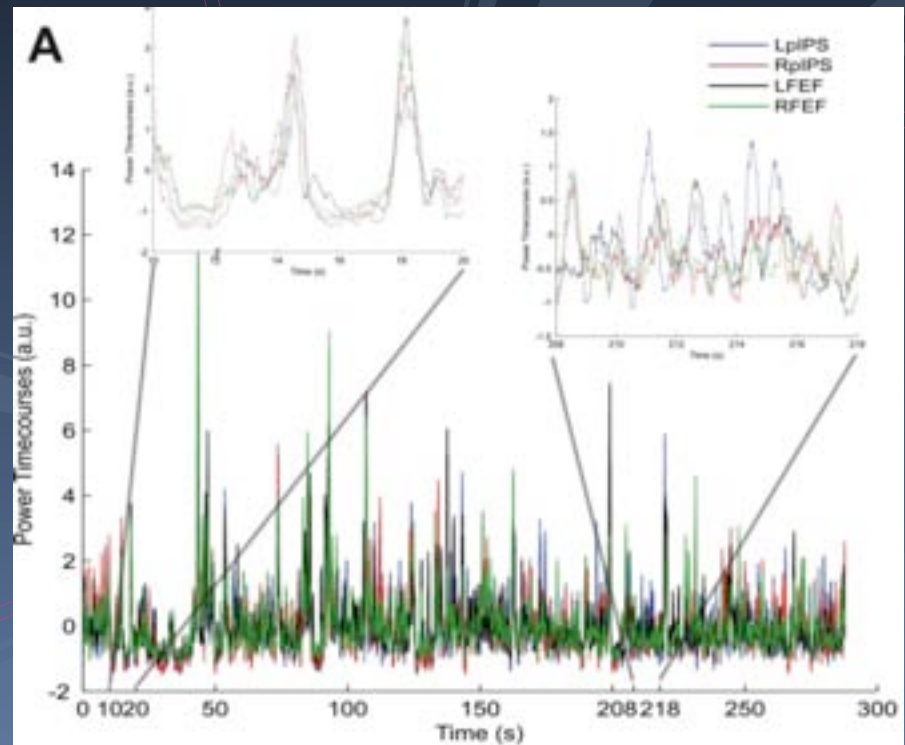


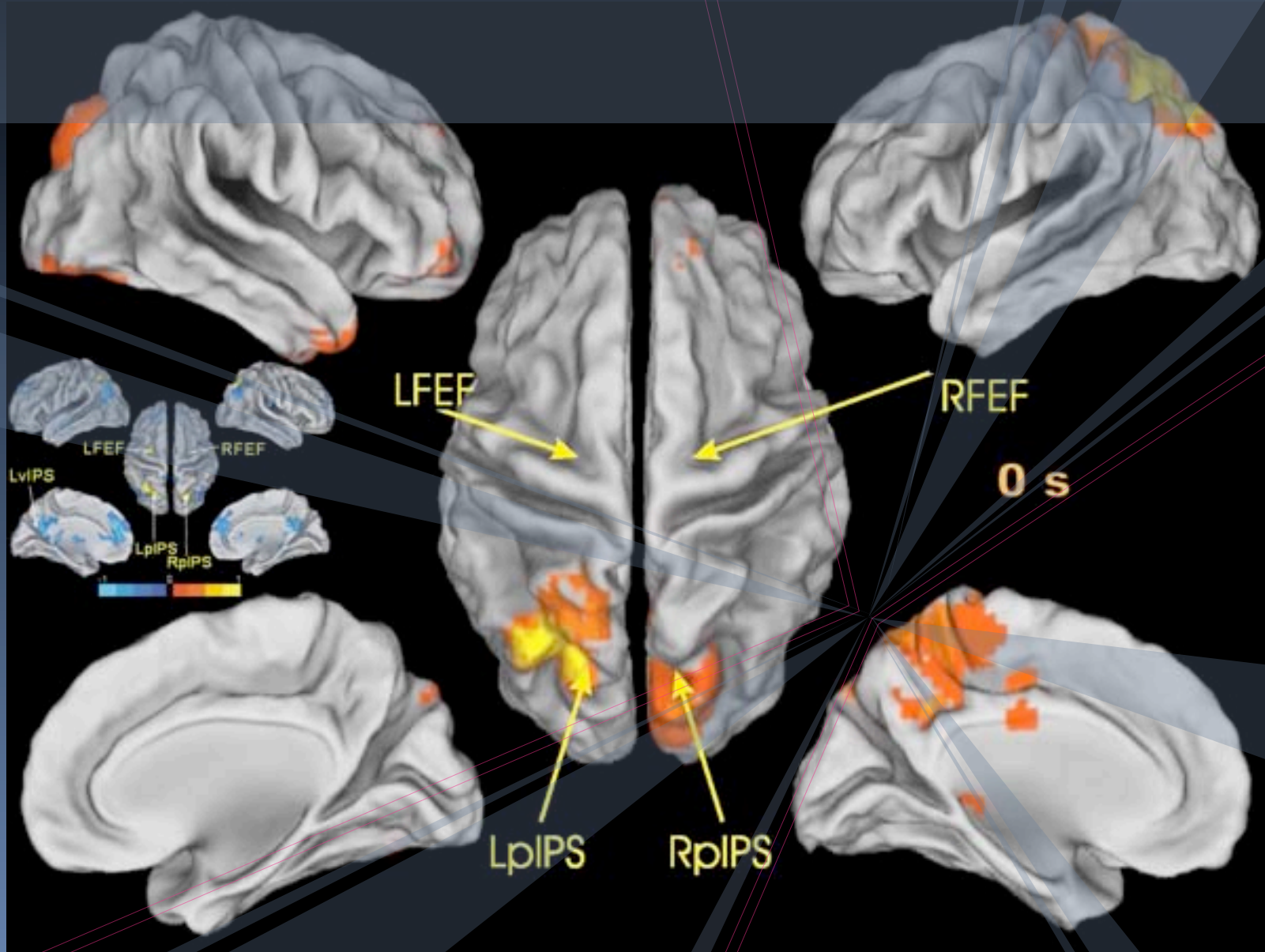
Monto et al. *JNeurosci* 08



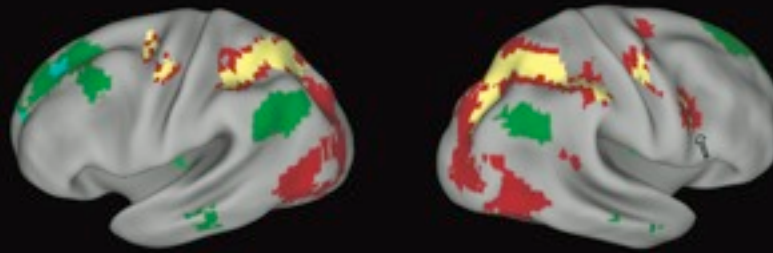
Slow (0.1 Hz) MEG power fluctuations correlate between distant cortical regions

(De Pasquale et al., *PNAS in press*)



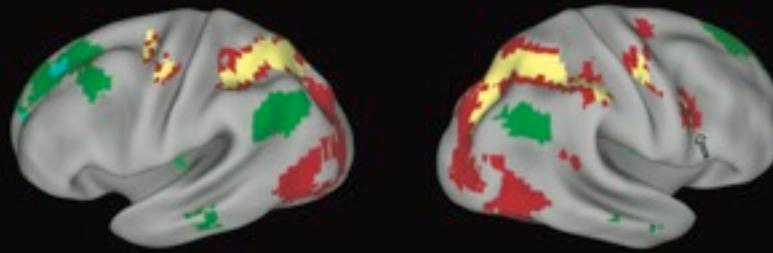


(a)



He et al.
Neuron, 2007

(a)



(b)

