The Human Brain

HOW DO WE LEARN ABOUT THE HUMAN BRAIN?

Methods of Studying the Human Brain

Courtesy of University of Oregon Child and Family Center.

Courtesy of Marcus E. Raichle. Used with permission.

Methods of Studying the Human Brain

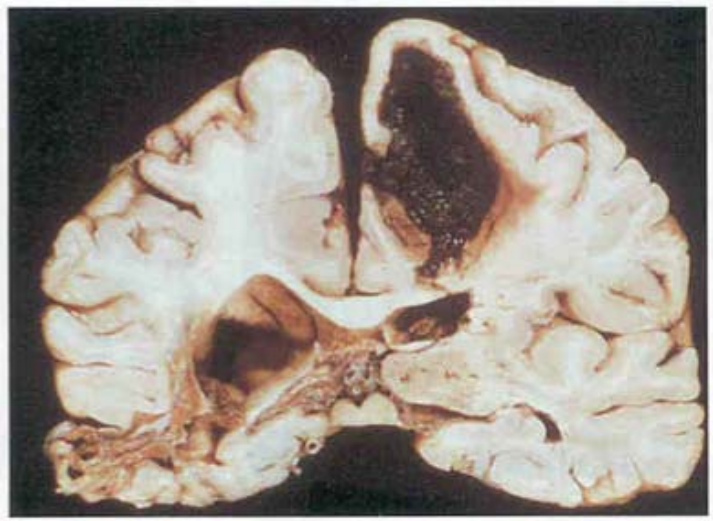
- **Lesions**
- **Stimulation**
- **Recording**

OUTLINE

1) **Lesion**
2) **Stimulation**
3) **Recording**
   - **a. Structure**
   - **b. Function**
     - **i. Electrical/Magnetic**
       - **- EEG**
       - **- MEG**
     - **ii. Metabolic**
       - **- PET**
       - **- fMRI**

Goals: • ***introduce techniques***
• ***present strengths and limitations***

STROKE



LESIONS

Causes of Brain Injury

stroke (CVA) : blood flow is disrupted

hypoxia : lack of oxygen

tumors : abnormal cell growth

degenerative disorders : Alzheimer's, Huntington's, Parkinson's, Korsakoff's

epilepsy : resection

NEURONAL DEATH

LESIONS

Strengths

- **Causal - brain area necessary**
- **Dramatic deficits: Phineas Gage, Tan, H.M., prosopagnosia**
- **Counterintuitive deficits: Blindsight, Category-Specific Deficits**
- **Dissociations**

  declarative memory (knowing that) & hippocampus
  procedural memory (knowing how) & basal ganglia

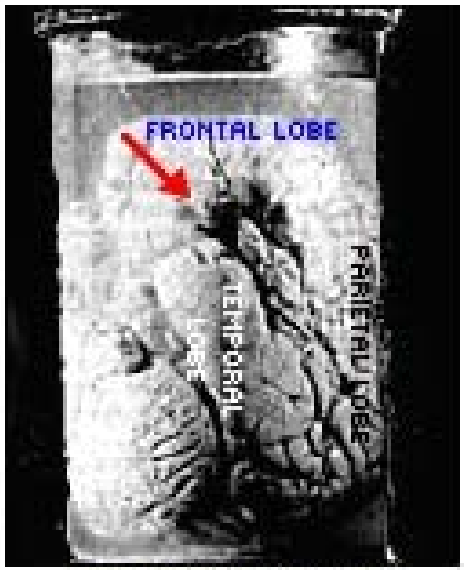
LESIONS

Limitations

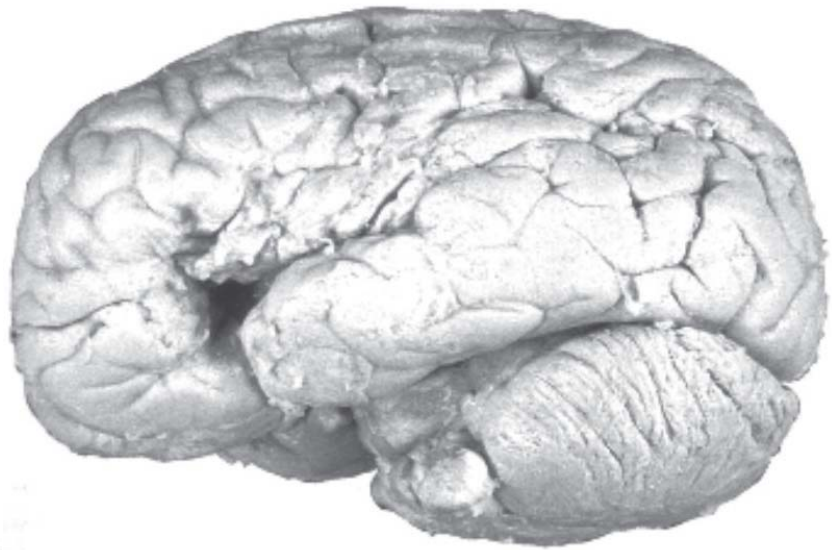
- damage extensive, hard to localize, not systematic
- individual variability:
  - case v.s. groups studies
- nearby systems likely to get injured together
- degeneration, recovery, compensation
- may offer limited views of normal brain functions

Paul Broca (1824-1880)

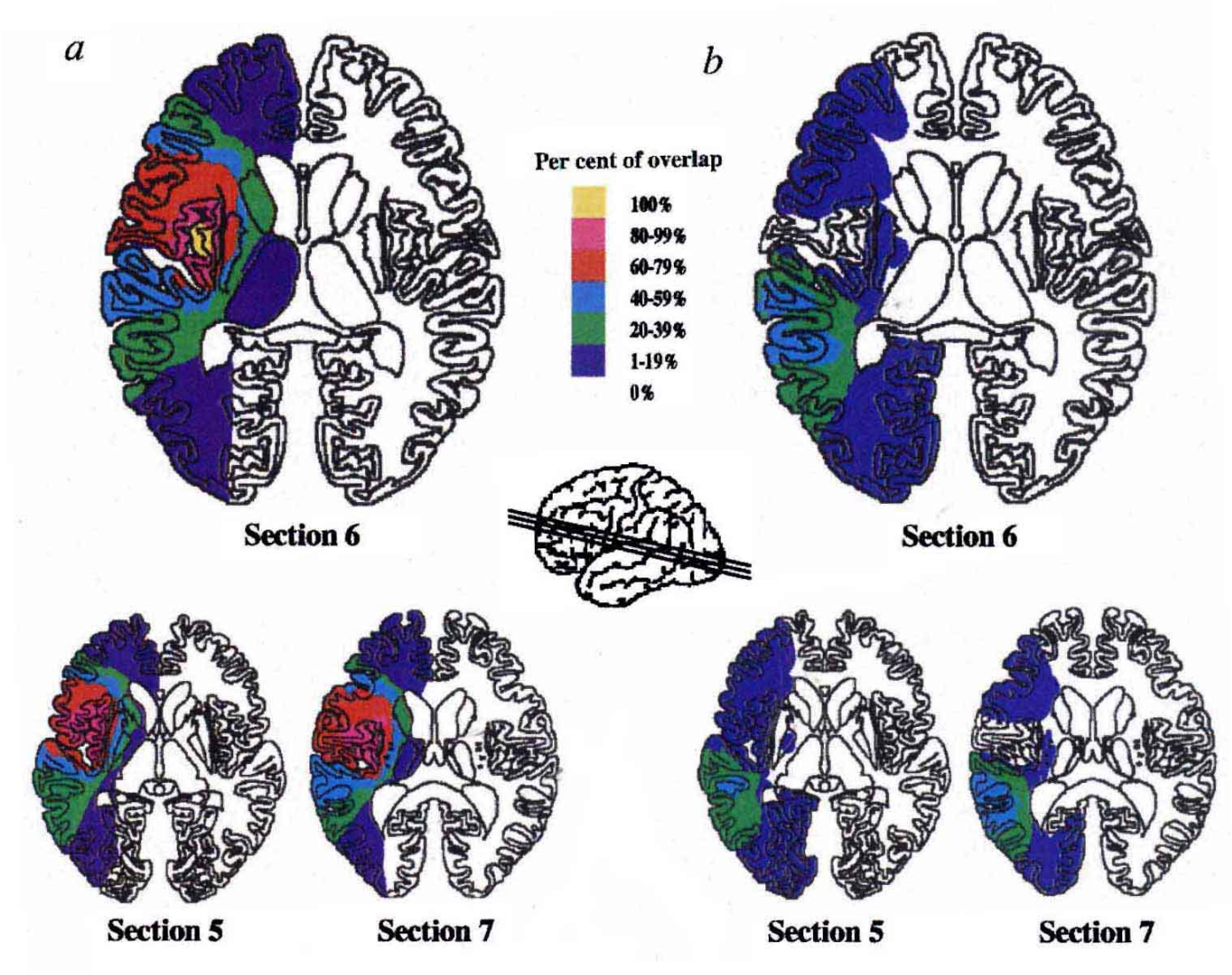
PAUL BROCA



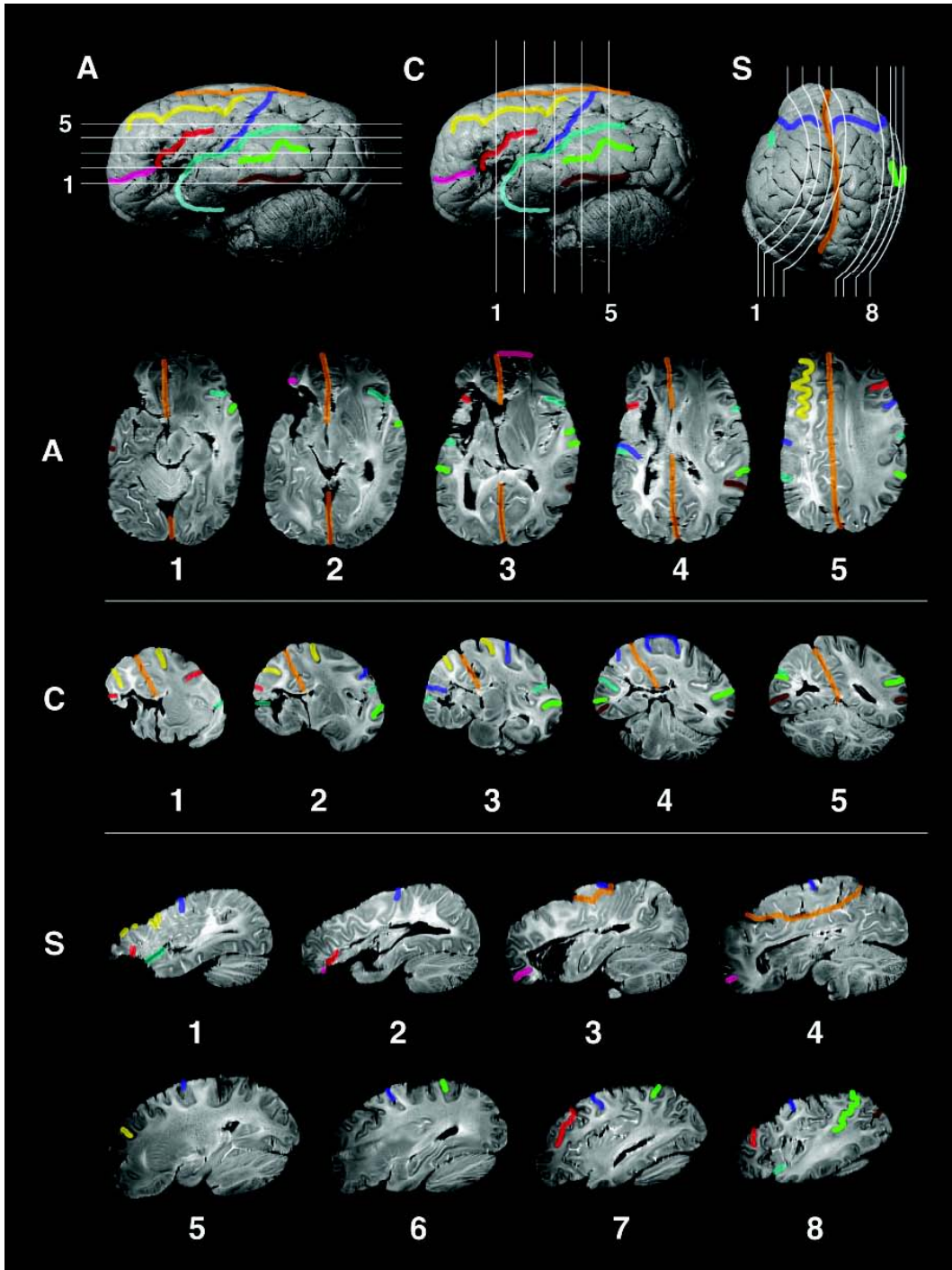
THE BRAIN OF MR. 'TAN'



“Broca’s Area”: Left Precentral Gyrus of Insula



High-Resolution MRI of Leborgne/Tan reveals extensive medial damage including arcuate/ superior longitudinal fasciculus



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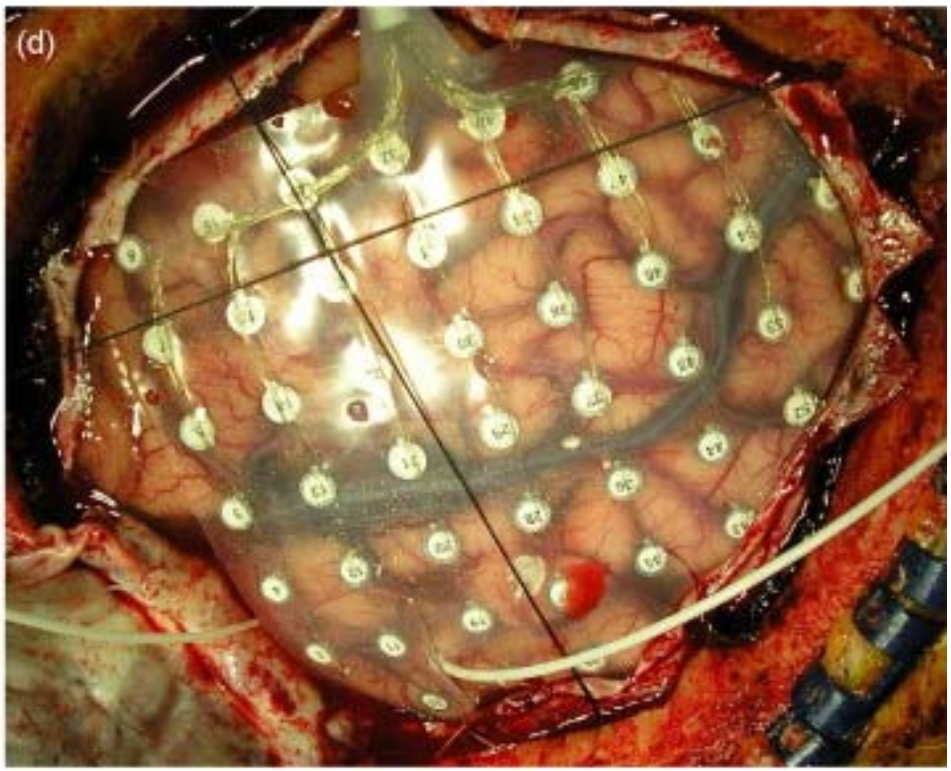
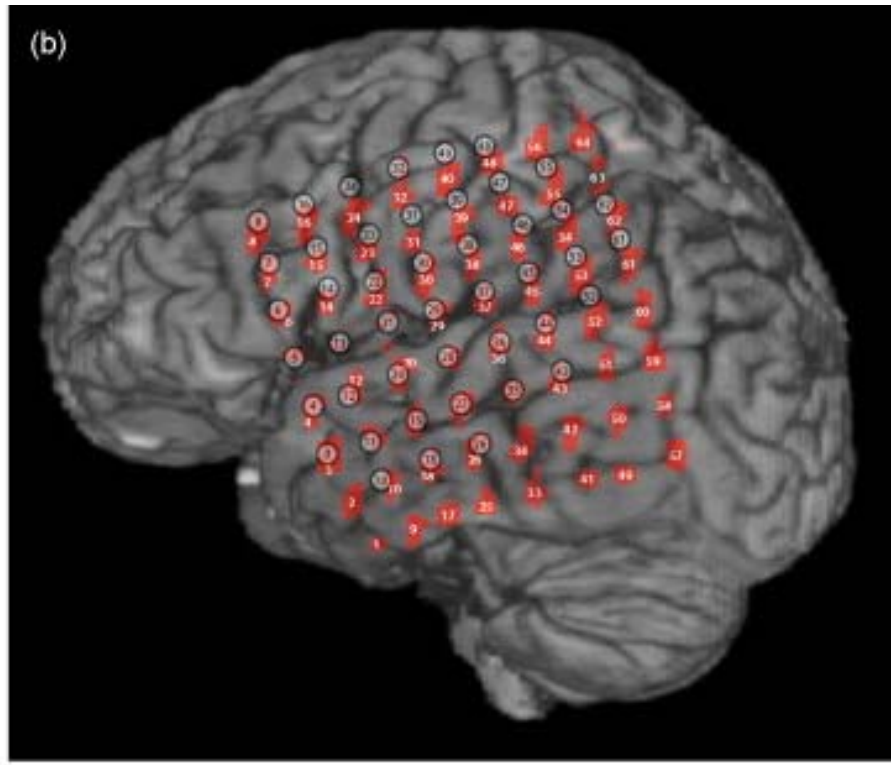
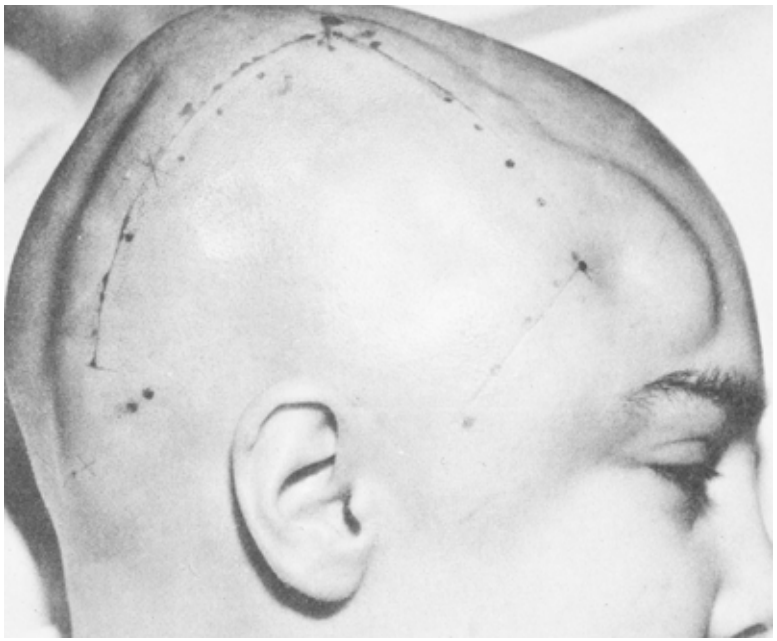
Stimulation

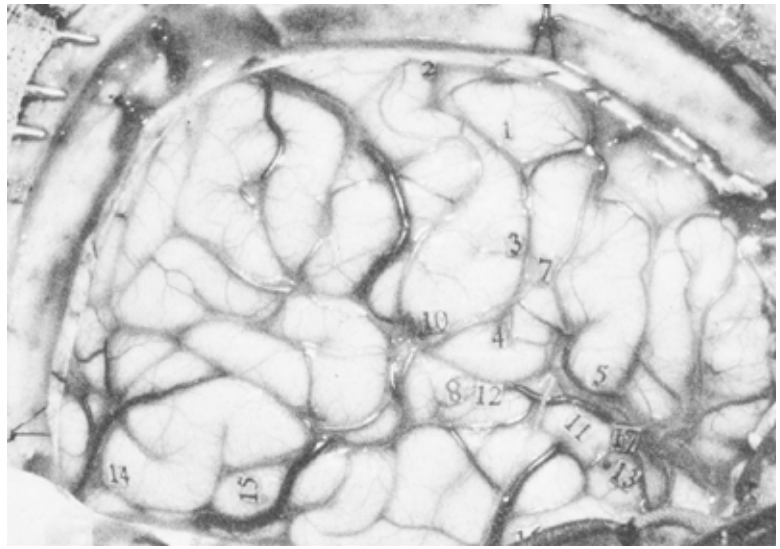




Source: Dalal, S. S., et al. *J Neurosci Methods* 174, no. 1 (2008): 106-15.

