The History of Cognitive Neuroscience

- ❑ Historical timeline of thinking and research on the neural basis of mind.

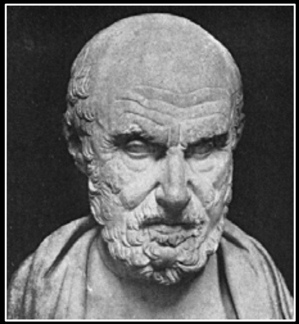
- ❑ Major figures in the localization / equipotentiality debate.
- ❑ Fields contributing to the development of Cognitive Neuroscience.
  - Behavioral Neurology & Neuropsychology.
  - Cognitive Psychology.
  - Technological advances in brain measurement.

- ❑ The Future of Cognitive Neuroscience.

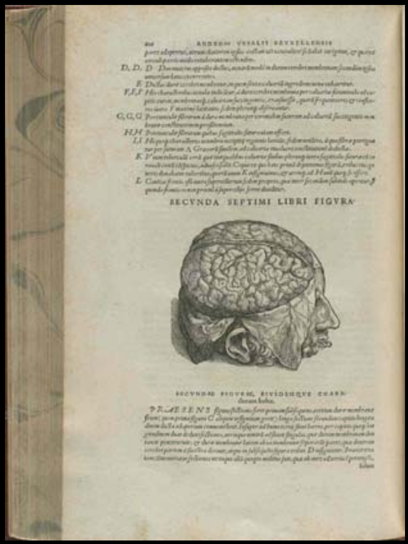
Timeline of the Neural Basis of Mind

- **Neolithic times (~7000 B.C.) – Evidence of Trephination.**
- **400 B.C. - Hippocrates (the "father of western medicine"), then Herophilus & Galen, hypothesize that the brain is the basis of mental functions.**
- **1543 - Andreas Vesalius publishes the first comprehensive anatomic text, *De Humani Corporis Fabrica*.**
- **1649 - Descartes claims pineal gland as the site of mind/body interaction.**
- **1717 - van Leeuwenhoek uses microscope to describe nerve fibers.**

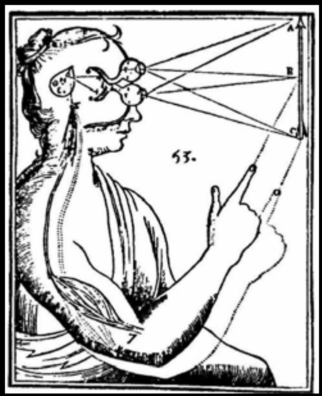
Trephinated Skull



Hippocrates



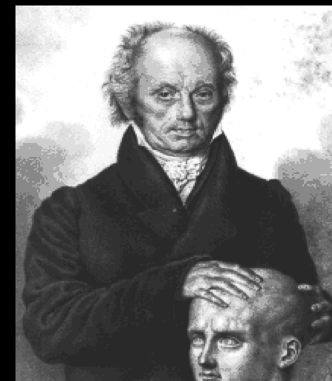
De Humani Corporis Frabrica, 1550



"Cartesian Dualism"

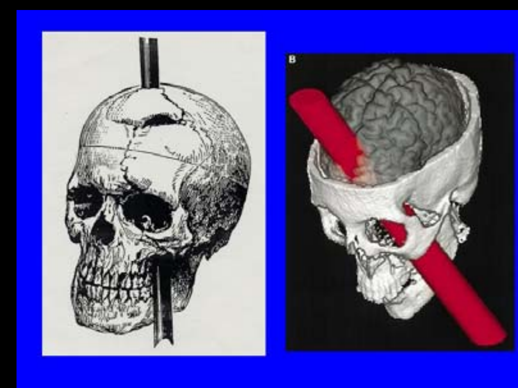
Timeline of the Neural Basis of Mind

- 1808 - Gall & Spurzheim create the "science" of Phrenology.
- 1848 - Phineas Gage has his brain pierced by an iron rod.
- 1852 - Hermann Helmholtz measures the speed of neural impulses in frogs.
- 1861 - Paul Broca describes his work on the neural localization of language.
- 1889 - Cajal argues that nerve cells are separate elements, contrary to Golgi's "syncytium" (nerve net) hypothesis.
- Development of EEG (1920s), CAT (1970s), PET & MRI (1980s), & fMRI (1990s).

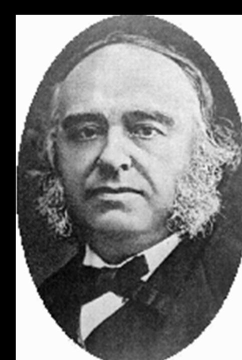


Franz Joseph Gall

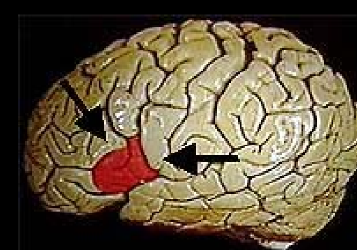
Phrenology Heads



Phineas Gage



Paul Broca



Broca's Area

How Does Neural Tissue Enable Cognition?

Localization

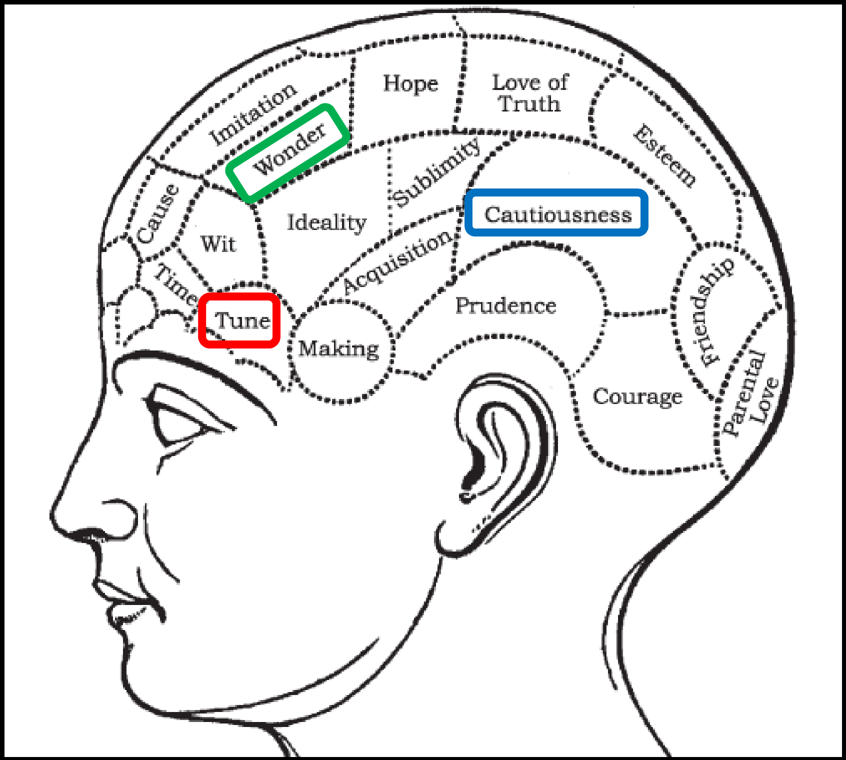
- Gall's (early 1800s) Phrenology: "Strict Localization".
- Broca's area (mid 1800s): Strict Localization.
- Fritsch & Hitzig's (1870s) dog electrical stimulation expts: Strict Localization.

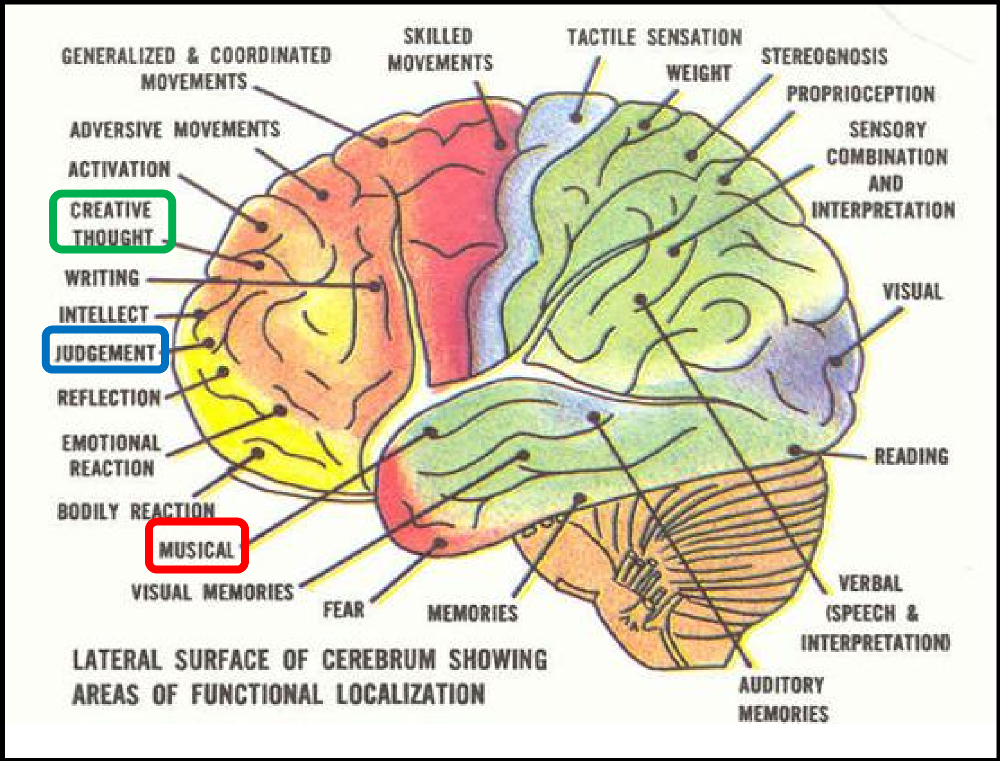
Equipotentiality

- Florens' (early 1800s) bird ablation expts: "The aggregate field".
- Wernicke's area (mid 1800s): Connectionism.
- Goltz's dog ablation expts (1890s): Equipotentiality

- John Hughlings-Jackson (late 1800s):
  - topographic organization in seizures.
  - partial localization: *the question is not what an area does, but what contribution it makes*.
  - functions both localized & distributed
  - neural *layers* in a functional hierarchy.