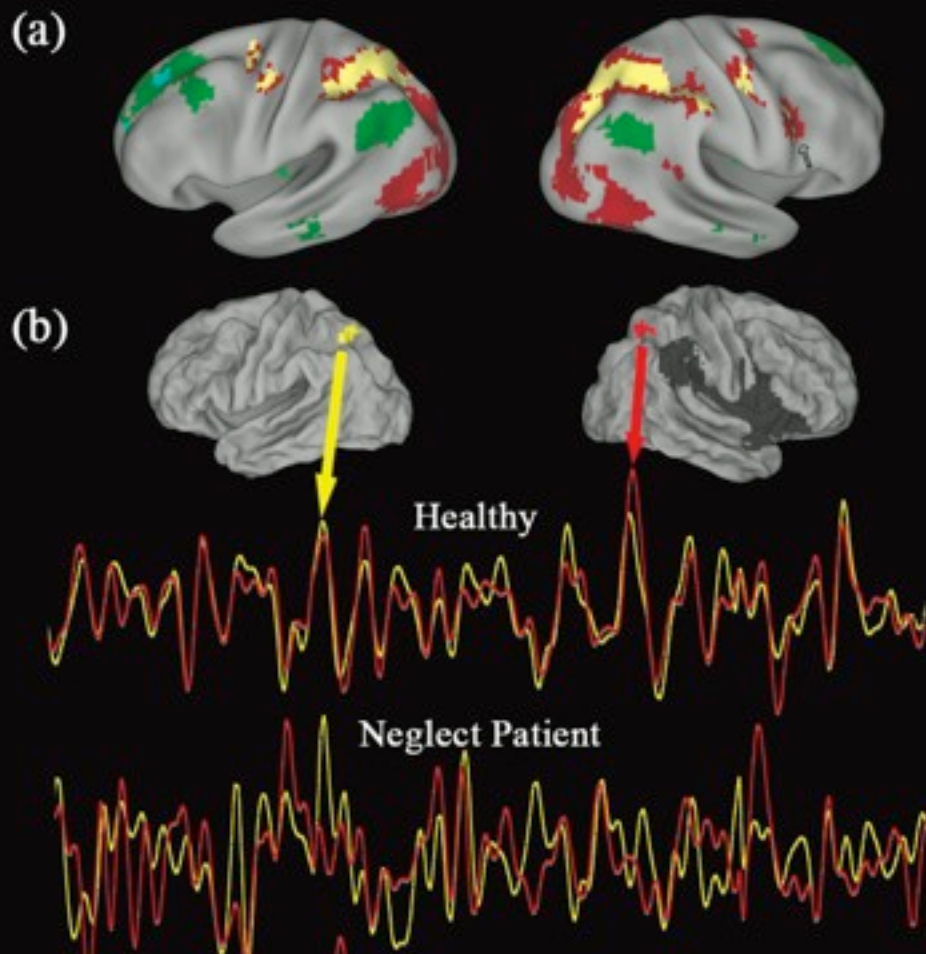


He et al.
Neuron, 2007



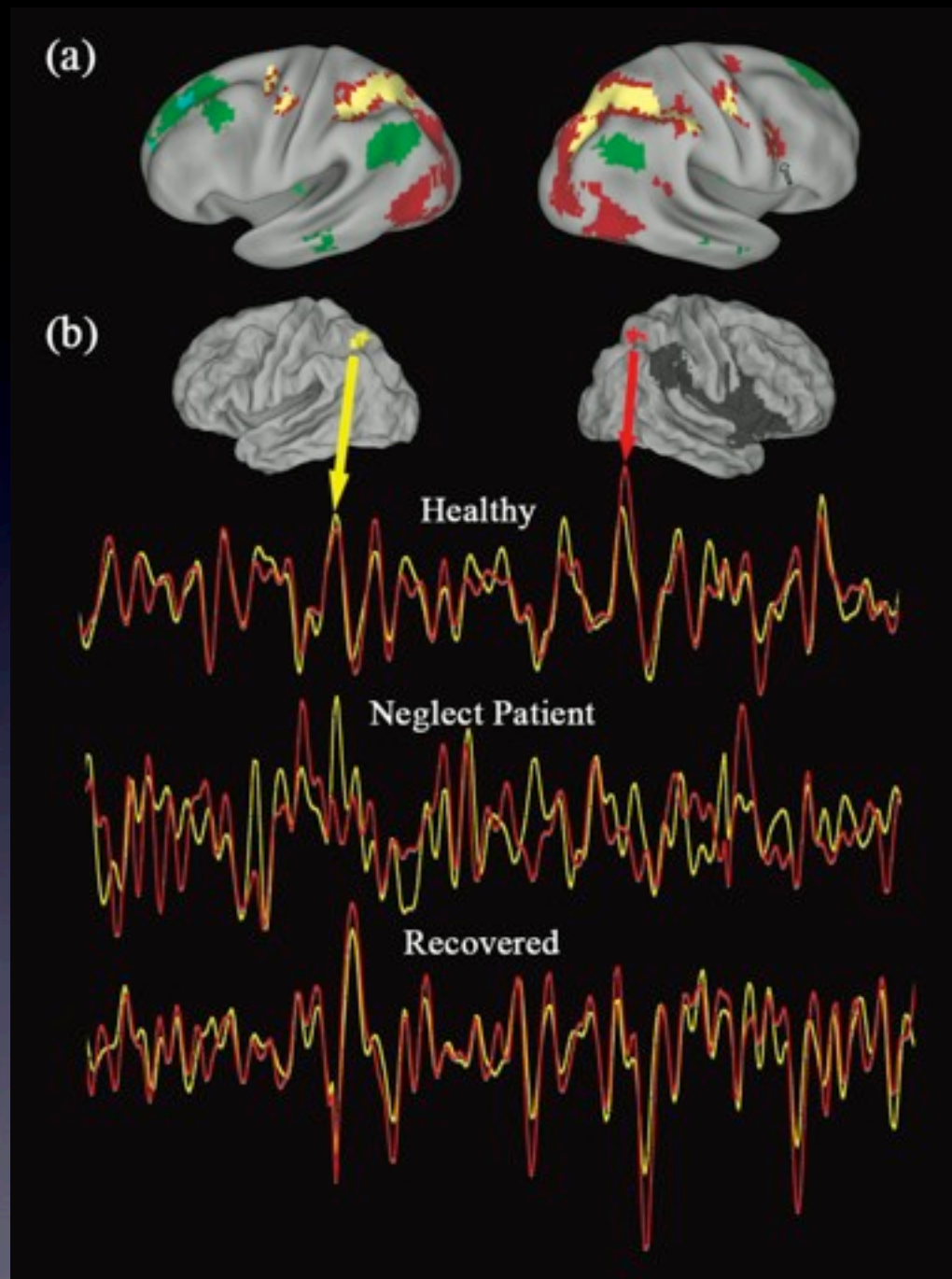


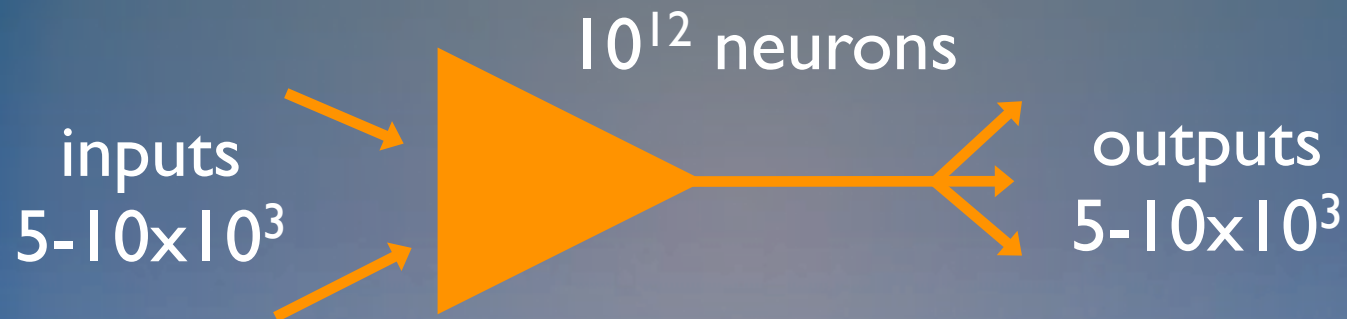
He et al.
Neuron, 2007





He et al.
Neuron, 2007





Total number of synapses in the cerebral cortex
 $\sim 2 \times 10^{16}$

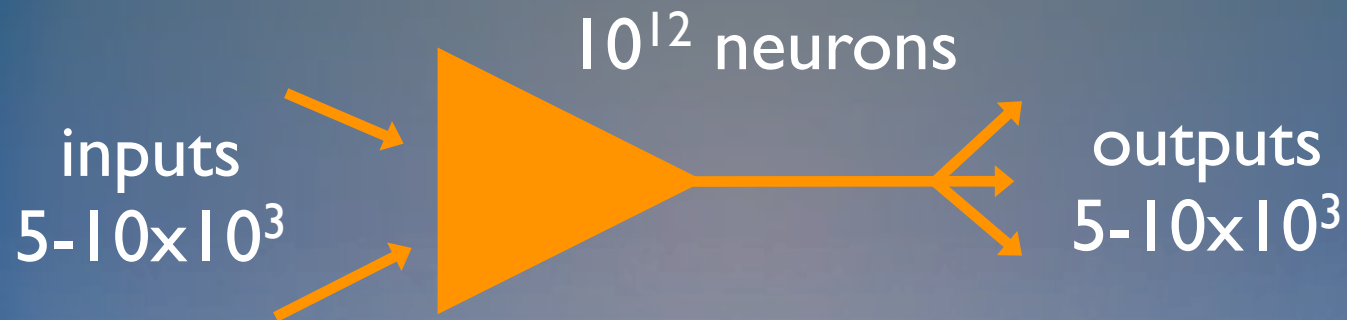
↑
Optic nerve:
 $5-10 \times 10^9$
synapses

↑
Corticospinal
tract:
 $5-10 \times 10^9$
synapses



Total number of synapses in the cerebral cortex
 $\sim 2 \times 10^{16}$

Cortical synapses=198,000 pixels



Total number of synapses in the cerebral cortex
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▲ Optic nerve

0.1 pixel

▲ CST