Electrical stimulation





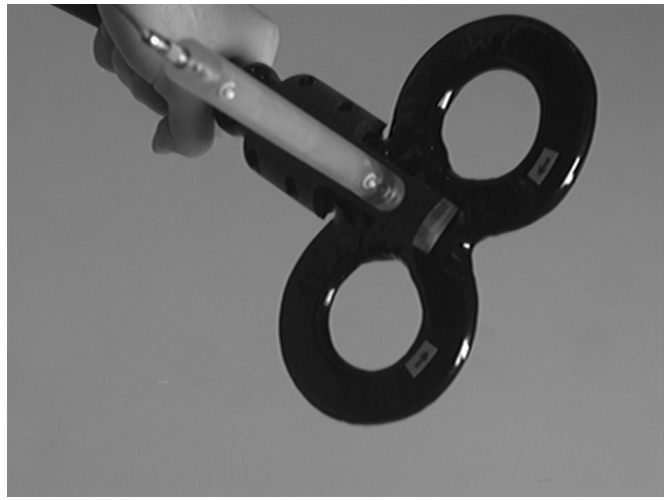
Pioneered by Penfield (1940s) while treating epilepsy patients

- Limited use

STIMULATION

Transcranial Magnetic Stimulation - TMS

- disrupts neural function
- figure-8 wire coil
- generation of magnetic field
- passes through skull; induces current; neurons fire
- spatial resolution: 1.0-1.5 cm^2



- sensation of scalp being withdrawn up, loud click, muscle twitches
- interferes with sensations

 Source: Ettinger, G., et al. "Non-Invasive Functional Brain Mapping Using Registered Transcranial Magnetic Stimulation." *Proceedings of MMBIA '96*.

STIMULATION

Uses of TMS

- Motor Mapping

- Suppress neural activity

    - Low-frequency stim (<1 Hz)

- Enhance neural activity

    - High-frequency stim (>1 Hz)

    - i.e., faster picture naming with temporal lobe stimulation

- Possible TX of neuropsychiatric disorders

    - low-freq stim in auditory cortex of SZs decreases auditory hallucinations

STIMULATION

TMS - strengths & limitations

Strengths

- non-invasive

- directly assesses ± critical regions (causal)

Limitations

- spread of activation

- mild headache

- can only go 2cm below the scalp (due to weakening of magnetic field)

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RECORDING

Structure vs. Function

Structure (anatomy)

- only images anatomy
- angiography, CT, MR
- diffusion tensor imaging (DTI)

Function (physiology)

- investigates brain activity during cognitive processes
- electrical: single-cell, multi-electrode, EEG, MEG
- metabolic: PET, fMRI

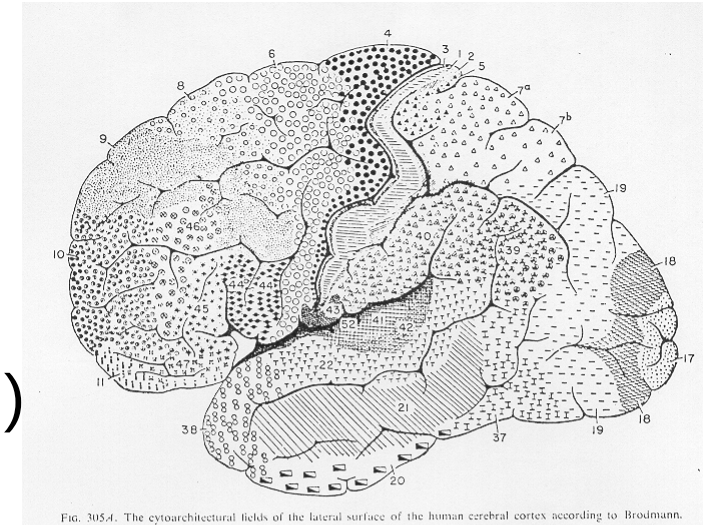


FIG. 305*A*. The cytoarchitectural fields of the lateral surface of the human cerebral cortex according to Brodmann.

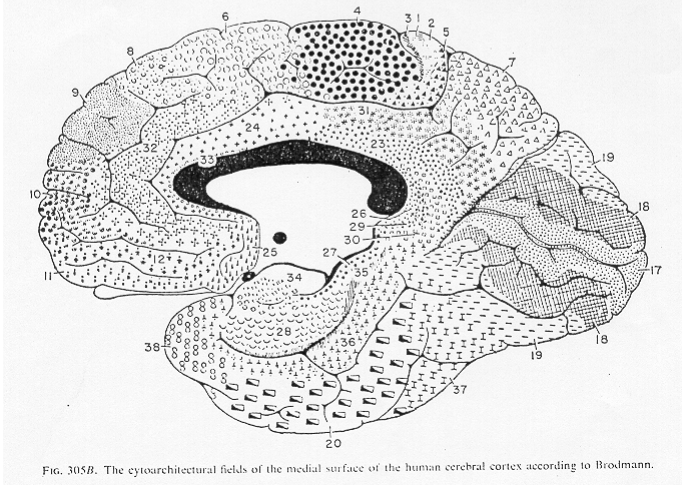
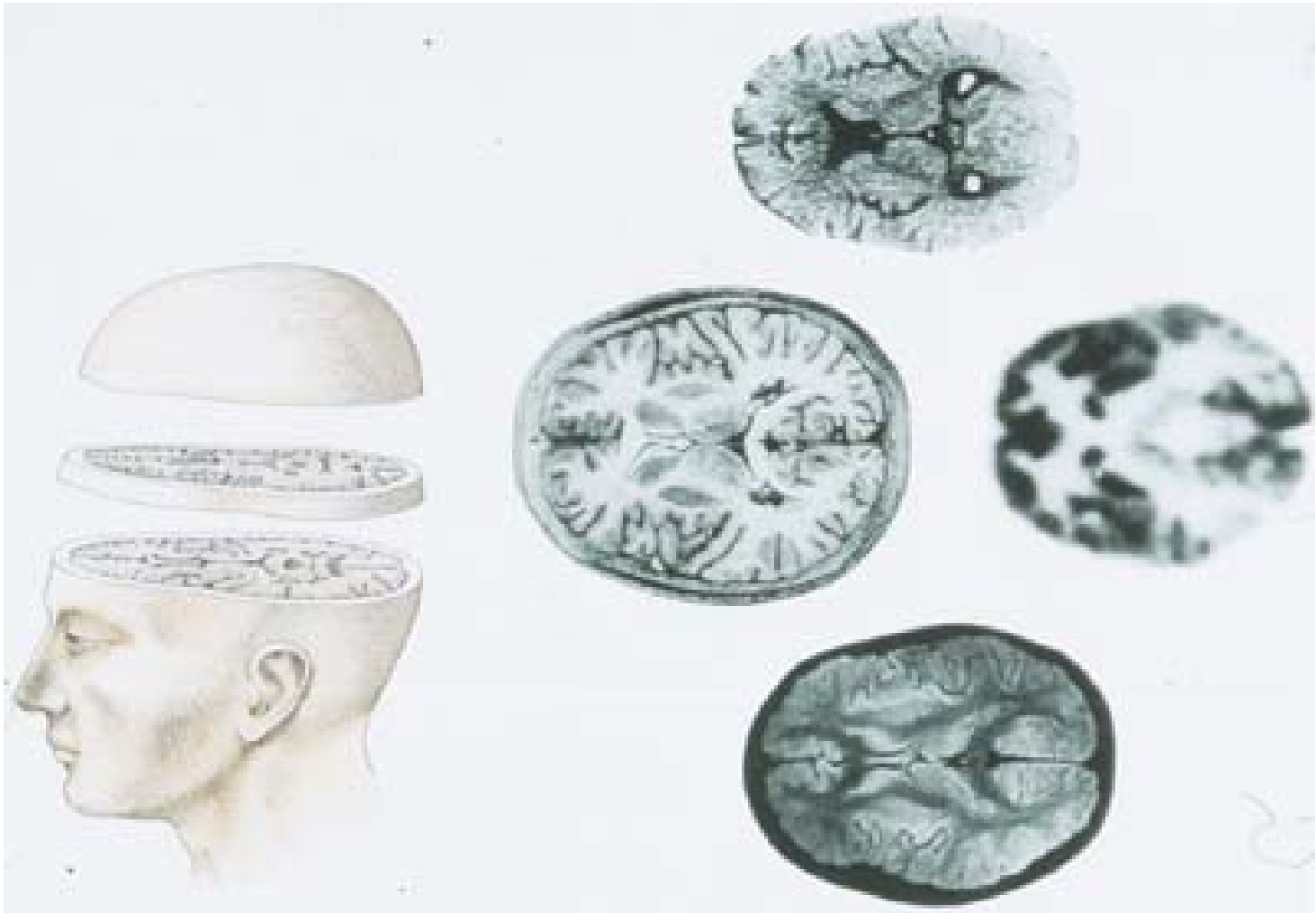


FIG. 305*B*. The cytoarchitectural fields of the medial surface of the human cerebral cortex according to Brodmann.

Public domain images.

Anatomical Images



RECORDING

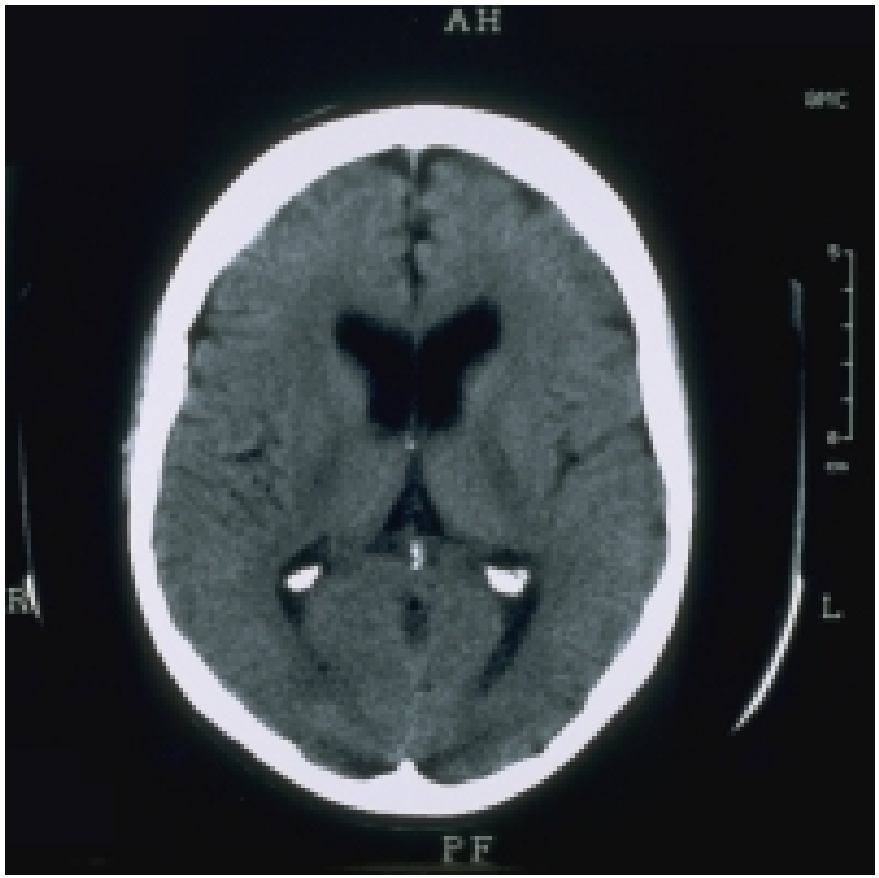
Structure - MRI

Magnetic Resonance Imaging

RECORDING

Structure - MRI resolution

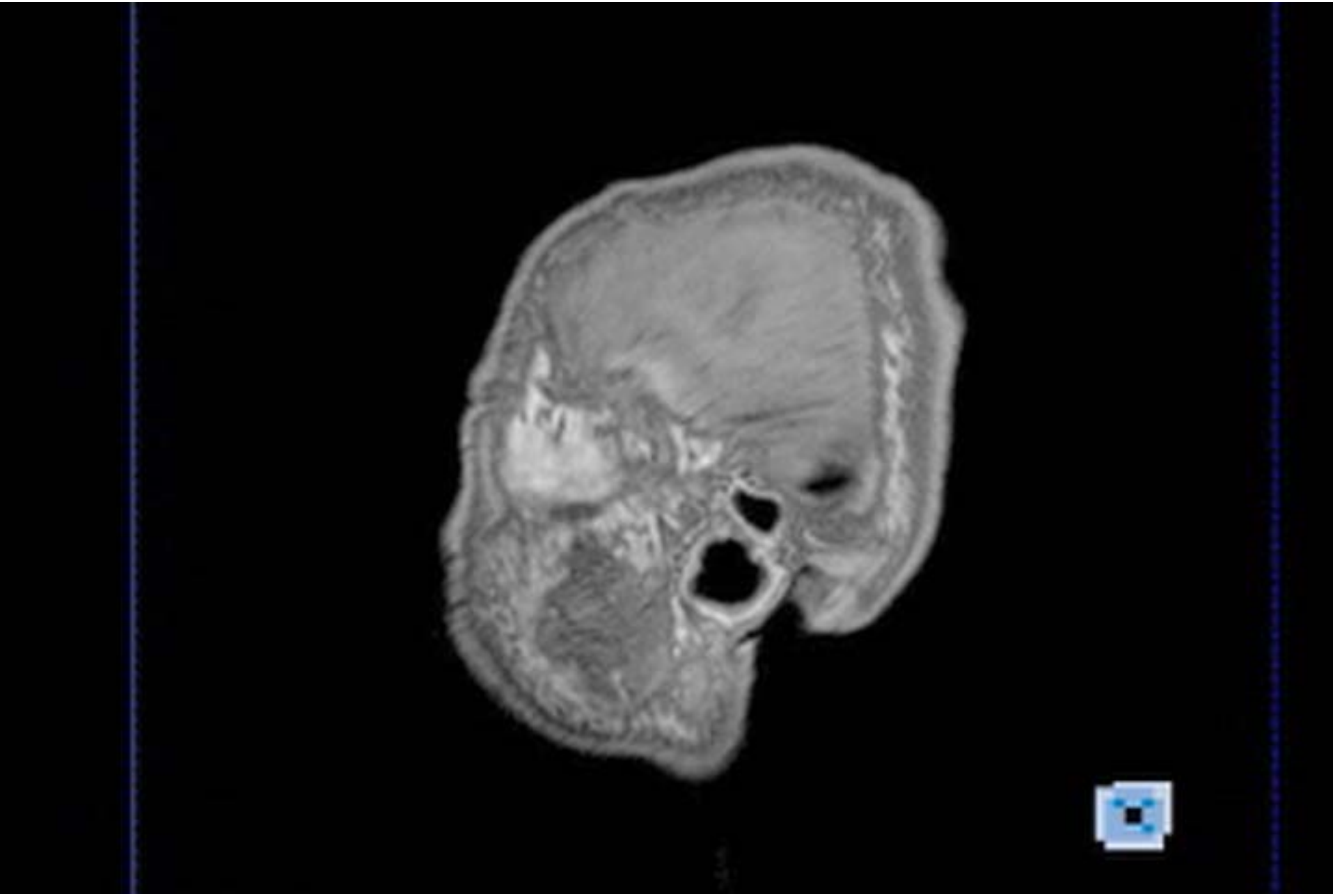
- clear distinction btw white and gray matter; great spatial resolution