What are we trying to localize?





Phrenology: Bad!
"look at how dumb they were"

Modern Phrenology?: Good!
"look at how smart we are"

Fields Contributing to the Development of Cognitive Neuroscience: Neuropsychology

- **Behavioral Neurology (cf. neurology, neurosurgery).**
  - Emphasis on lesion localization via behavioral (neuro-psych test) abnormalities.

- **Clinical Neuropsychology.**
  - Emphasis on broad neuropsychological syndromes (aphasia, amnesia, etc.) via performance on standardized test batteries (e.g., Halstead-Reitan; Luria-Nebraska).

- **Individual (Case-Study) Approach (UK).**
  - Emphasis on intense study of brain damage in single individuals with the goal of better understanding normal neurocognitive function.

Fields Contributing to the Development of Cognitive Neuroscience: Cognitive Psychology

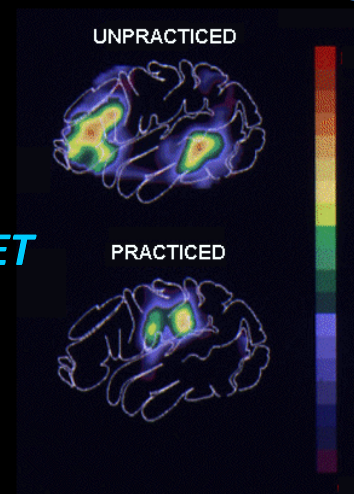
- Cognitive Psychology studies how people *acquire, store, transform, & use information*.
  - Focus is on mental processes, but research and theories are grounded in, and thought to give rise to, behavior.

- Major research interest is on the nature of cognitive representations & processes.
  - Representations are (neural) structures or patterns of activity that stand for something in the world. Examples include *memory traces*, words in our "*mental lexicon*", *concepts*, and *images*.
  - Cognitive processes are (neural) patterns of activity that operate on the external environment, or on internal (cognitive) representations. Examples include *visual search*, *short-term memory, selective attention,* and *executive functions* (like *planning*, *monitoring*, & *inhibition*).

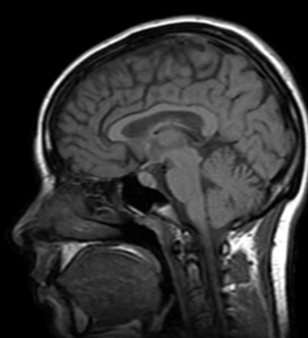
Fields Contributing to the Development of Cognitive Neuroscience: Technology

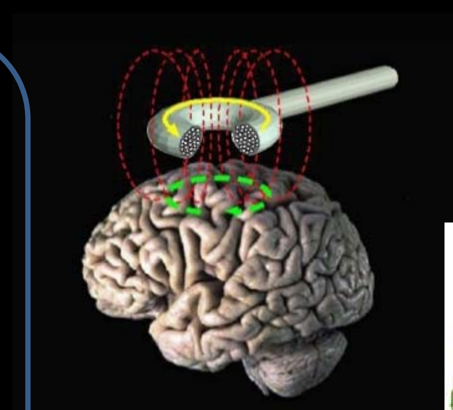
EEG/ERP

PET



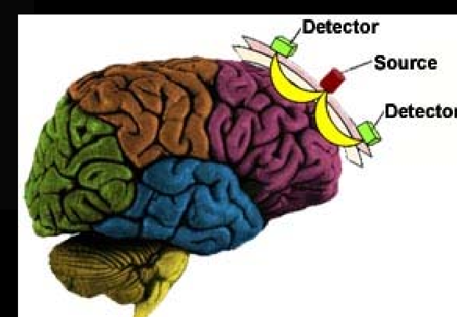
MRI & fMRI





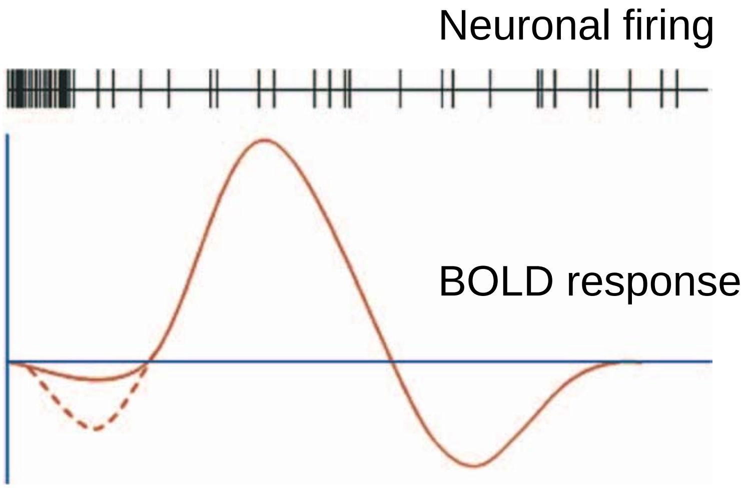
TMS

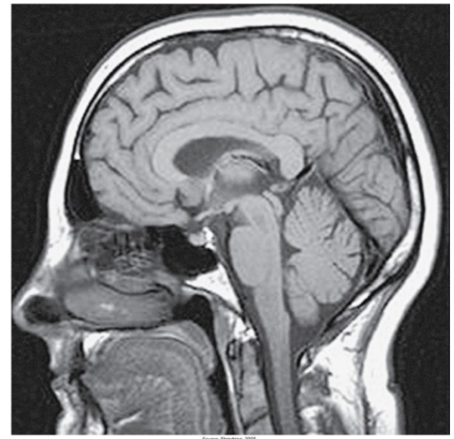
fNIRS



fMRI and PET: indirect signals for neural activity

fMRI provides a measure of hemodynamic (blood based) activity in the brain and is based on the premise that neuronal activation increases oxygen demand of neurons and related cells, leading to additional blood flow carrying oxygen molecules to the region. This can be measured using BOLD (Blood Oxygen Level Dependent) activity.