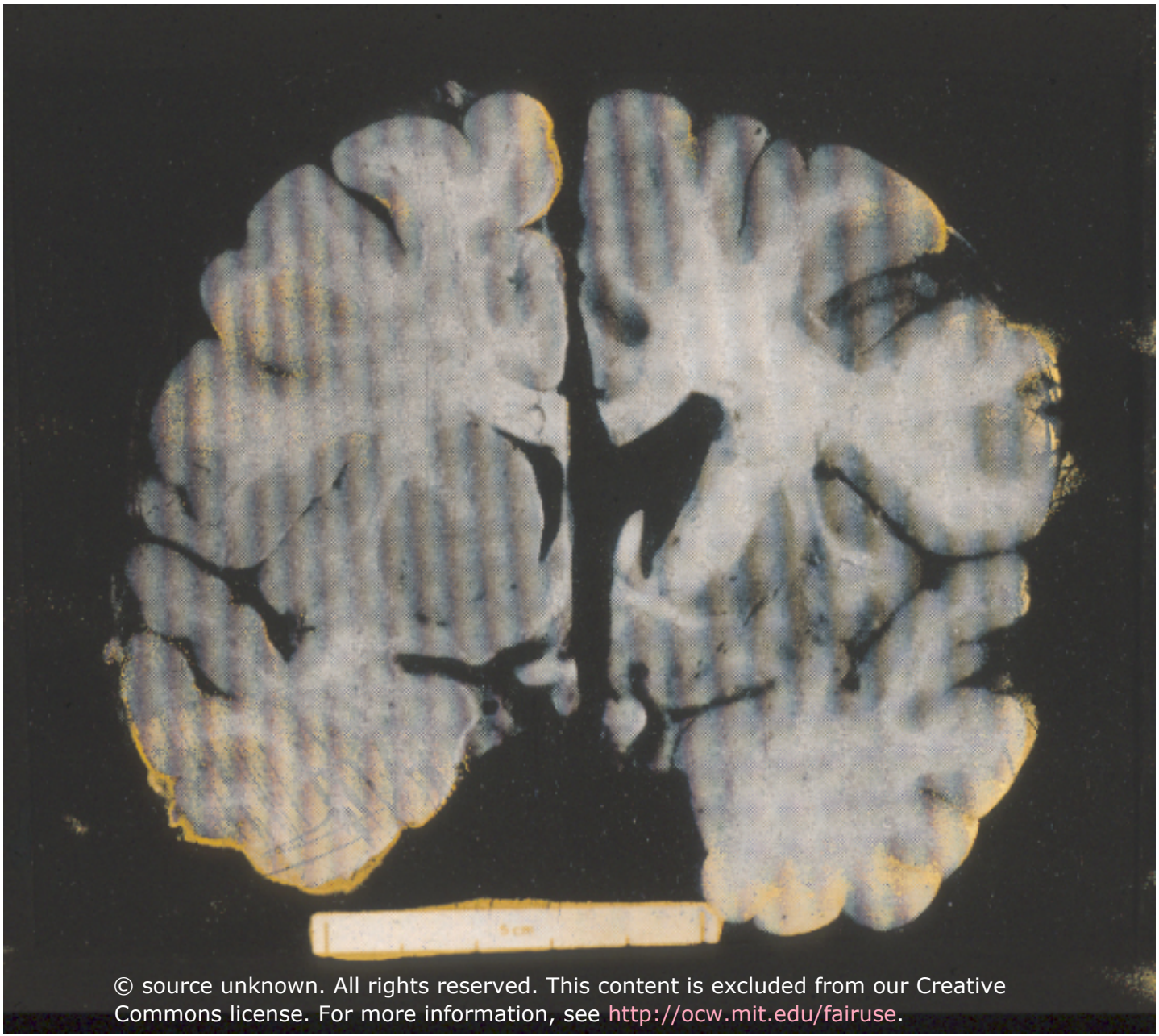
CT

MRI

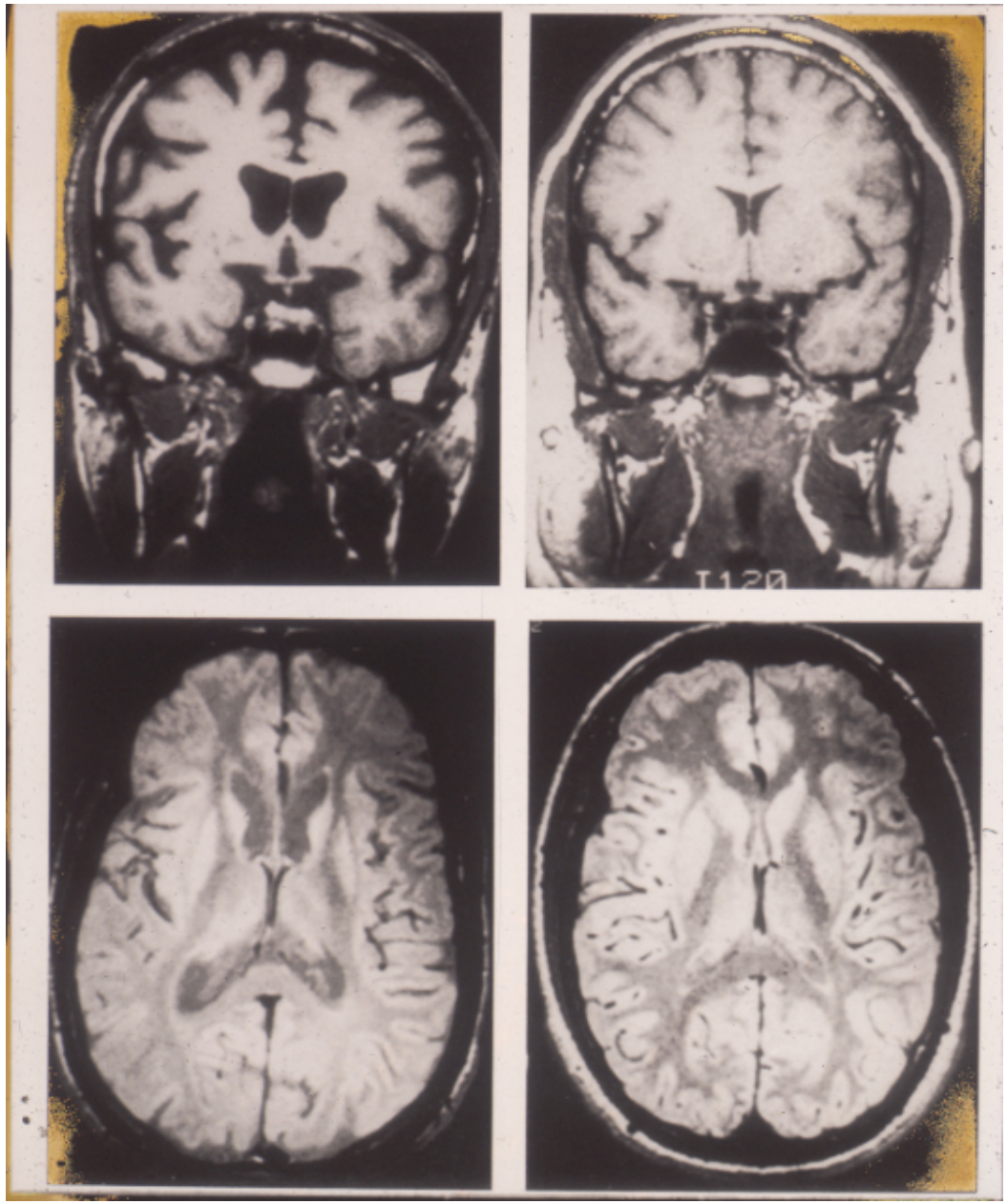
MRI – Lateral Views



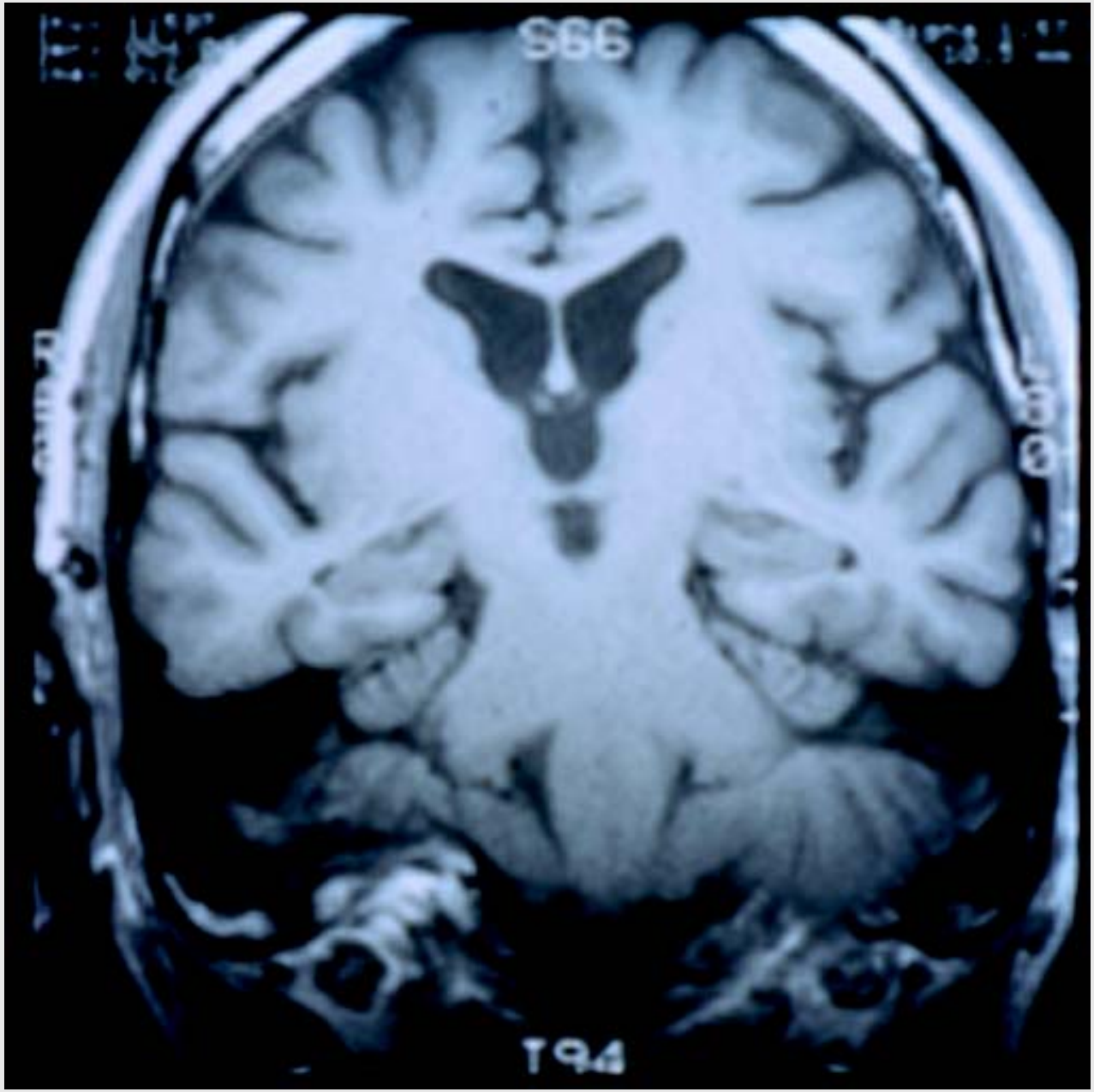
Huntington's disease – *post mortem*



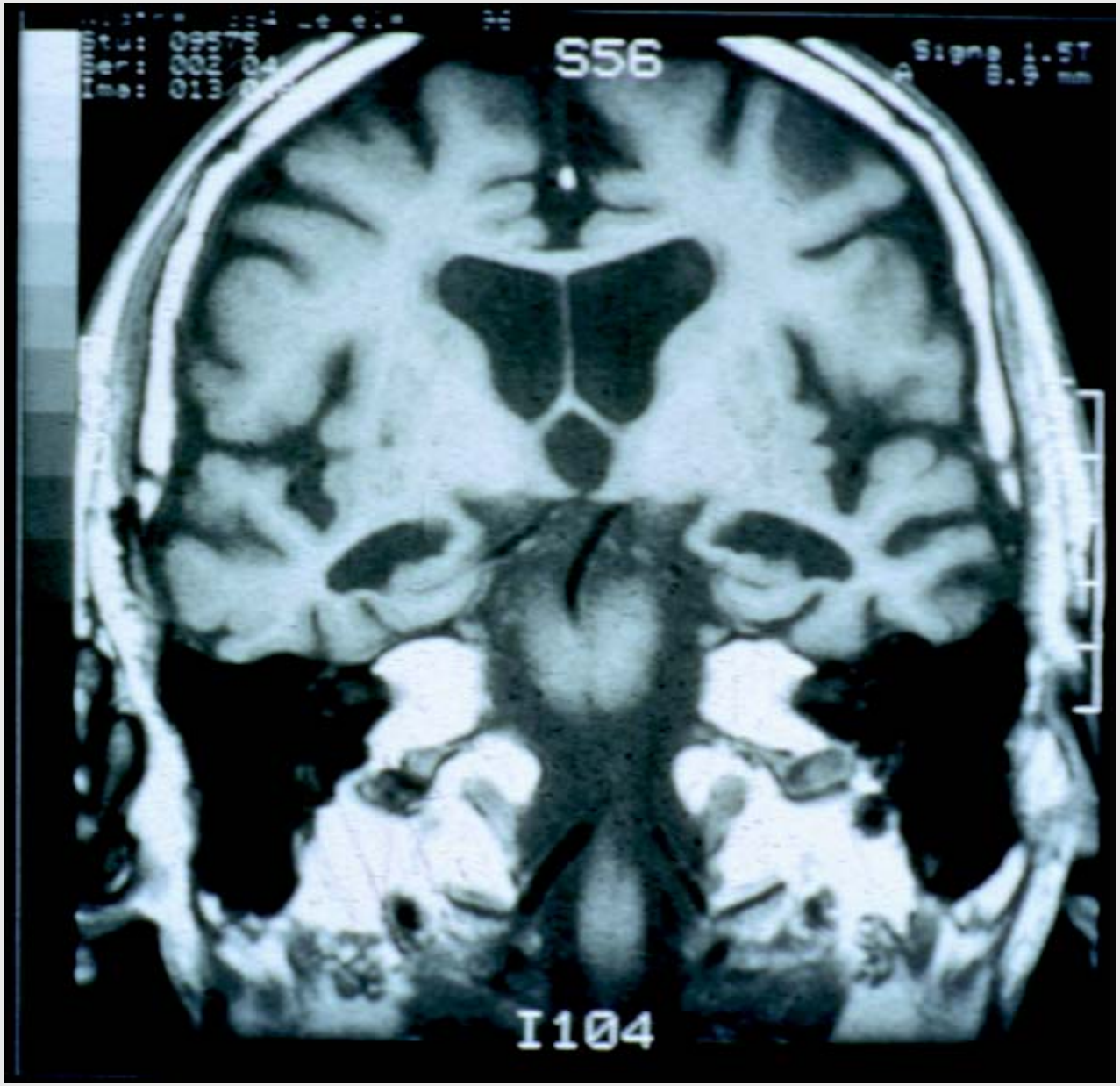
Huntington's disease – *in vivo*



Healthy Older Individual

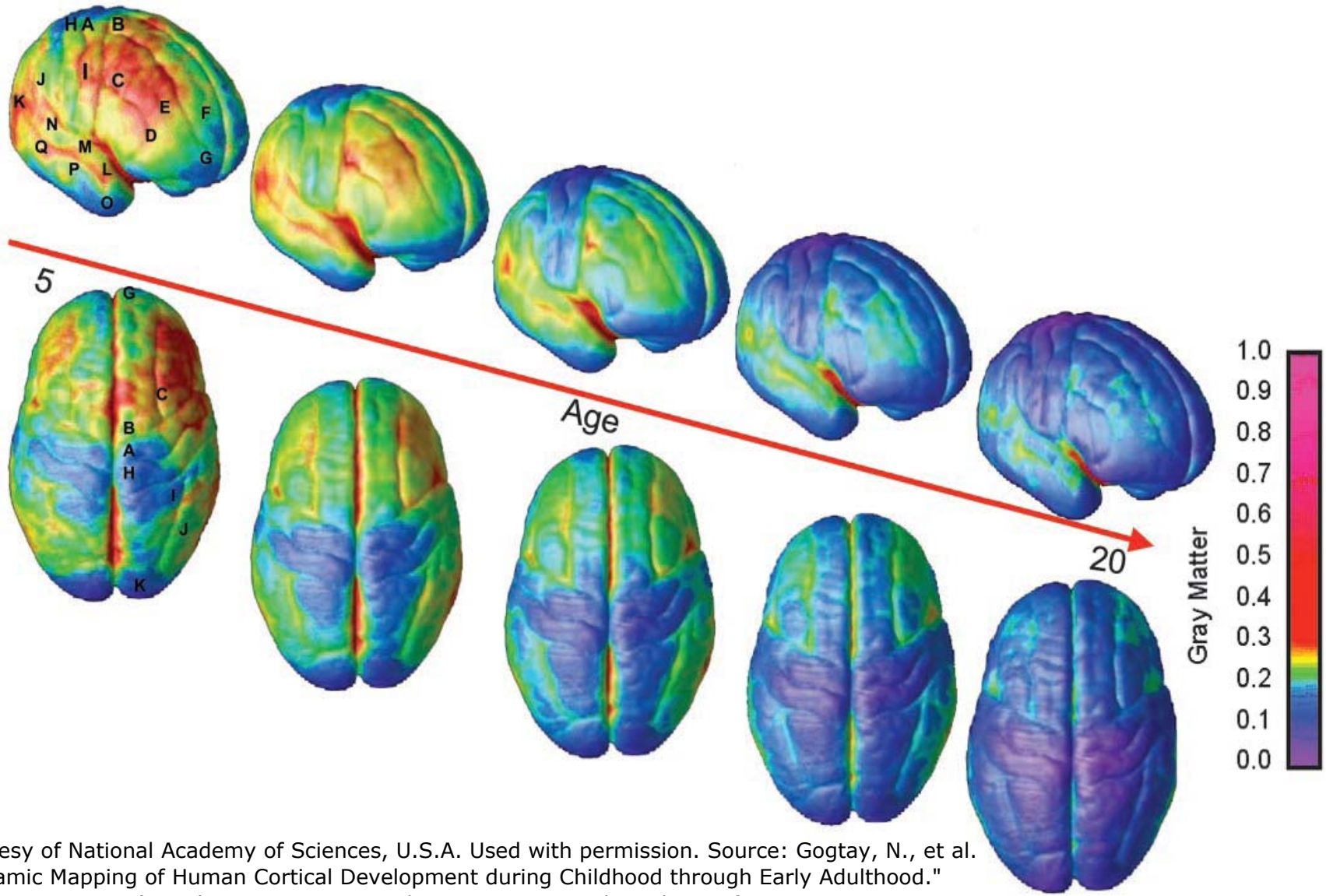


Individual with Alzheimer's Disease

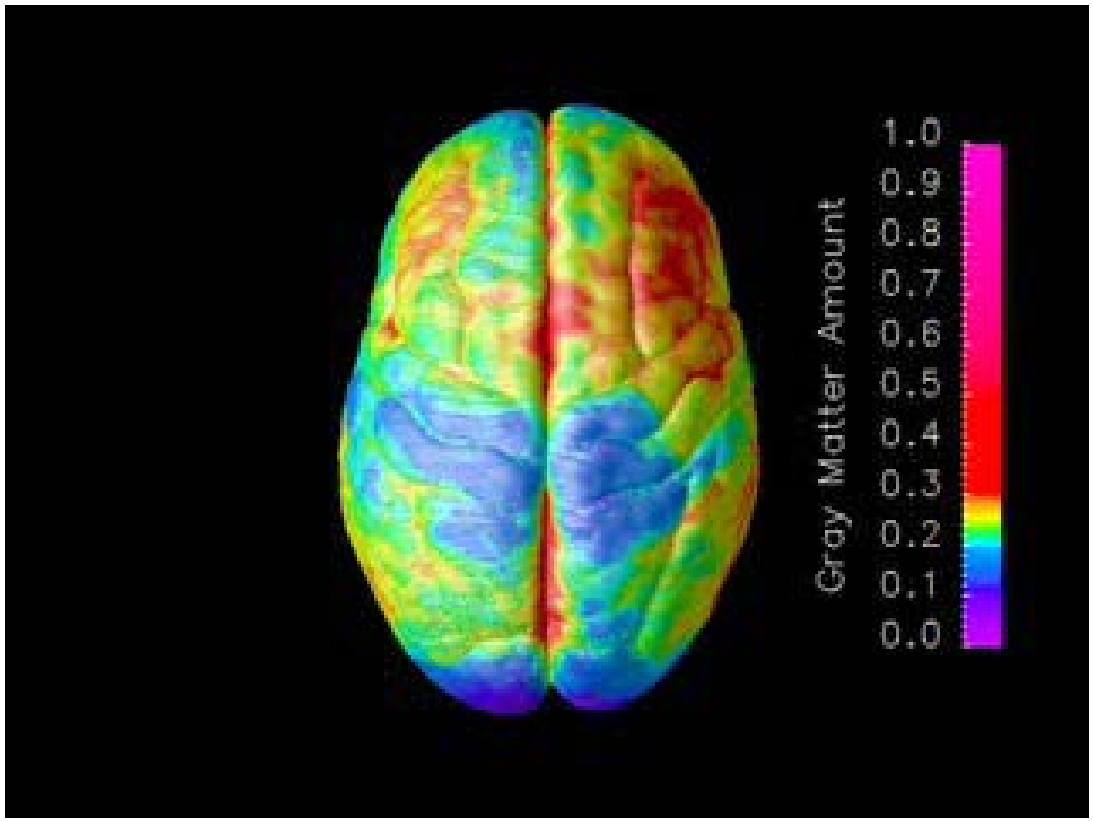


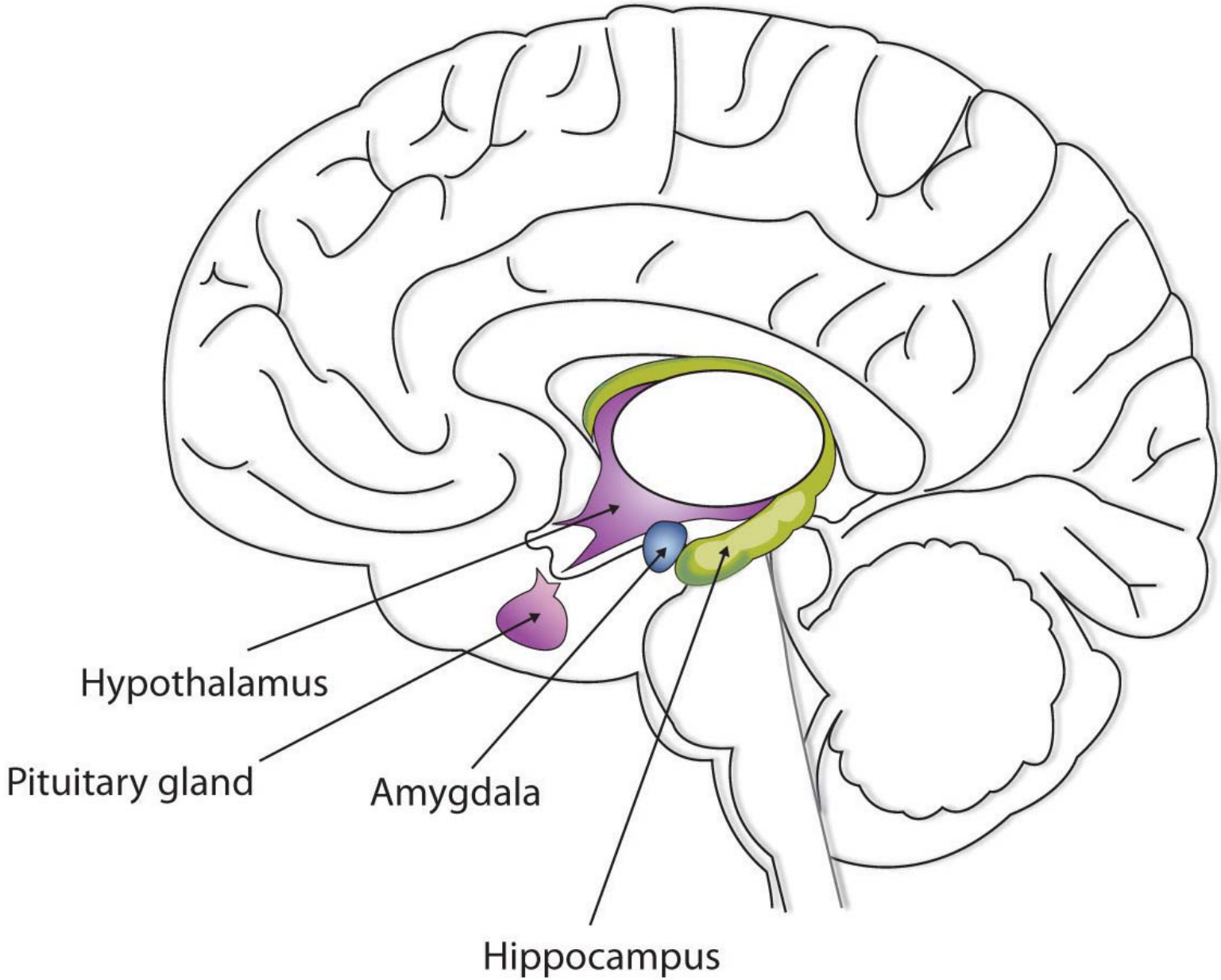
RECORDING

Structure – Brain Changes in Development



Cortical Brain Growth Ages 4-21





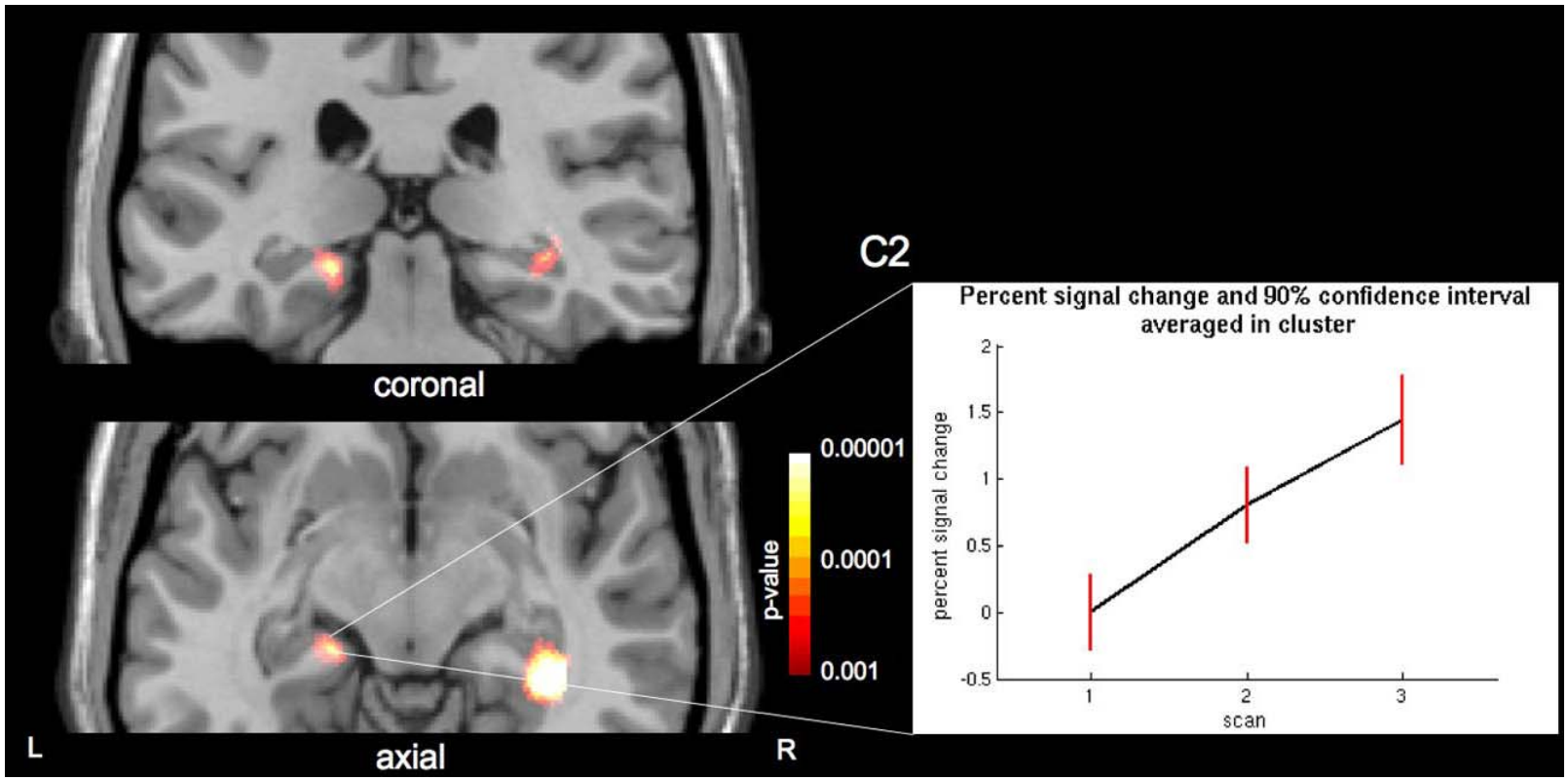
Source: Stangor, C. *Introduction to Psychology*. Flatworld Knowledge, 2010. Courtesy of Flatworld Knowledge.

RECORDING

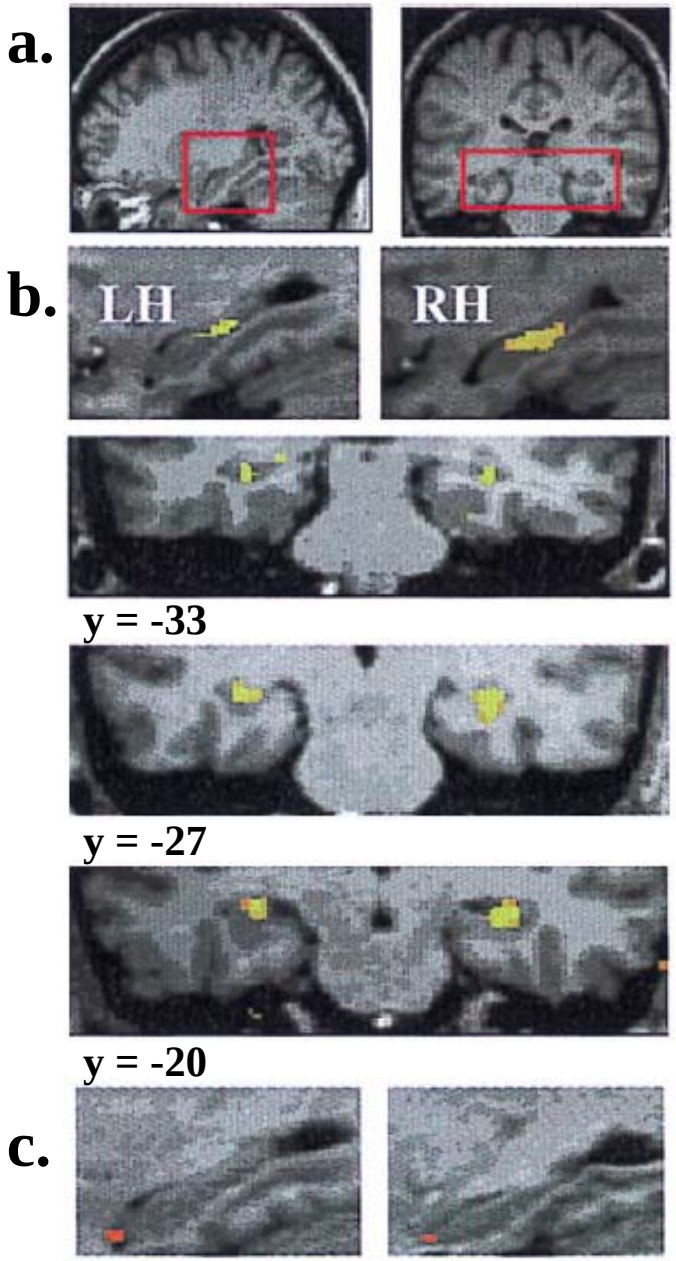
Structure – Brain Changes with Learning

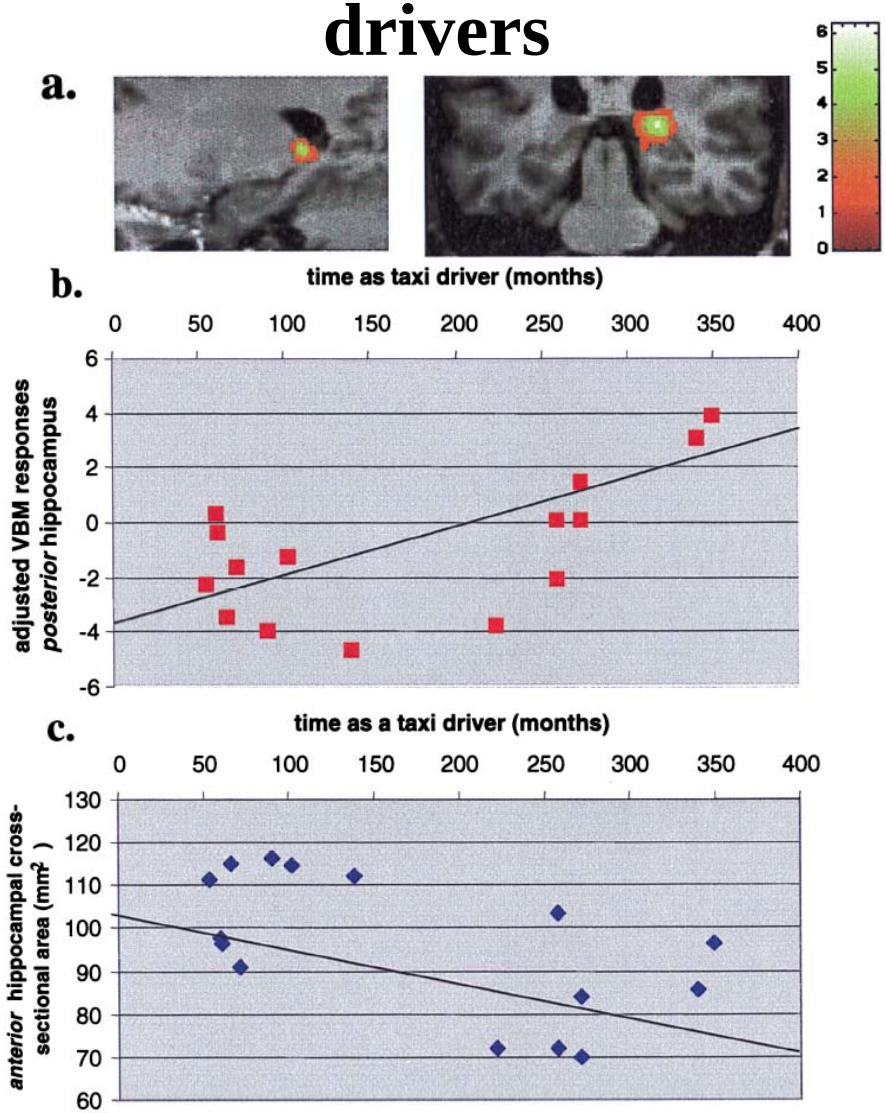
Medical students taking the German preliminary medical exam

Hippocampus Voxel Based Morphometry



Navigation-related structural change in the hippocampi of taxi drivers



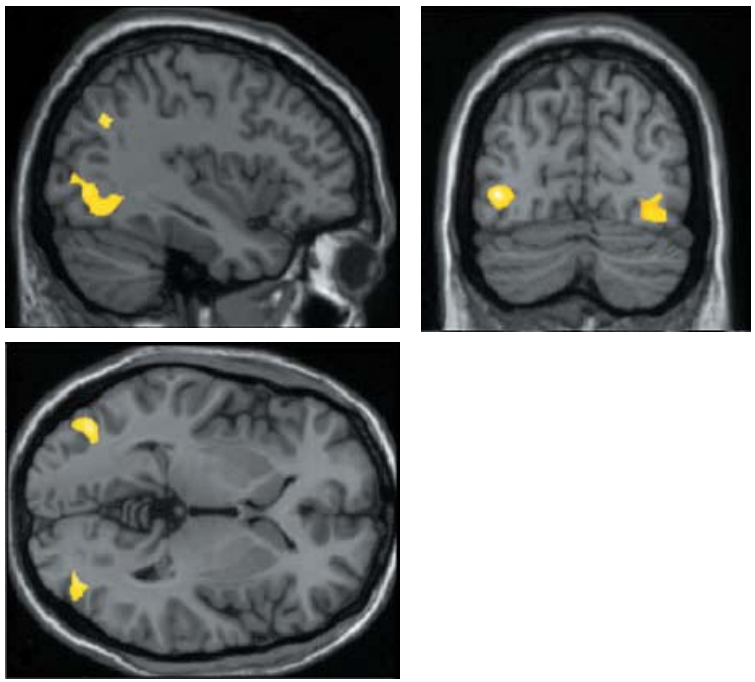


RECORDING

Structure – Brain Changes with Learning

Three-ball juggling routine 3 month

hMT/V5



Reprinted by permission from Macmillan Publishers Ltd: Nature. Source: Draganski, B., et al. "Neuroplasticity: Changes in Grey Matter Induced by Training." *Nature* 427 (2004): 311-2. © 2004.