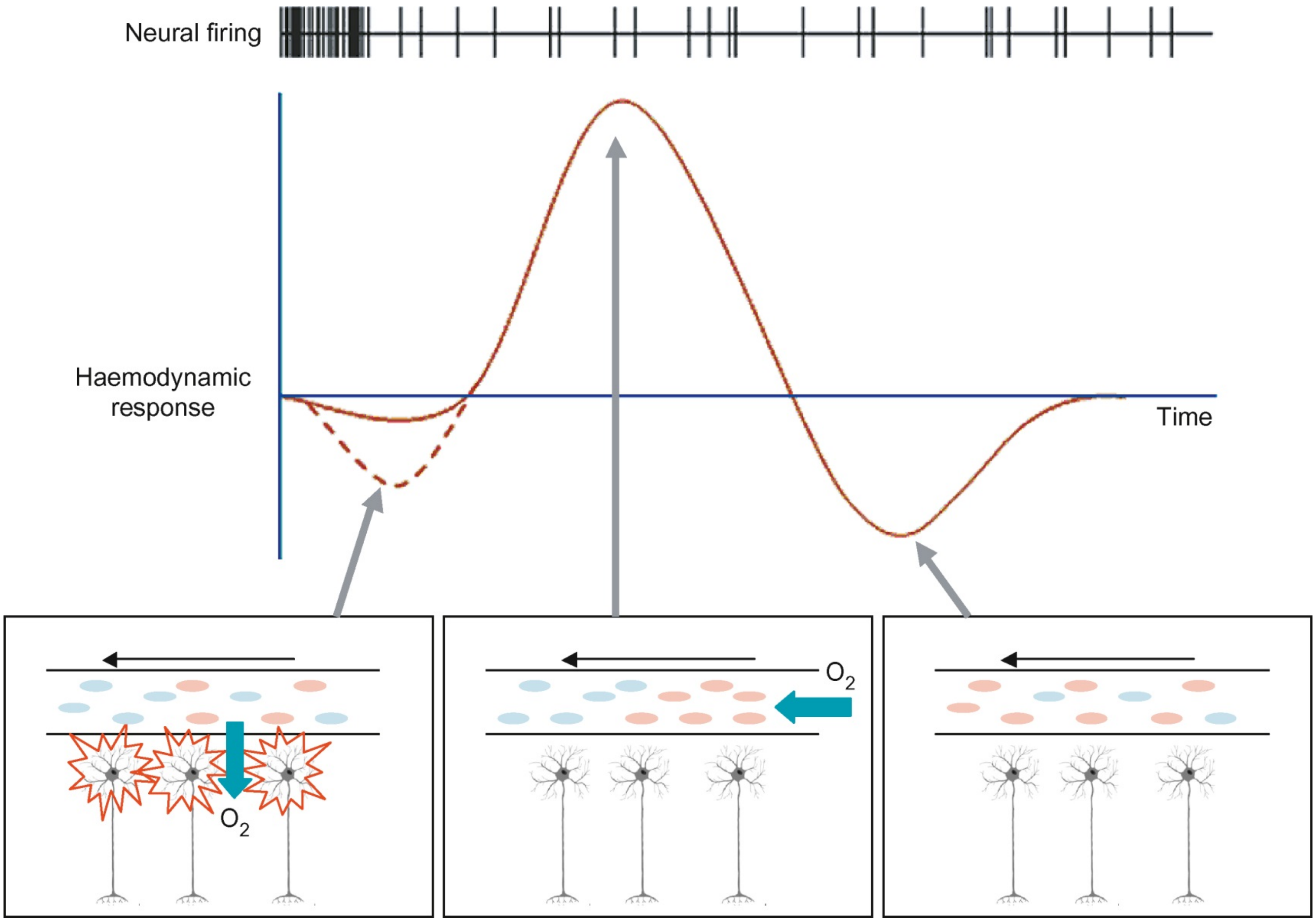


Source: Standring, 2005.

Source: Sharma and Sharma, 2004.

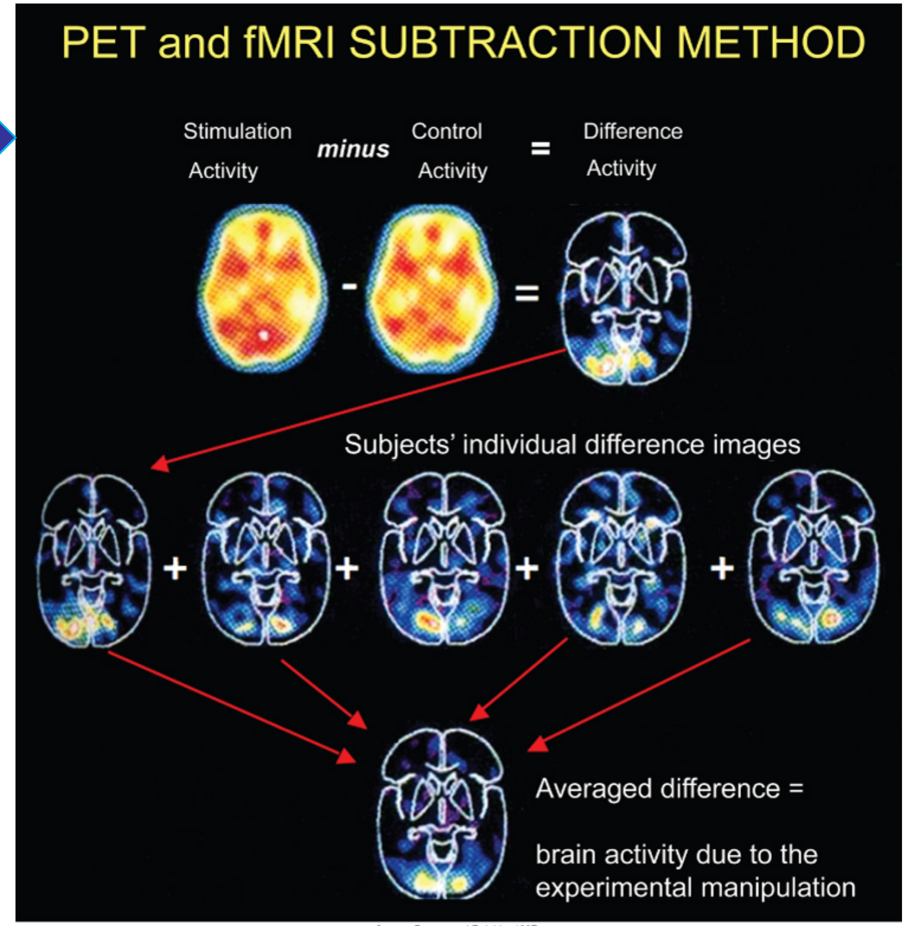
fMRI is the main neuroimaging technique today.

The Hemodynamic Response



fMRI and PET: The Subtraction Technique

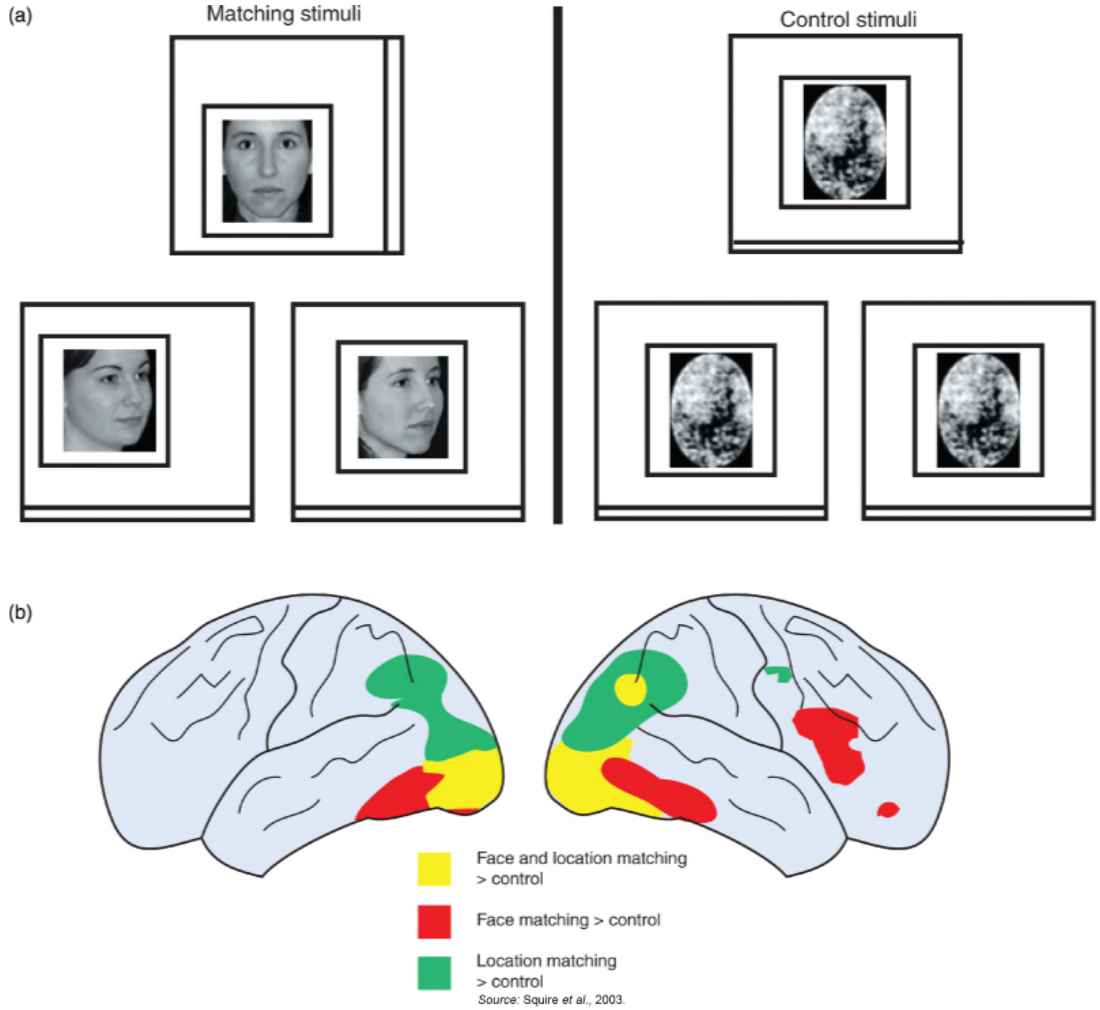
Both PET and fMRI often rely on a *subtraction method* where brain scans for different experimental contrasts are subtracted from each other.



Source: Posner and Raichle, 1997.

fMRI and PET: indirect signals for neural activity

The brain is a dynamic, complex entity. How do you know which brain activity corresponds to your research experiment? One technique is to define regions of interest (ROIs) before scanning to identify which areas you expect to see changes in activation.