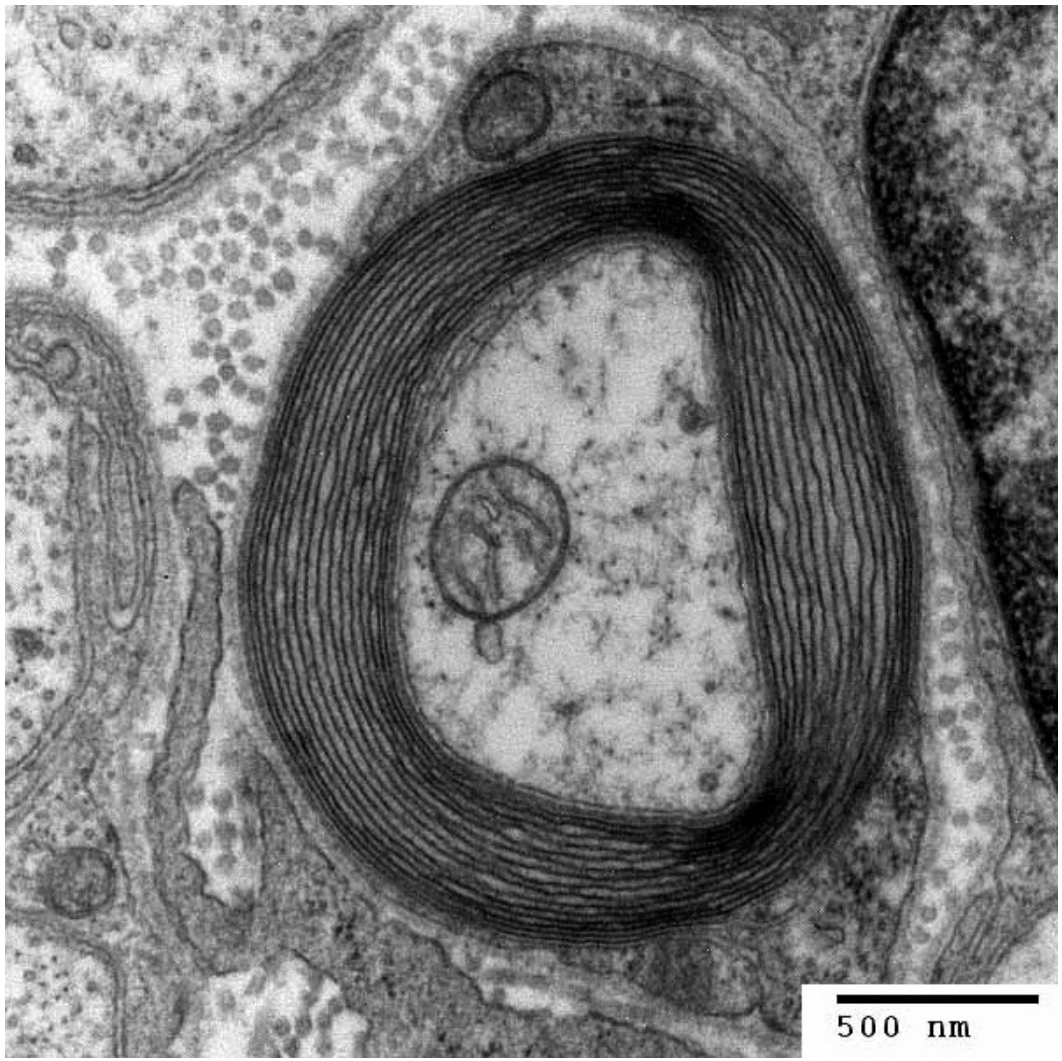
Photo courtesy of madaboutasia on Flickr.

Diffusion Tensor Imaging (DTI)

- **visualizes white matter connectivity in the brain**

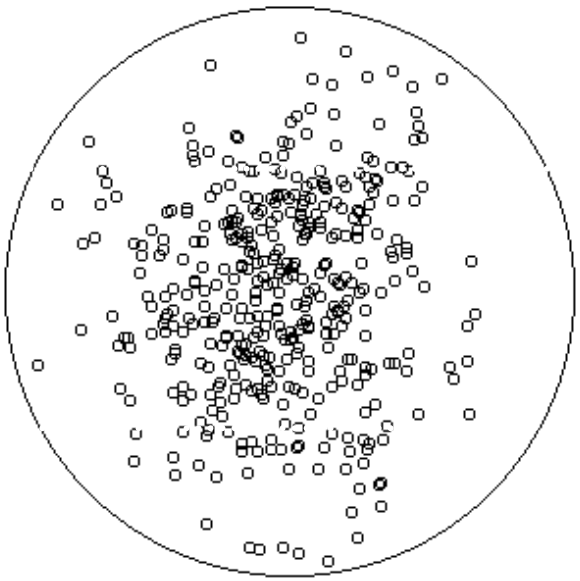
- **measures movement of water at microstructural level (microns)**

Myelinated Nerve Fiber

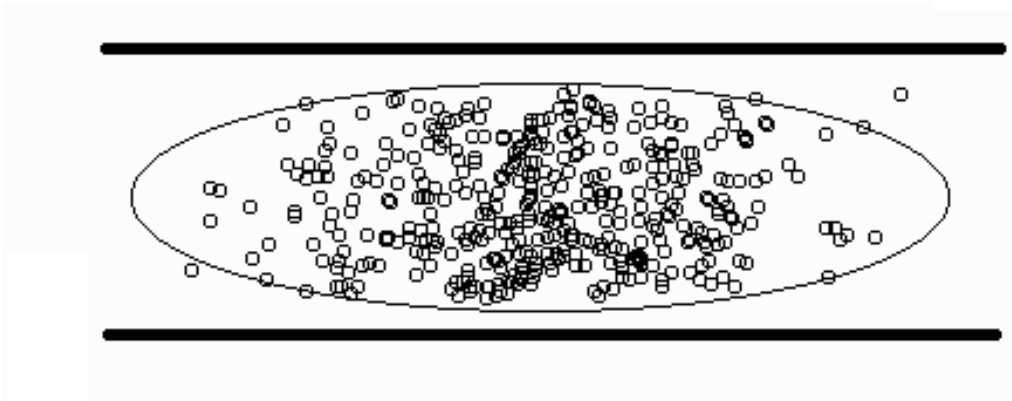


Diffusion anisotropy: Effects of myelination

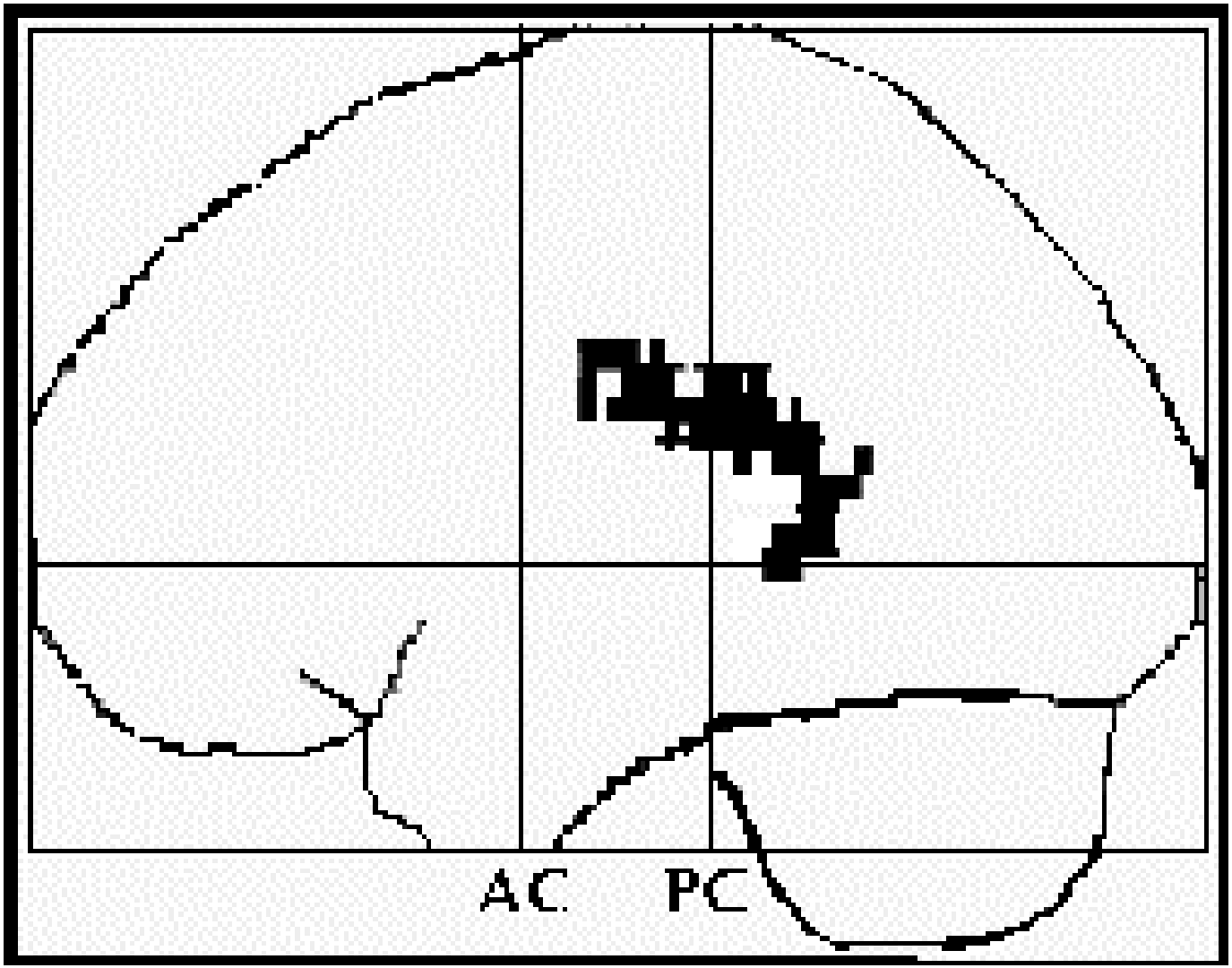
Weak/no myelin barrier



Strong myelin barrier

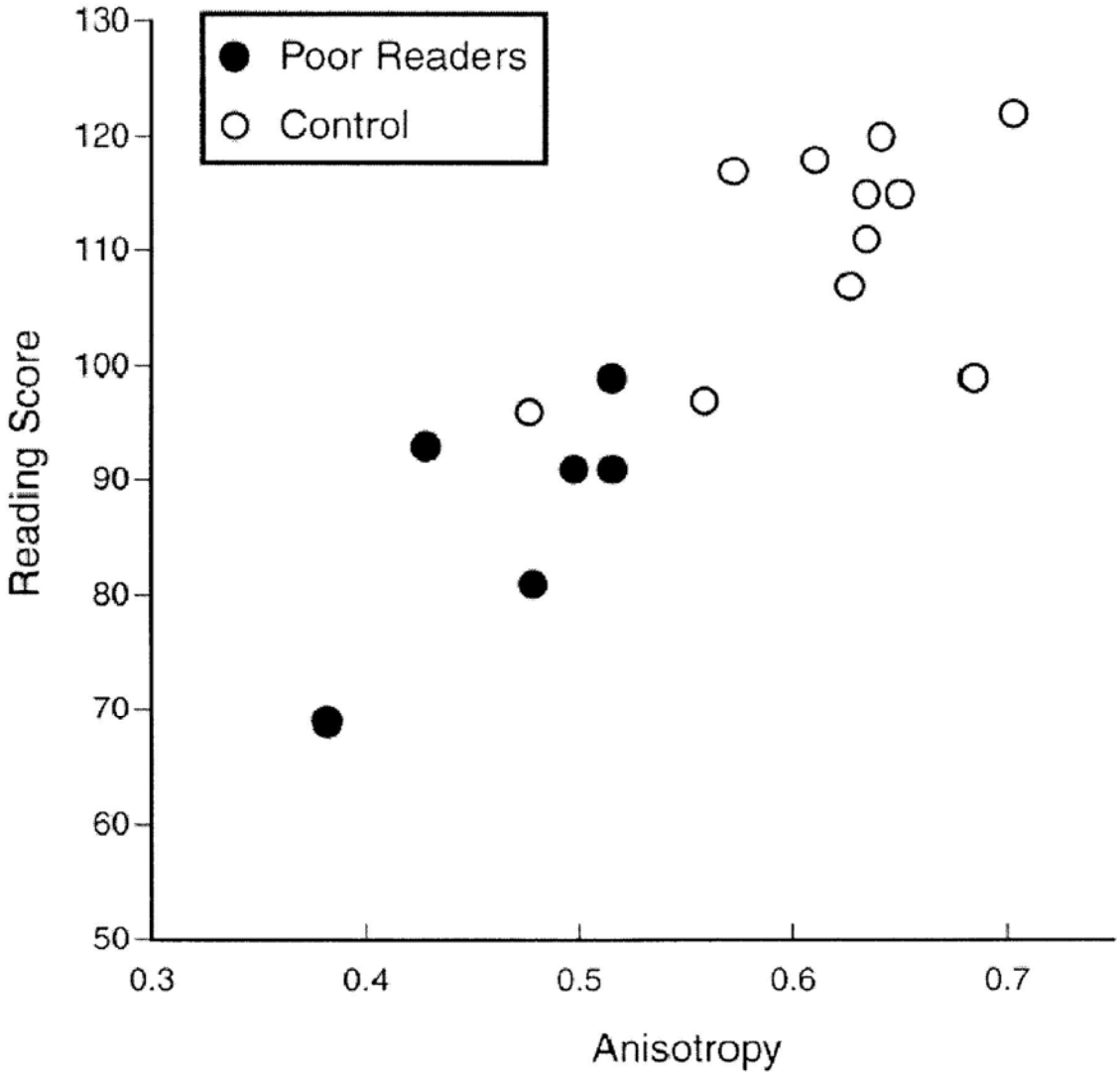


DIFFERENCE IN DTI (ANISOTROPY) BETWEEN DYSLEXIC AND CONTROL GROUPS

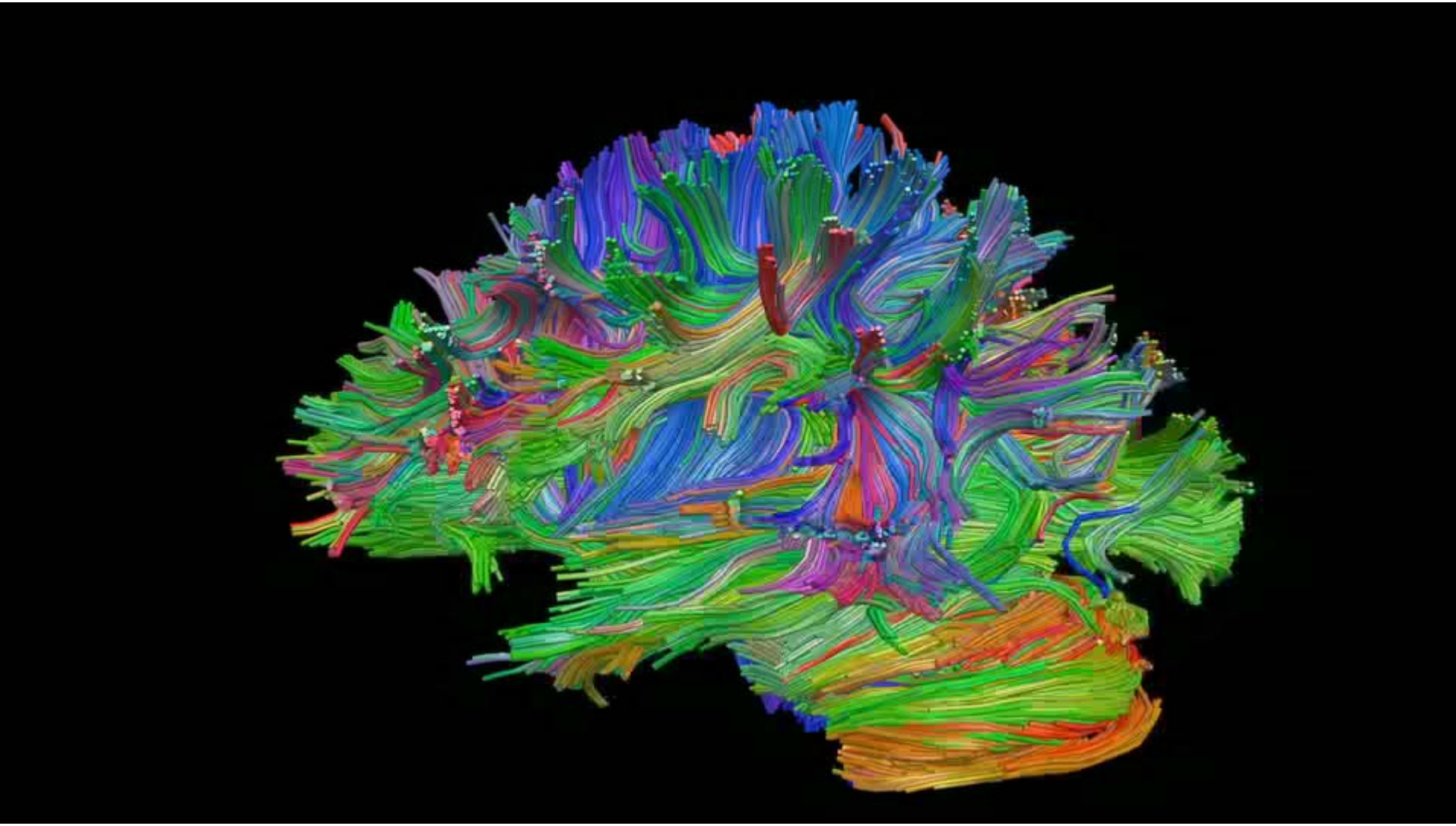


AC = Anterior Commissure **PC = Posterior Commissure**

Anisotropy & Reading Skill In Adults With or Without Dyslexia



Diffusion Tensor Imaging (DTI) – Tractography



red = left-right; blue = up-down; green = front-back

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RECORDING

Function - resolution

Spatial resolution: how specific can the source of signal be localized

Temporal resolution: time scale of the particular measurement

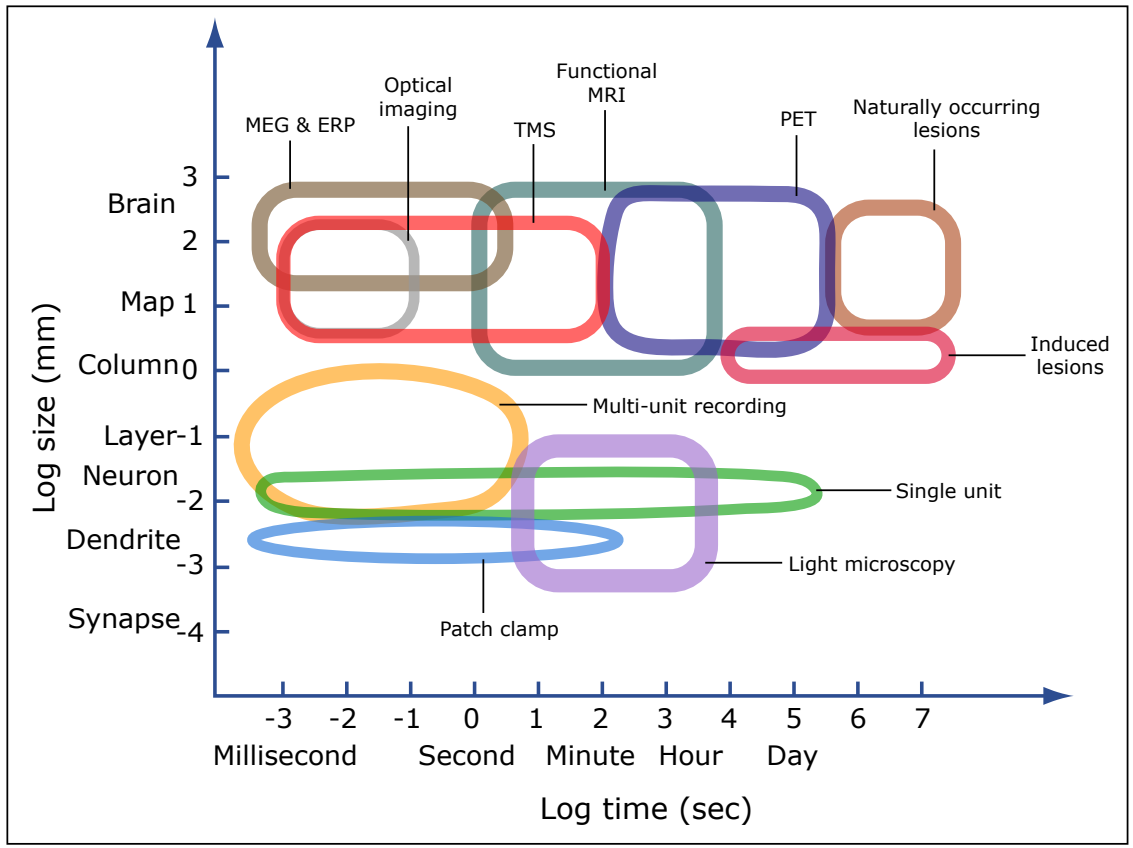


Image by MIT OpenCourseWare.

RECORDING

EEG - Principles

Courtesy of University of Oregon Child and Family Center.

- Electroencephalogram

- measures changes in electrical activity

- uses surface electrodes placed on the scalp (16-256)

- signal requires a *few hundred thousand* neurons to fire *synchronously*

RECORDING

EEG vs ERP

- EEG measures OVERALL brain activity - not related to stimulus presentation

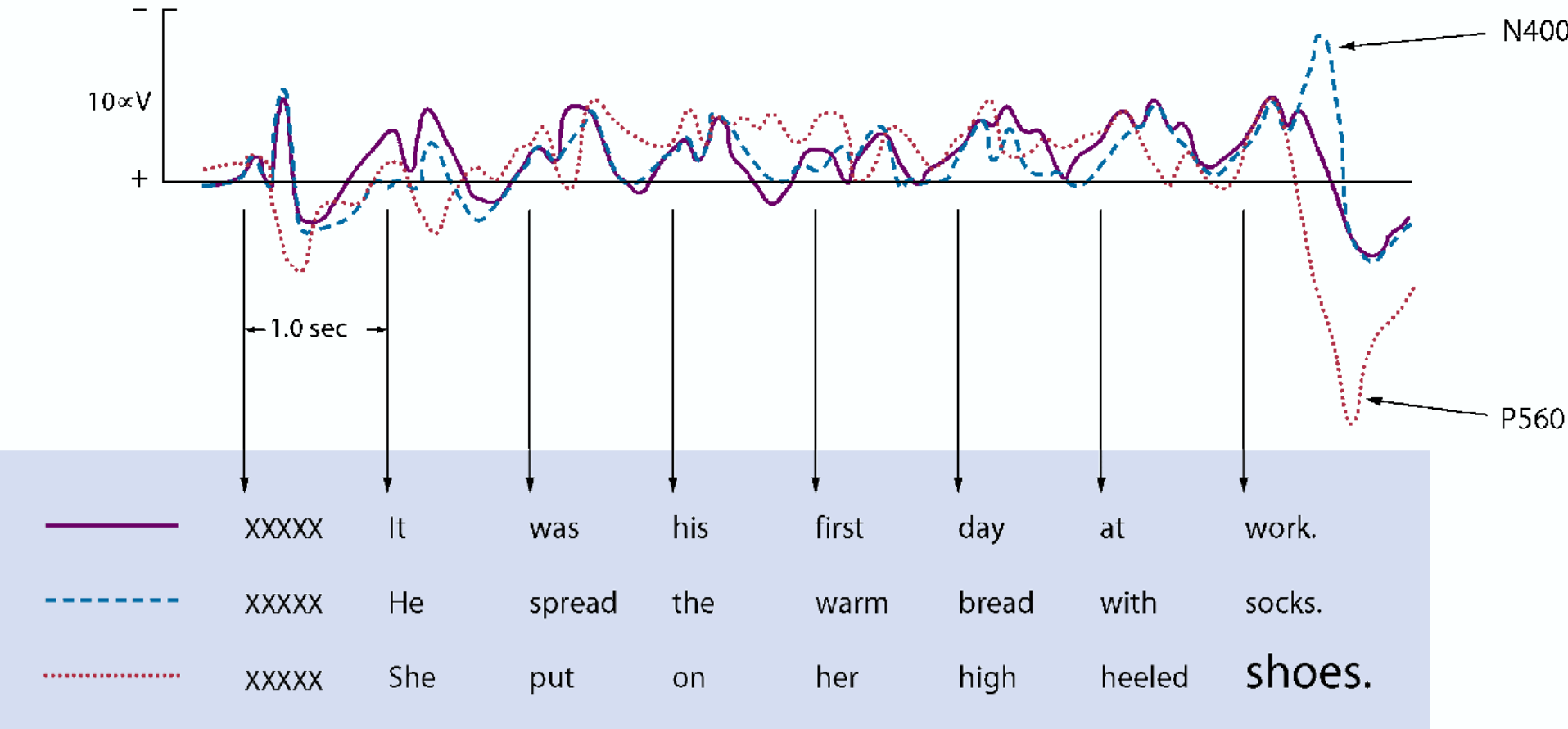
- Event-related Potentials (ERP)

- time-locked to stimulus

- averaged over trials

Images of EEG and ERP waveforms removed due to copyright restrictions. See lecture video and Figures 4.24 and 4.25 in Gazzaniga, M., R. Ivry, and G. Mangun. *Cognitive Neuroscience*. 2nd ed. W. W. Norton & Co., 2002.

ERPs & Language



N400 – semantic deviance; P560 – physical deviance

RECORDING

EEG/ERP – Strengths & Limitations

Strengths

- great temporal resolution (10ms)
- extremely non-invasive
- relatively inexpensive

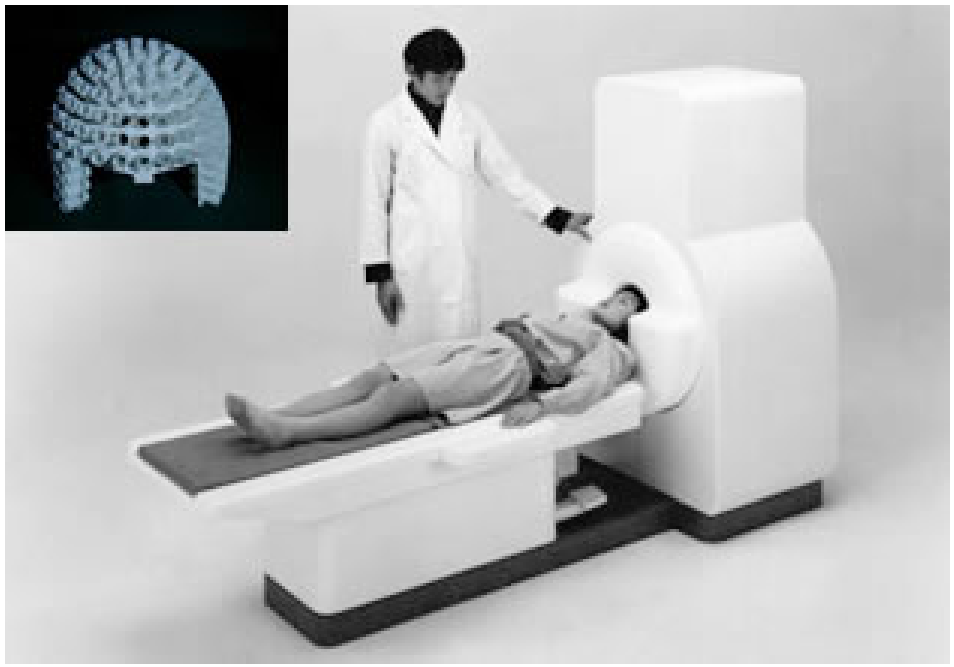
Limitations

- poor spatial resolution
- records large population of neurons
- “where is (are) the signal generators?”
- many trials needed for averaging

RECORDING

MEG - Principles

- Magnetoencephalography



Courtesy of STAR Cryoelectronics, Susumu Matsukura (Yokogawa Electric Corporation) and Gen Uehara (Kanazawa Institute of Technology). Used with permission.

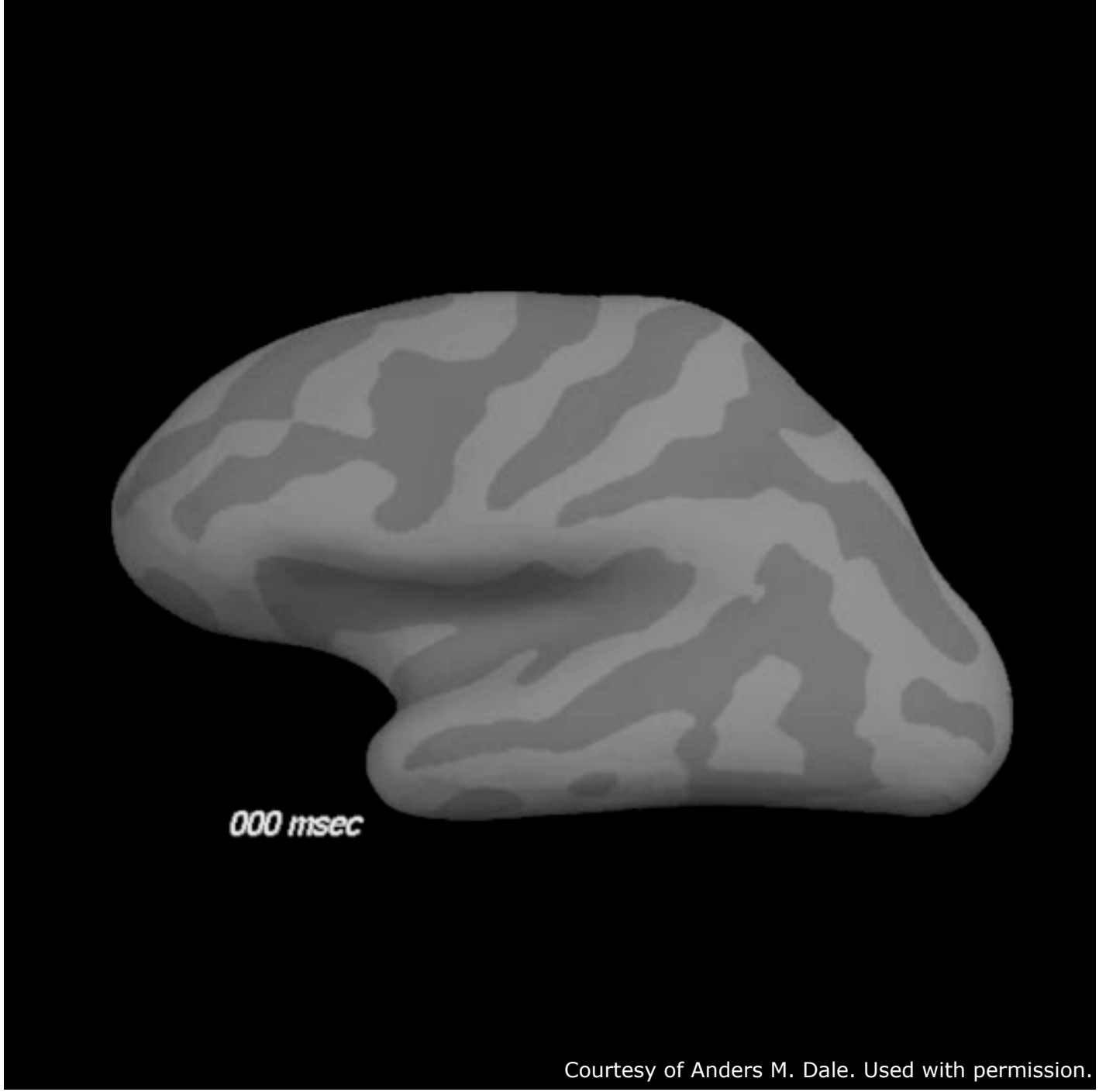
- active neurons produce small magnetic fields

- uses Superconducting Quantum Interference Devices (SQUIDs) to detect magnetic changes

- signals are 100 million time smaller than the earth's magnetic field

Reading a word

Dale & Halgren,
Neuron, 2000



RECORDING

MEG – Strength & Limitations

Strengths

- great temporal resolution (10ms, exactly like ERP)
- non-invasive

Limitations

- okay spatial resolution (better than ERP b/c magnetic signal does not get distorted going through skull/scalp, unlike electrical signal)
- many trials needed for averaging
- can only measure neurons parallel to the skull
- expensive (> $1 million)

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RECORDING

Metabolic Activity

- Neurons require energy (oxygen and glucose)

- brain area active, increased blood flow brings energy supplies

BRAIN FACTS

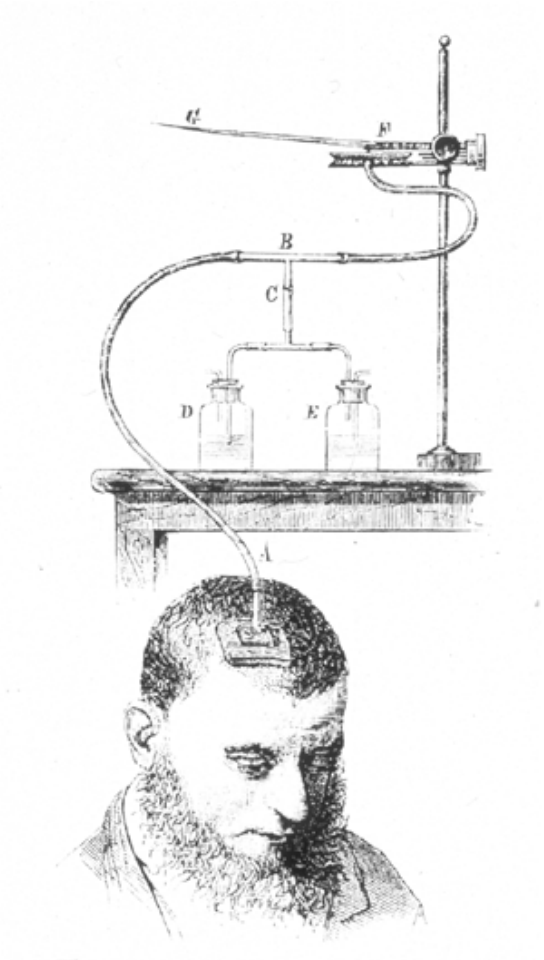
- **3 1/2 pounds**

- **2% total body mass**

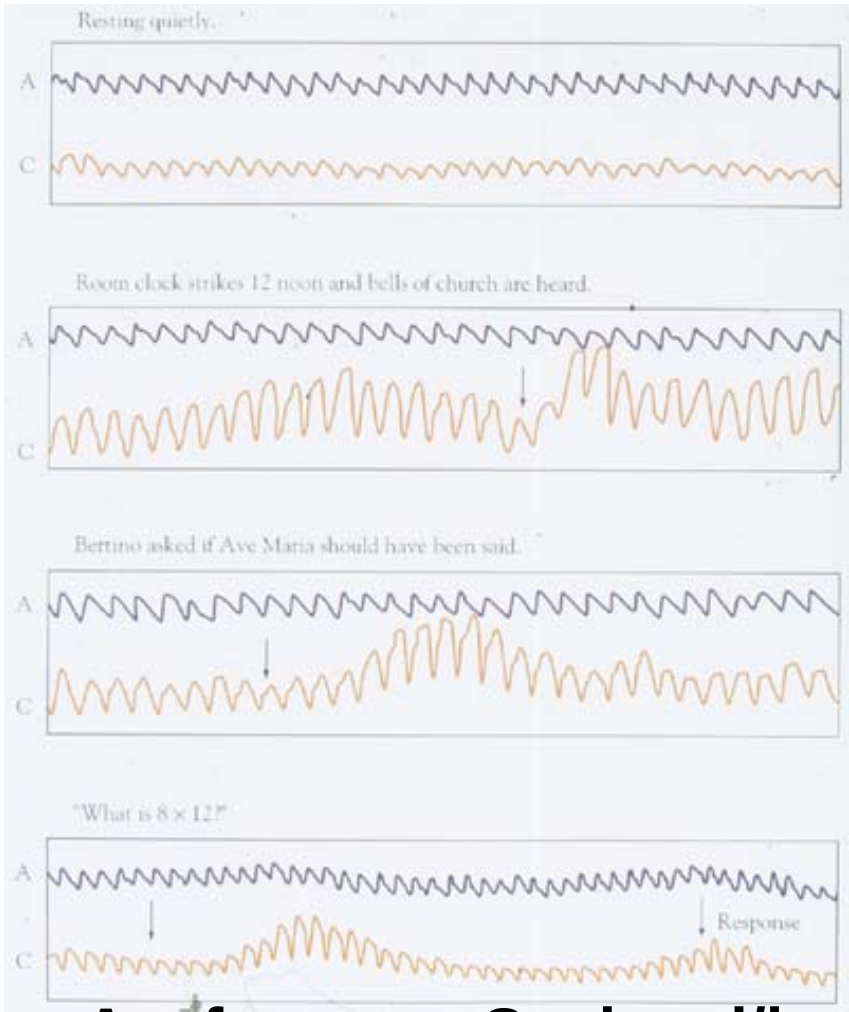
- **20% of body's oxygen**

- **loss of oxygen (10 min) causes irreversible brain damage**

Cerebral blood flow
Angelo Mosso - late 1880s



Public domain image.