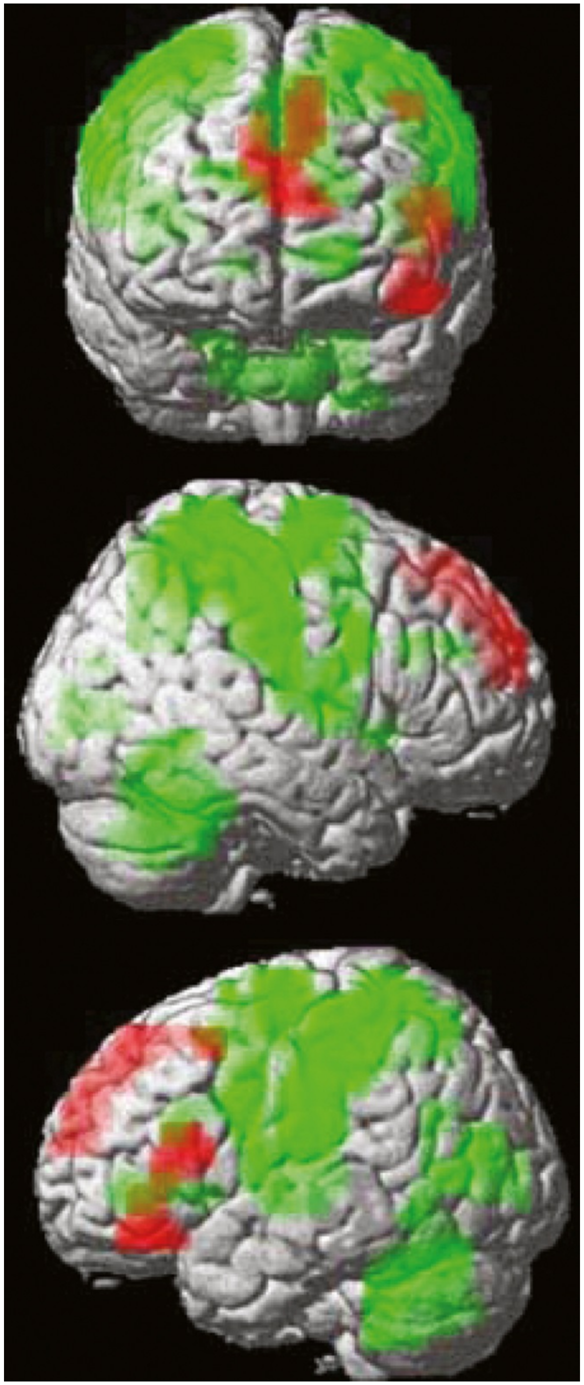


Interpreting neuroimages

The picture here, based on a study using playing cards, shows fMRI differences between brain regions that had greater BOLD activity when people were telling the truth (green) and regions that showed greater activity when they were telling a lie (red).

How should we interpret these patterns of activation?

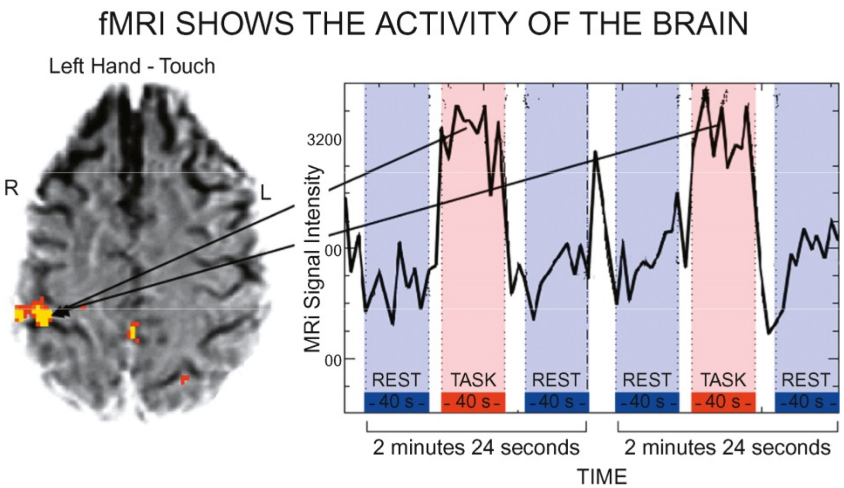
Does the image show us the truth telling (green) and the lying (red) areas of the brain? Why or why not?

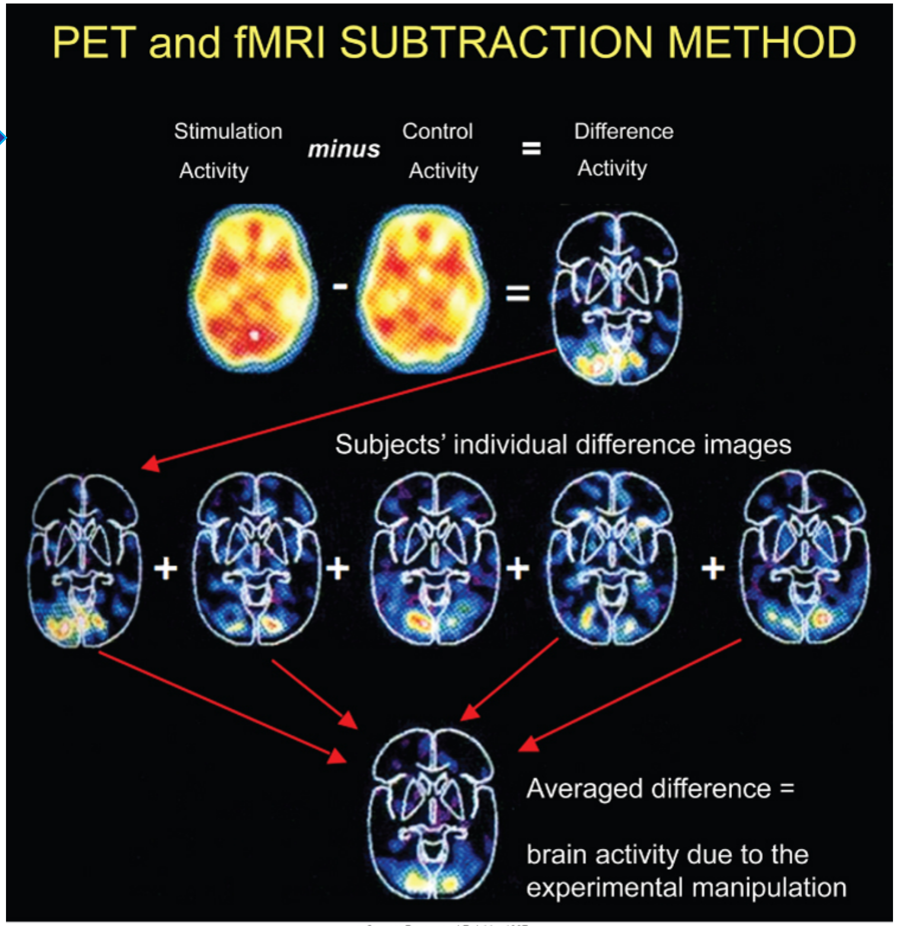


fMRI and PET: The Subtraction Technique

Both PET and fMRI often rely on a *subtraction method* where brain scans for different experimental contrasts are subtracted from each other.

Another method, used mainly with fMRI, is to cycle a task or source of stimulation on & off, and look for region specific tracking of this activity.