Resting

Noon bells

Ava Maria?

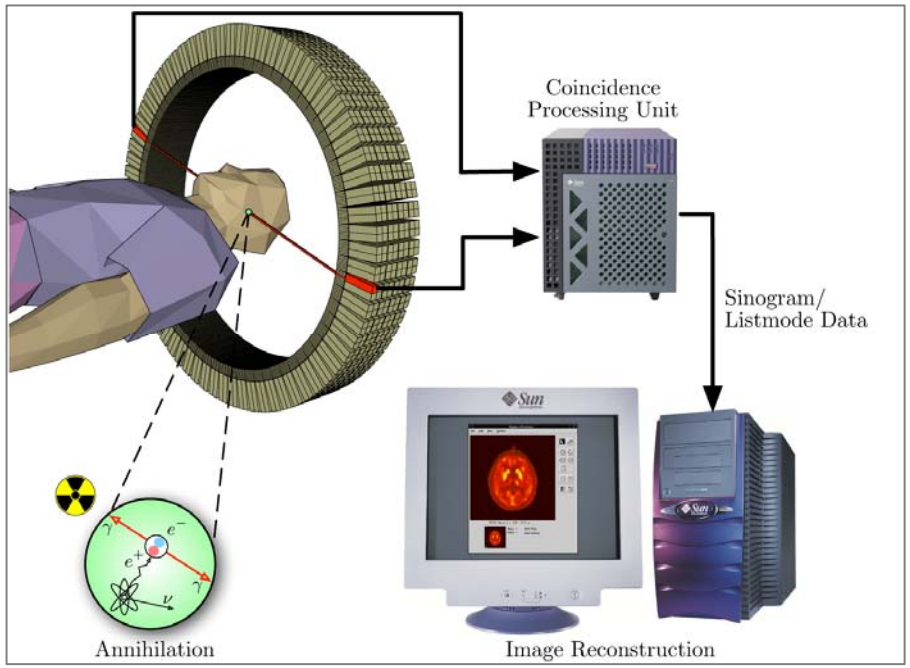
8 x 12?

A = forearm; C = head/brain

RECORDING

PET

Courtesy of Marcus E. Raichle. Used with permission.



Public domain image (Wikipedia).

- **Positron emission tomography**

- **measures local variation in cerebral blood flow (CBF) correlated with mental activity (thinking about a word)**

TASKS

+ + + + +

TASKS

\+ + + + +

rose cat apple pen plane

TASKS

+ + + + +

Fixation/Rest

rose cat apple pen plane

Looking at word

rose cat apple pen plane

Saying the word

rose cat apple pen plane

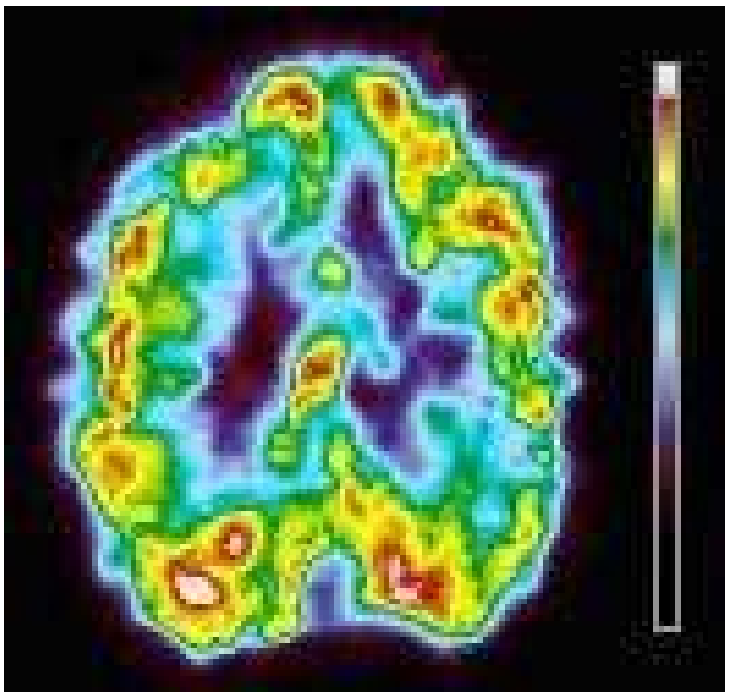
Thinking about the word - verb generation

RECORDING

PET - Experimental Design

Verb Generation

rose cat apple pen



How to isolate region specific for verb generation?

- **Use Subtraction Method:**
  - **Find control task that differs only in the process of interest (in this case verb generation)**
  - **Subtract out irrelevant processes**

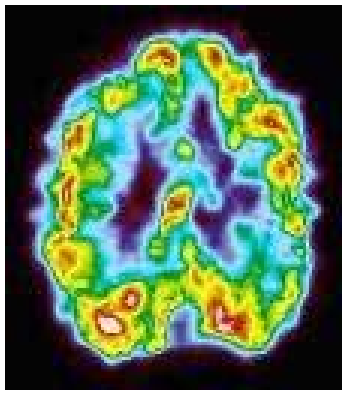
Hierarchical Design of the Lexical Access Experiment

Control state	Stimulated state	Cognitive operations
Fixation point only	Passive words	Passive sensory processing Word-level coding
Passive words	Repeat words	Articulatory coding Motor programming and output
Repeat words	Generate uses	Semantic association Selection for action