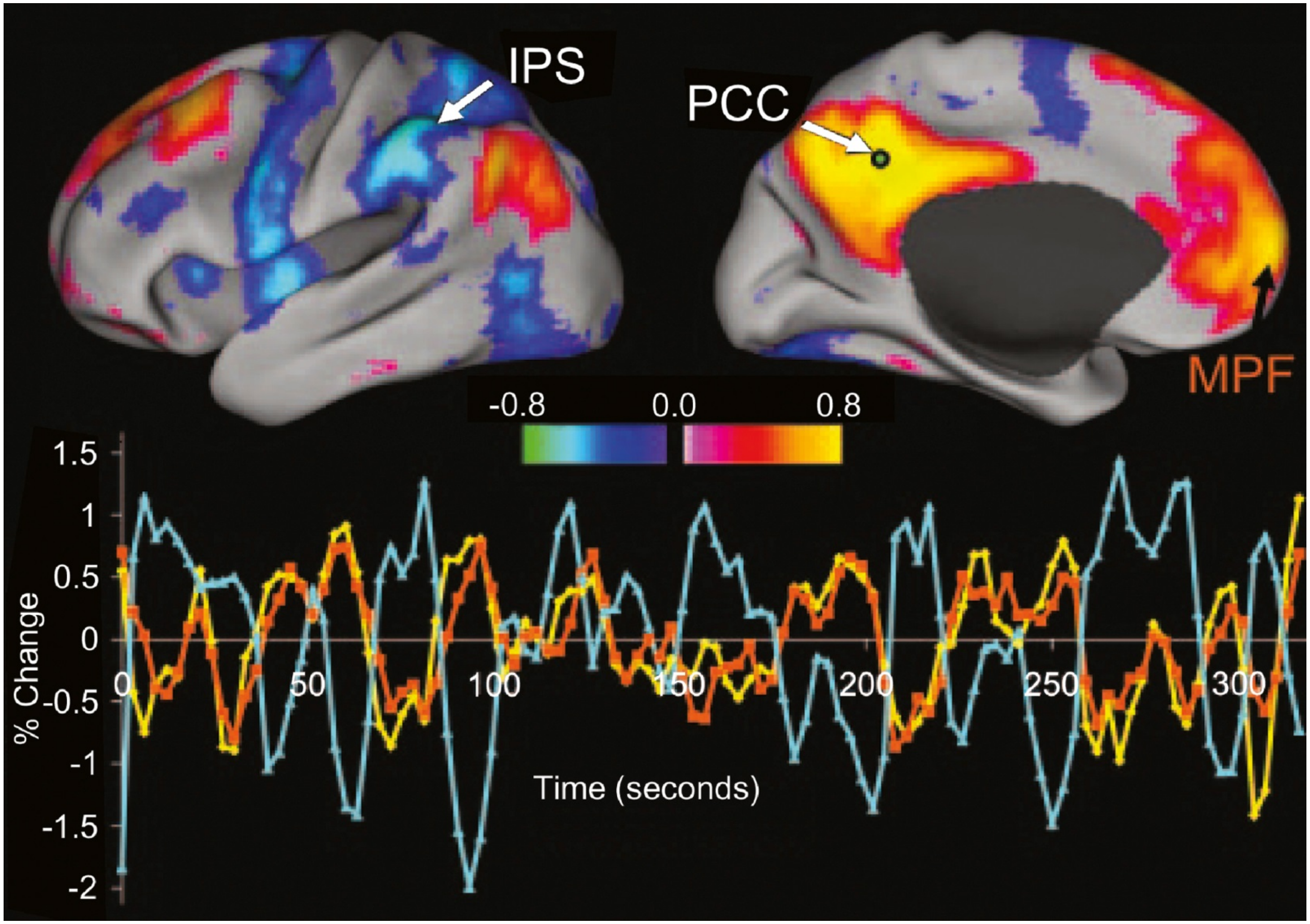




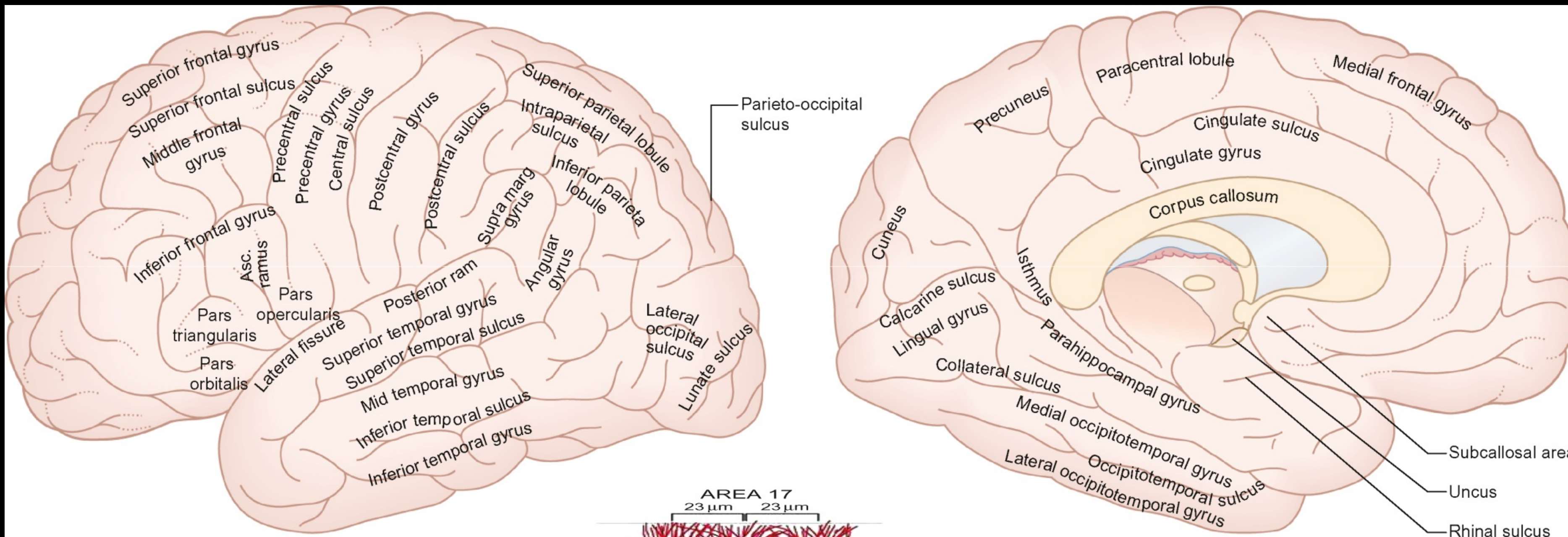
Source: Posner and Raichle, 1997.

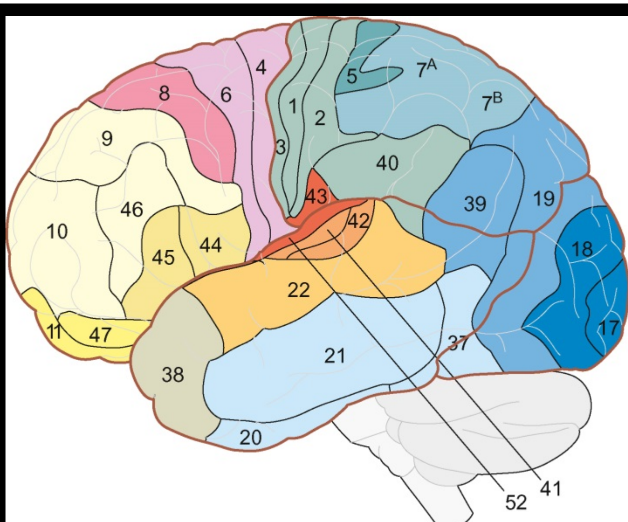
The Default Mode Network

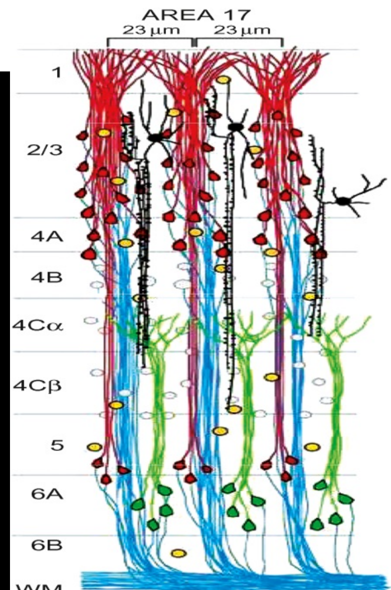
Examination of brain activity during "rest" periods has revealed a coherent pattern of activity that appears to be a fundamentally important brain state. What does it do?

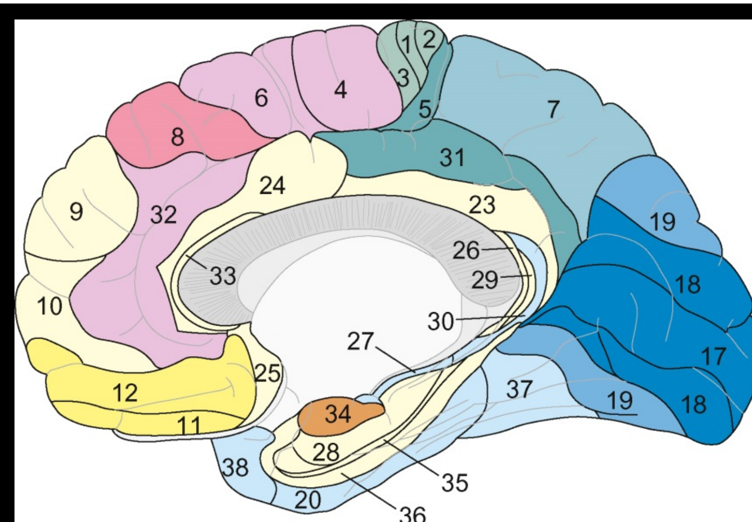


The Future of CogNeuro: Better Understanding of Regional Functionality

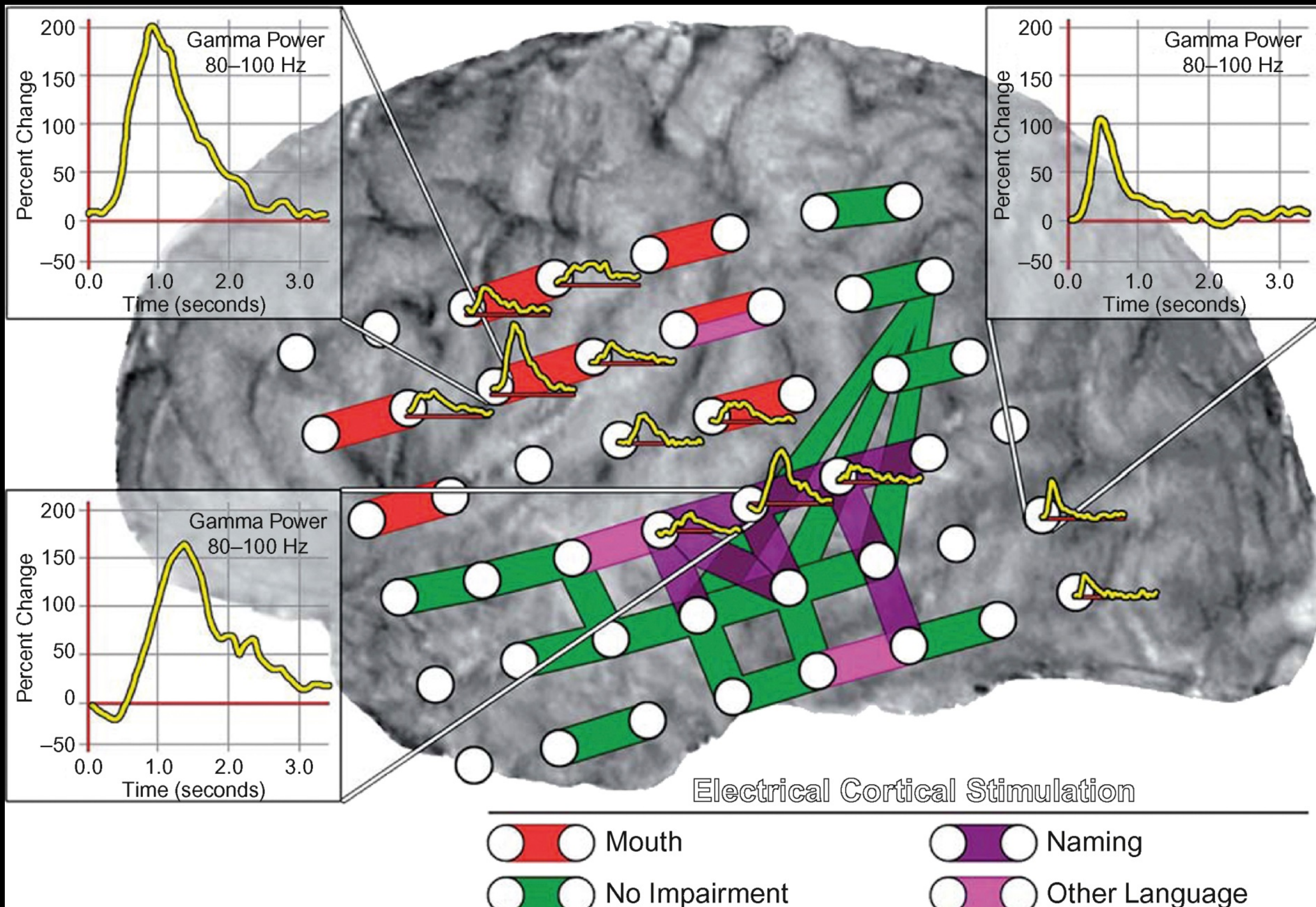






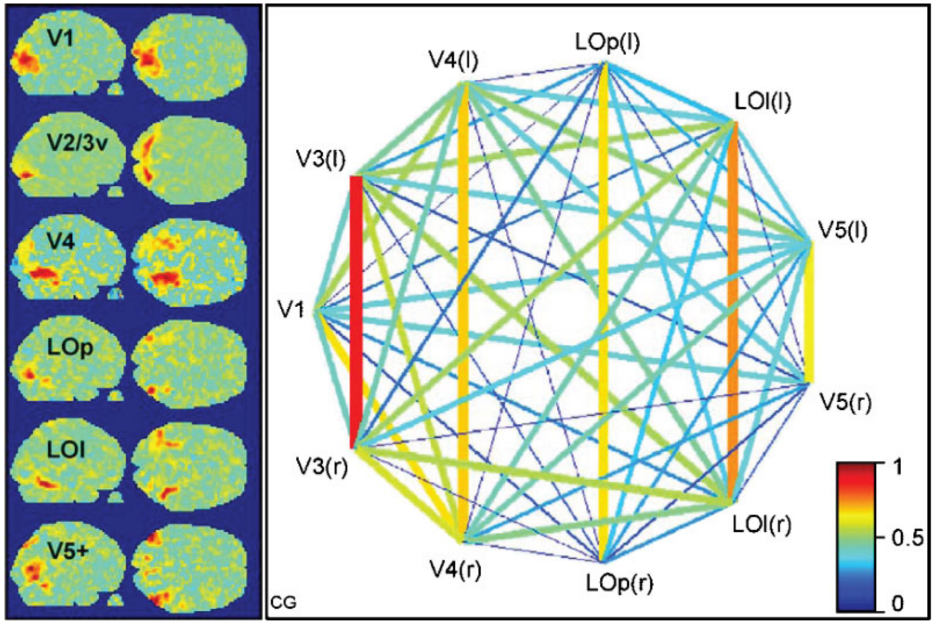


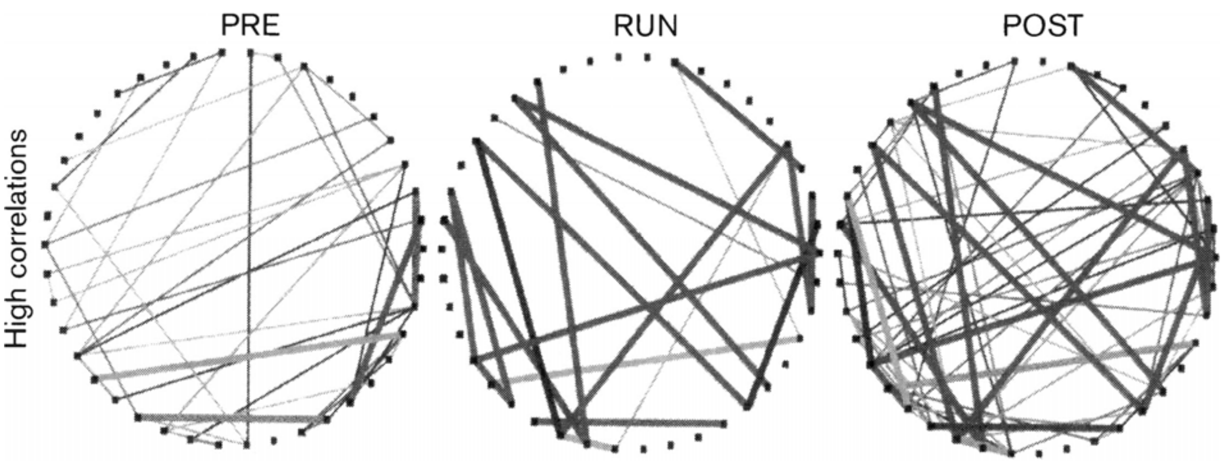
The Future of CogNeuro: Understanding Connectivity (Networks)



Coordinating Neural Nets

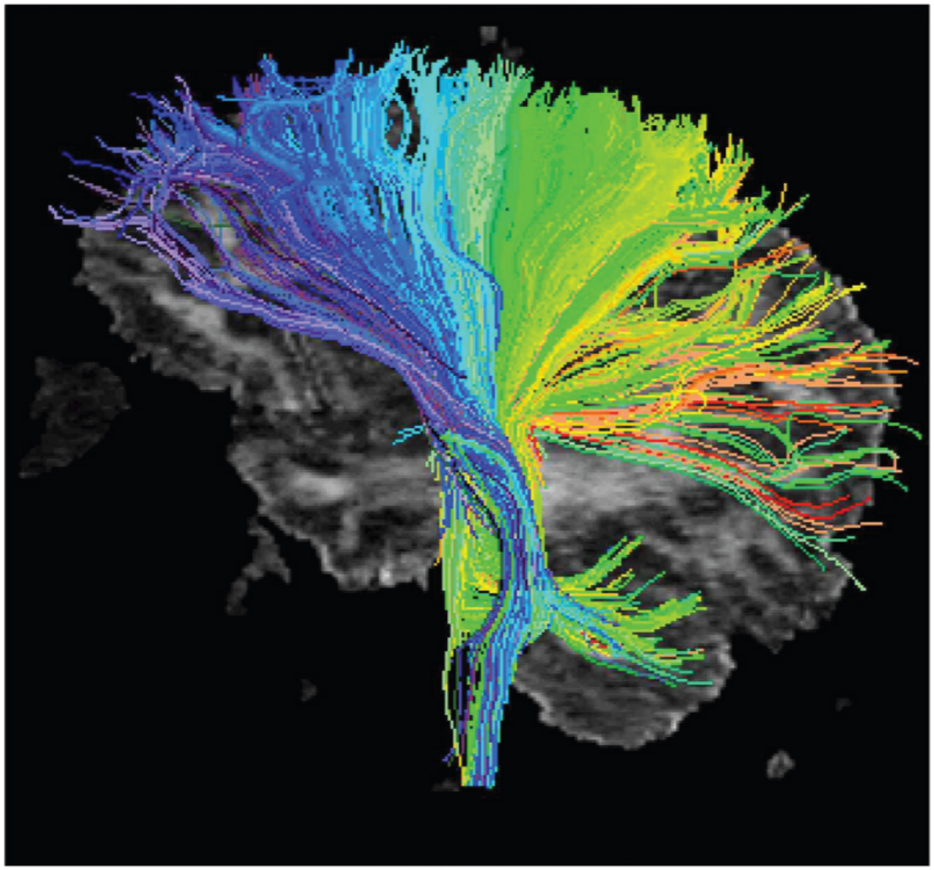
An activation map of visual areas active while a subject watched a movie. Note the correlation of neural activity in the left hemisphere (top of figure, marked with 'l') and the right hemisphere (bottom of figure, marked with 'r') across differing visual areas such as V3 and V4.



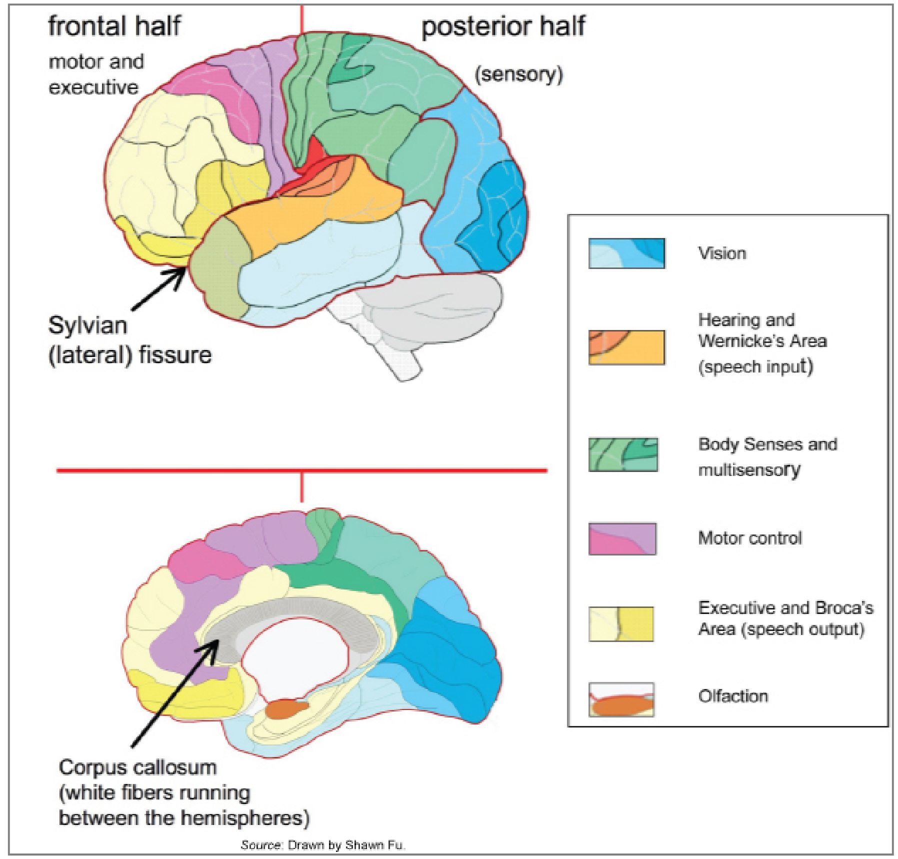


Strengthening of neuronal connections in hippocampal neurons of a cat after spatial learning, showing an example of Hebbian learning.

Image of the brain using diffusion tensor imaging (DTI) which reveals white-matter (myelinated) fiber tracts.



Source: Maria Lazar, with permission.

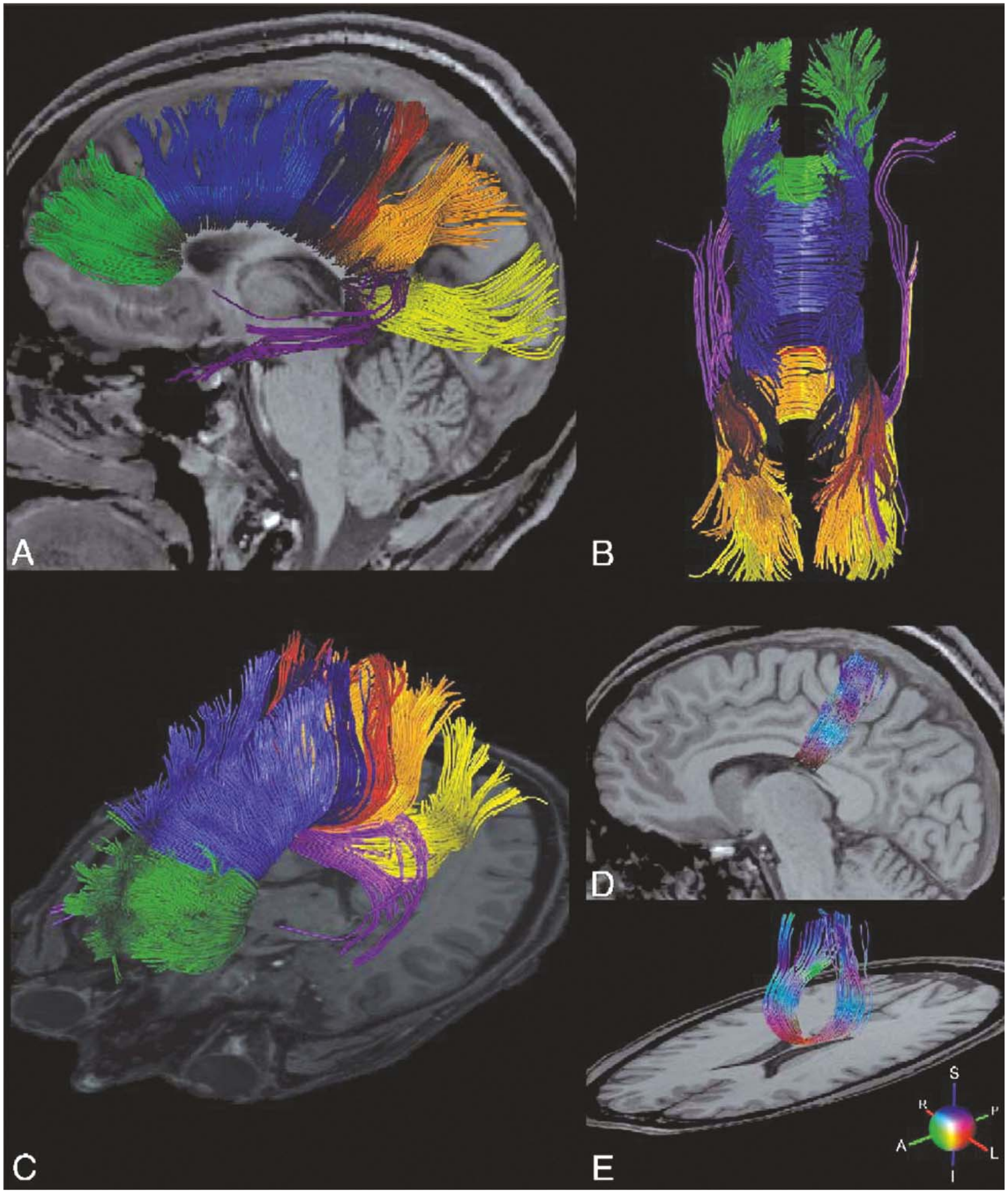


Schematic figure of the brain showing where perceptual and motor regions are located. Compare their locations with the brain image of the fiber tracts.

(A) DTI image showing white matter tracts through the corpus callosum, color-coded by cortical region:

Green = Prefrontal.
Light blue = Premotor cortex.
Dark blue = Motor cortex.
Orange = Parietal.
Yellow = Occipital.
Violet = Temporal.

(B) Fiber bundles alone (without structural MRI), viewed from back (yellow) to front (green).



Correlated activity between brain areas in the counting Stroop task

Each circle represents a brain region.

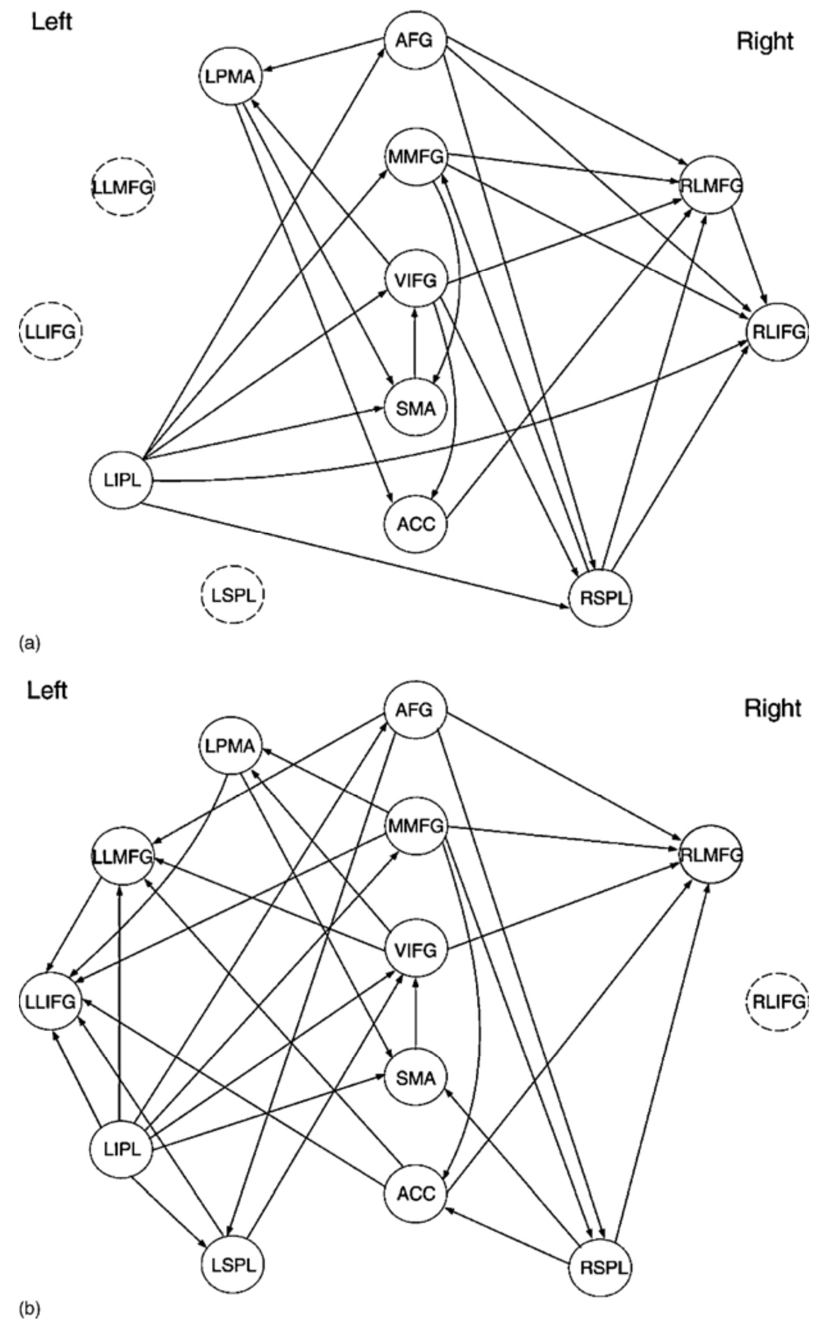
The top image shows brain activity during simple counting of unrelated words. The bottom image shows activity when the to-be-counted words produce interference from competing responses

As can be seen, interference leads to the engagement of a more widespread network than the control condition.

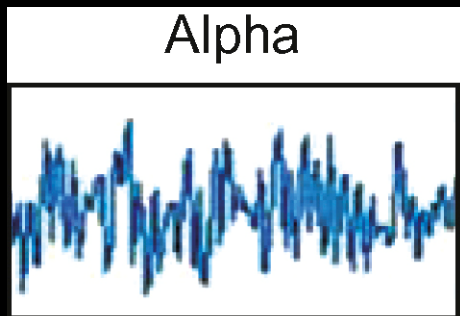
This change in coupling between areas is seen despite the fact that many of the same areas are active in both conditions.

Note also that some of the connections are lost between the control and the interference condition.

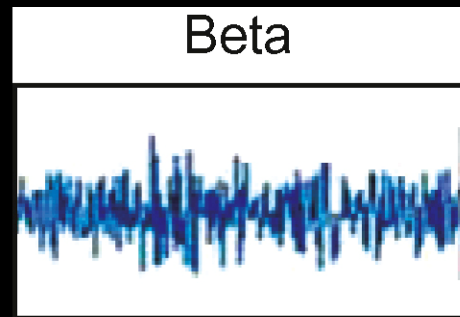
(Zheng and Rajapakse, 2006).



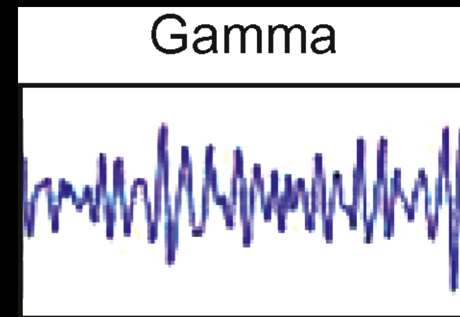
The Future of CogNeuro: Understanding Temporal Relations (Synchrony)



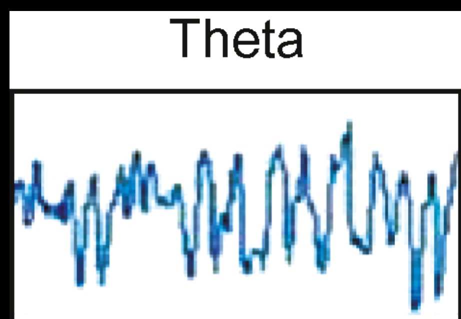
7.5-13 Hz;
relaxation; occipital.



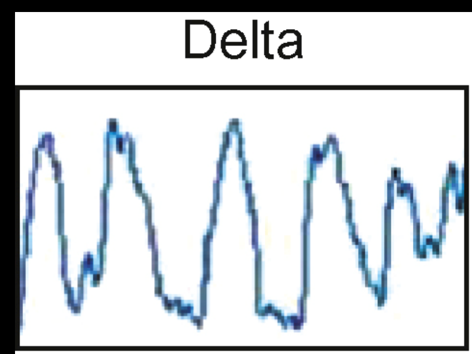
12-25 Hz; focused
activity; frontal.



26-70 [40] Hz; interaction
btw cortex & sub-cortex in
waking & sleep (REM).



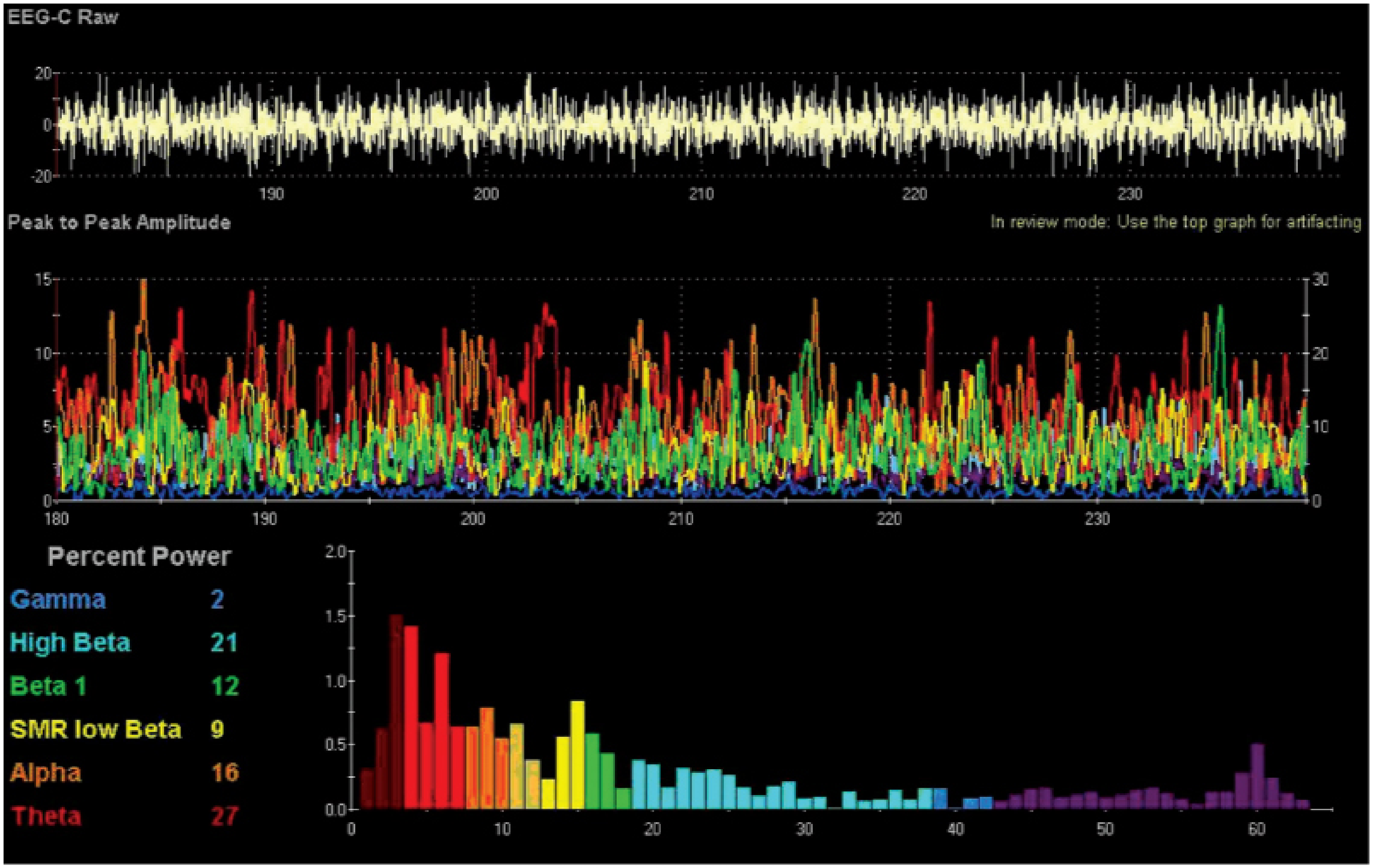
3.5-7.5 Hz; sleep, quite
focus, meditation; interaction
btw cortex & hippocampus



< 4 Hz; deep sleep; coma;
unconsciousness

A range of useful tools --
measuring electric and magnetic signals

Electroencephalography (EEG) recordings reveal brain rhythms such as Gamma (40Hz). Gamma activity is thought to signal exchange of information between cortical and subcortical regions.



Three waveforms with important cognitive functions are alpha (associated with relaxed and alert states), frontal theta (believed to reflect interactions between the hippocampus and cortex), and gamma activity (thought to reflect transient assemblies of neurons associated with conscious processing). *Spectral power* reflects the amount of physical energy in each frequency band. **(Source: Ward, 2002).**