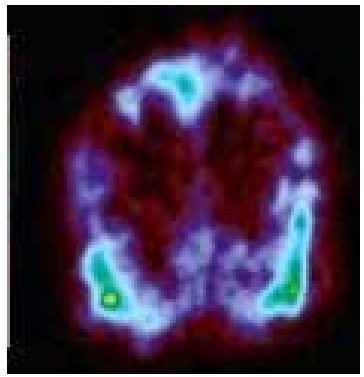
RECORDING

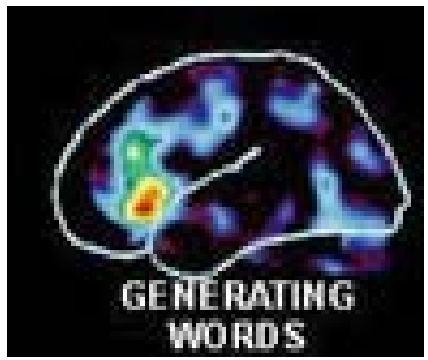
Imaging - Experimental Design

TASK



CONTROL





generating verb

~~reading~~

~~speaking verb~~

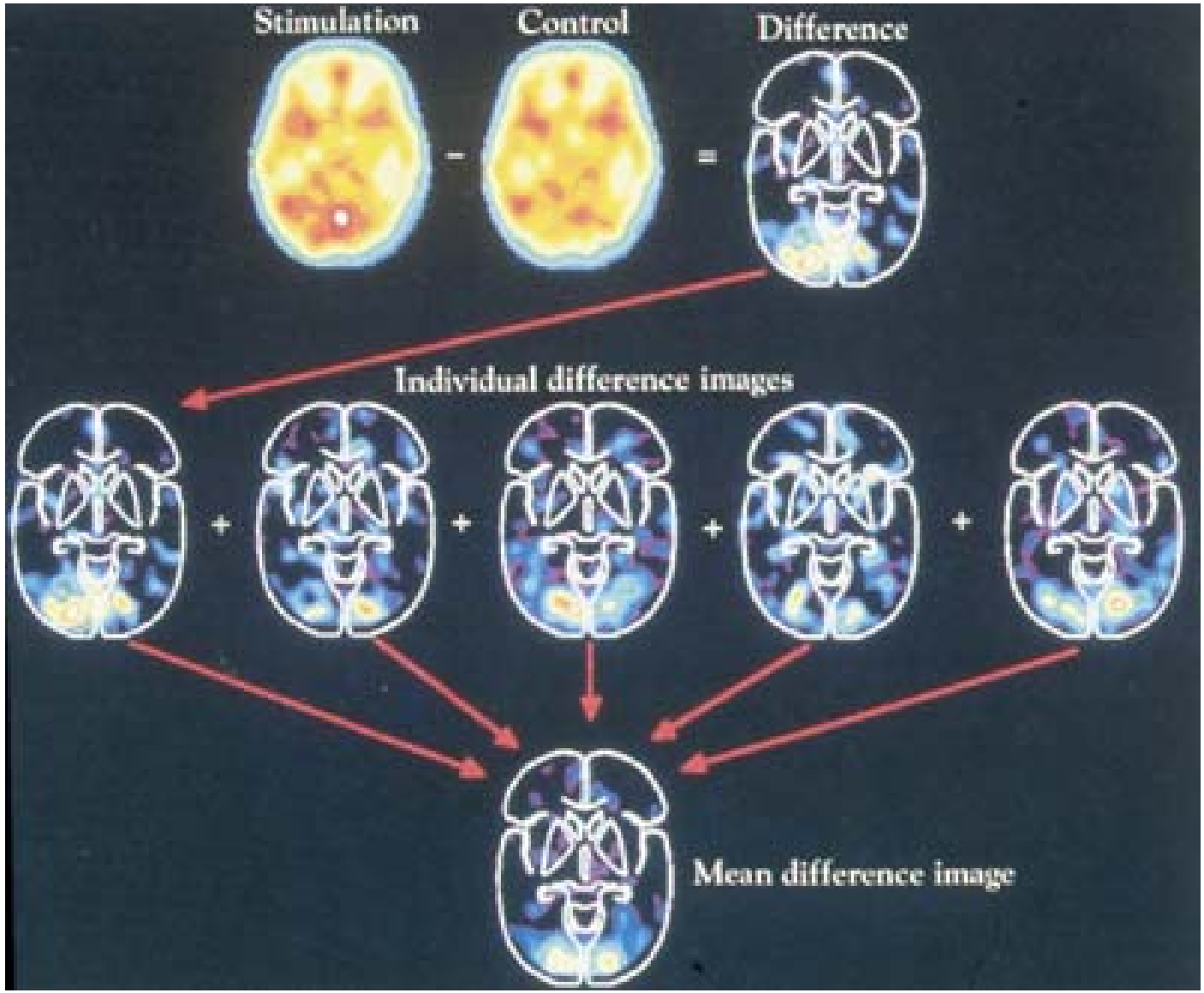
~~reading~~

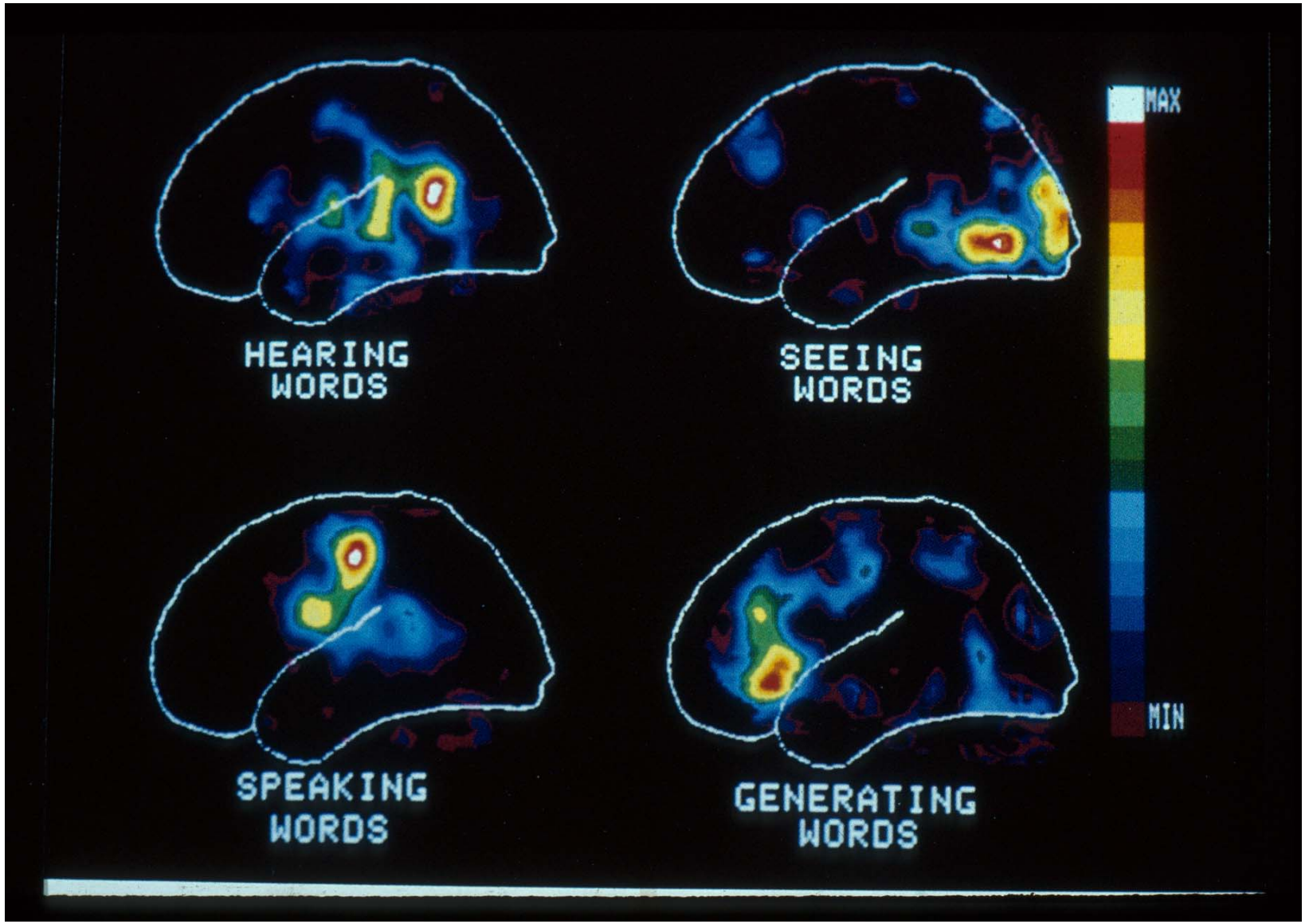
~~speaking verb~~

generating verb

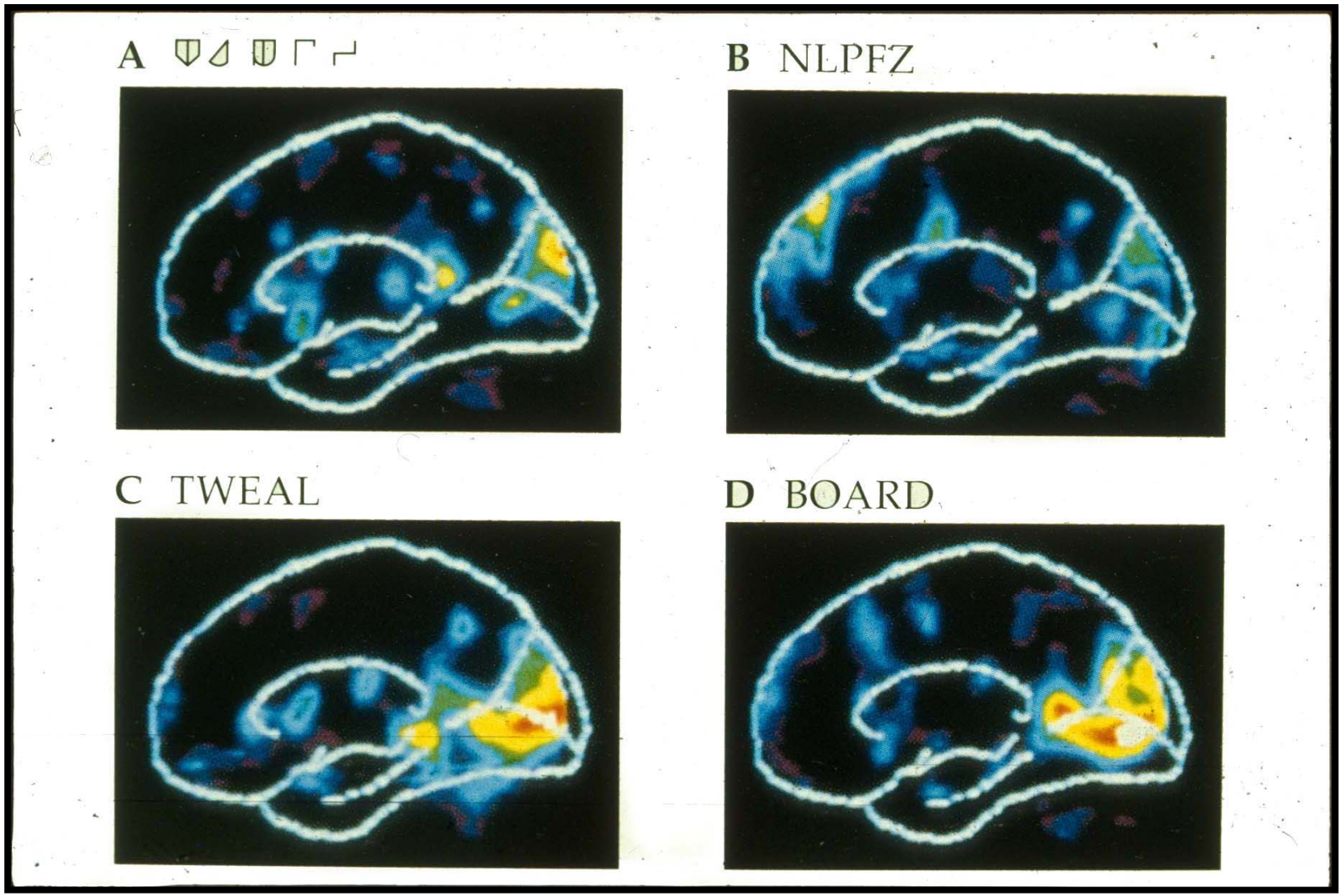
RECORDING

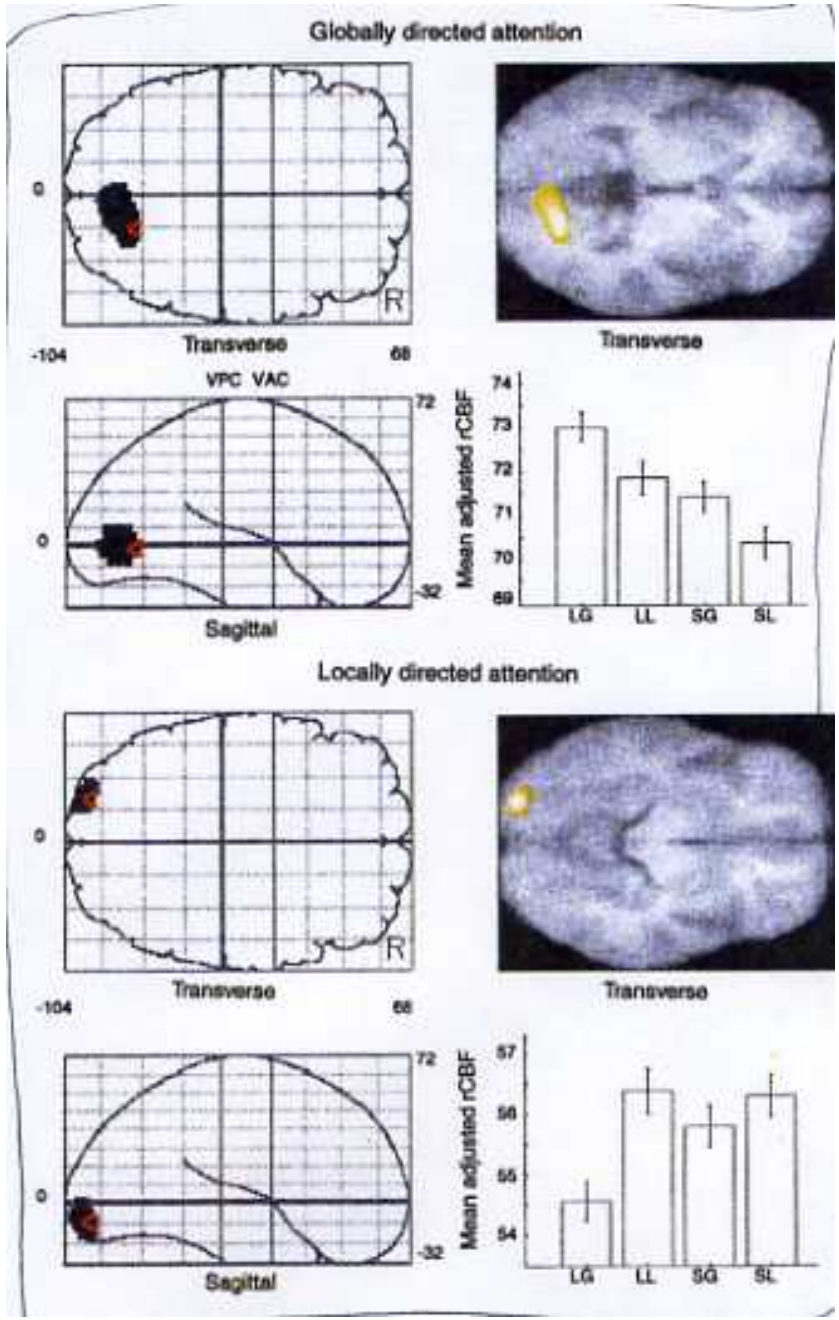
PET - Experimental Design





“Seeing a word” = (BOARD) - (+)





RECORDING

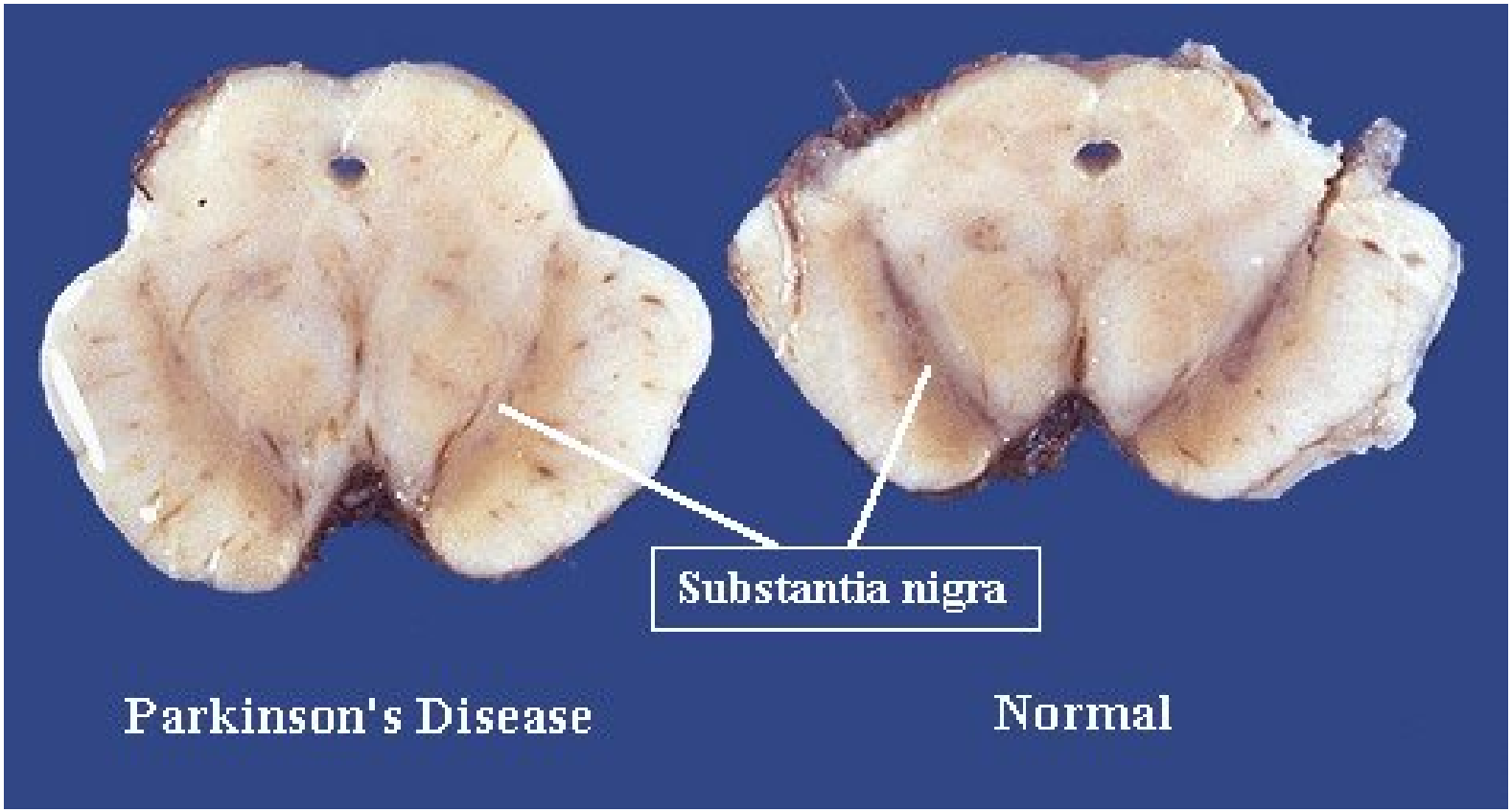
PET – Strengths and Limitations

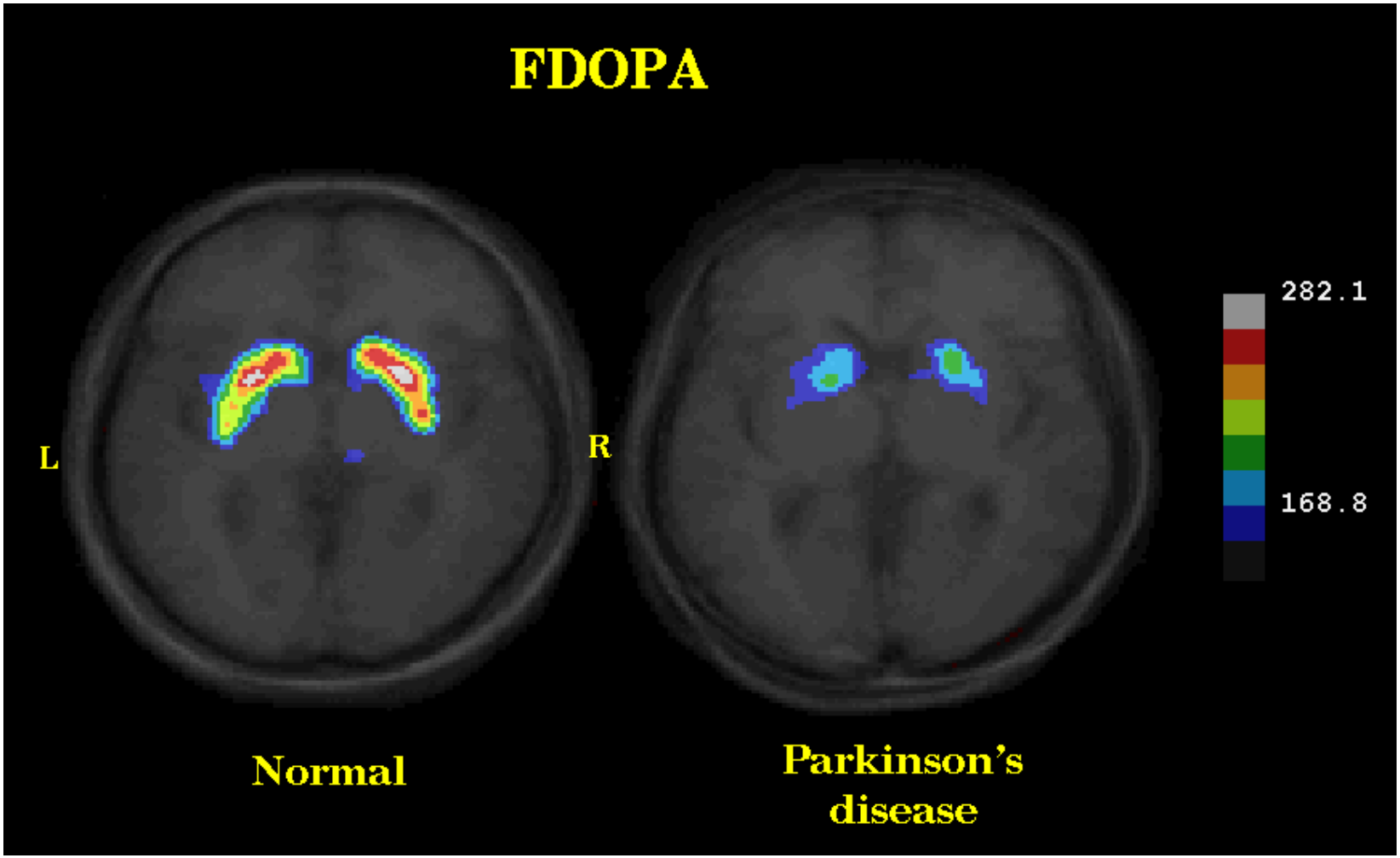
Strengths

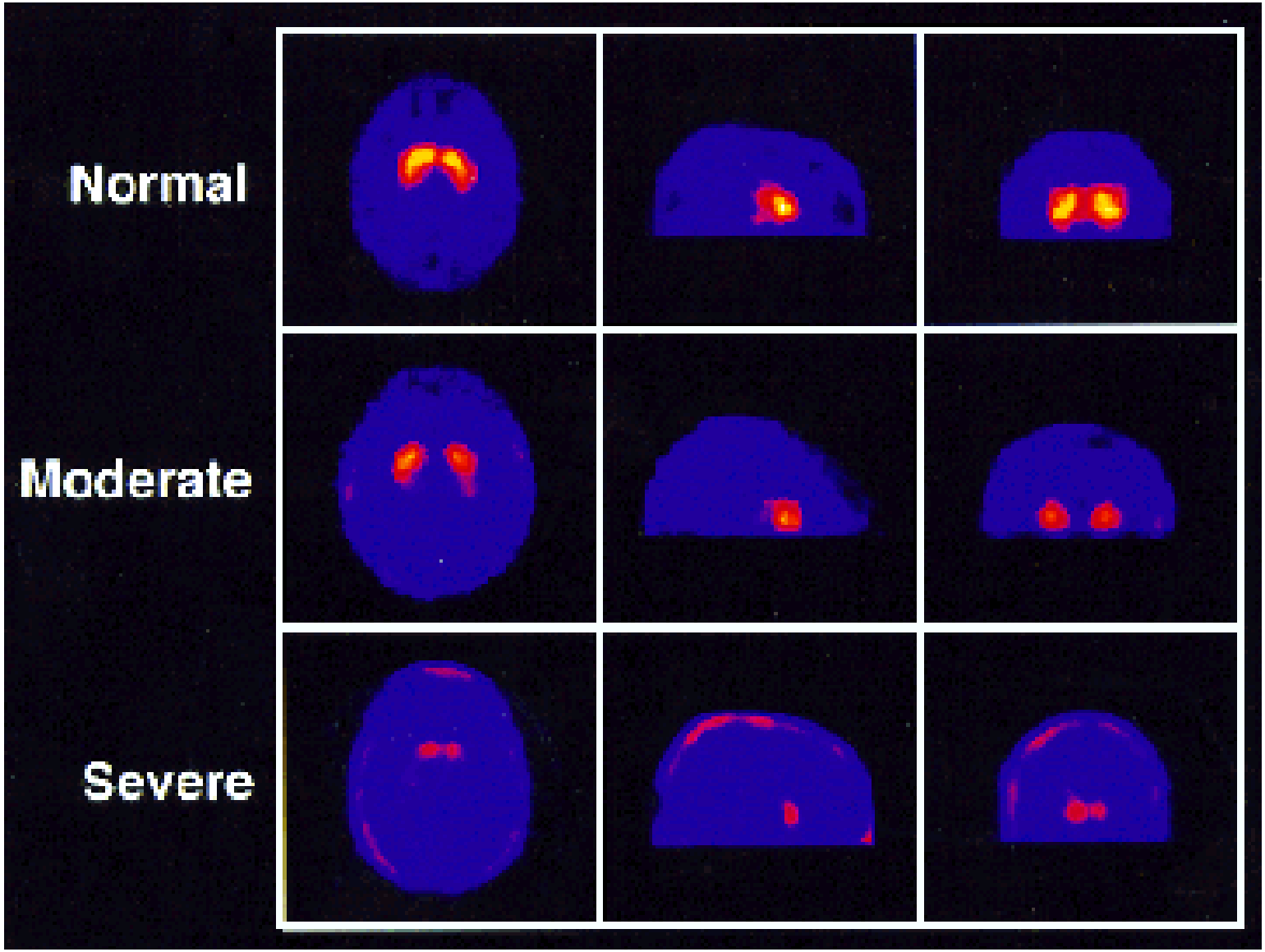
- good spatial resolution (5-10mm); better than ERP/MEG but worse than fMRI

Limitations

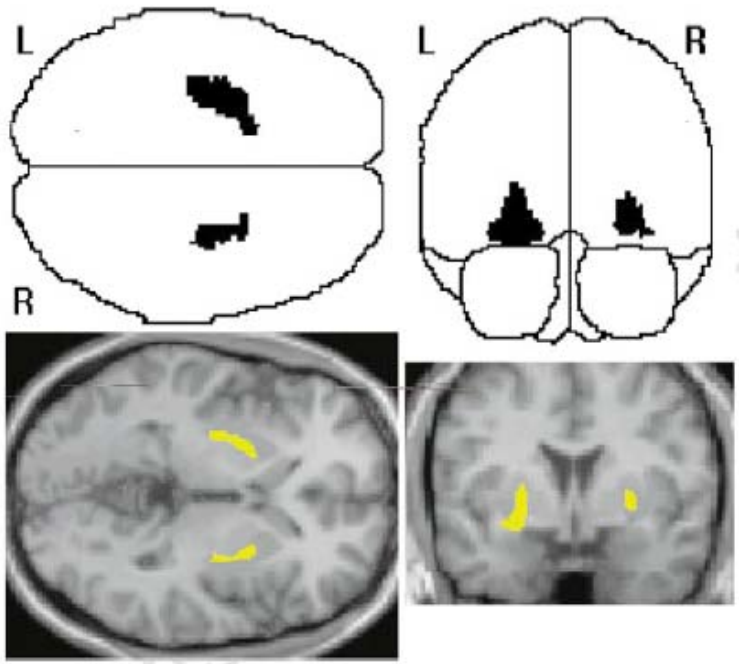
- poor temporal resolution
- extremely invasive (injection of radioactive tracer)
- rare & expensive ($3 million, $700K yearly maintenance)
- correlational (not causal)

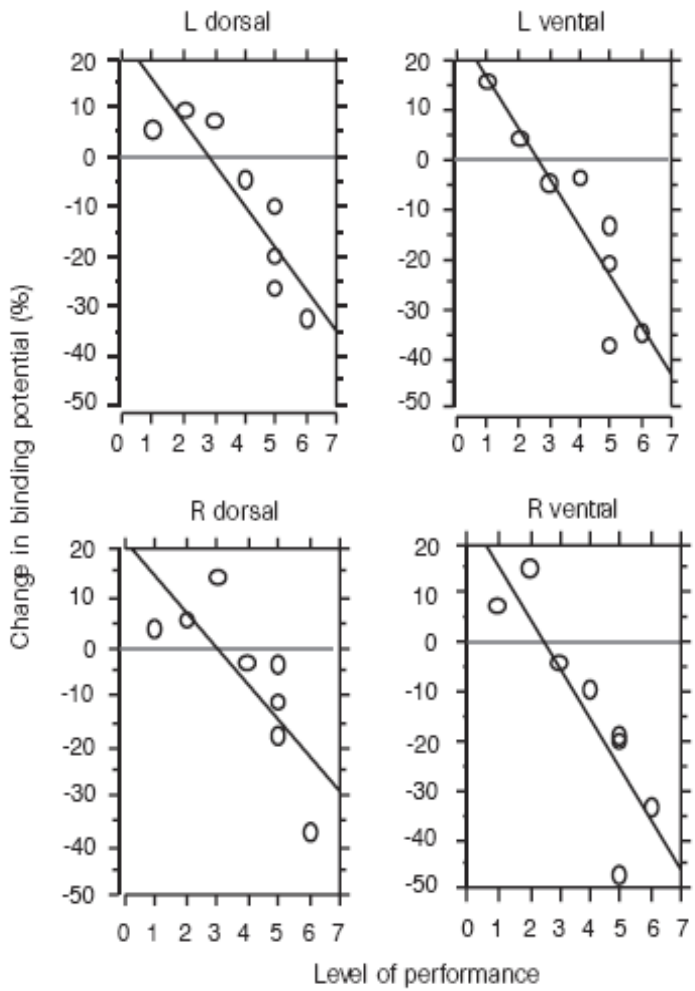






Parkinson's Disease

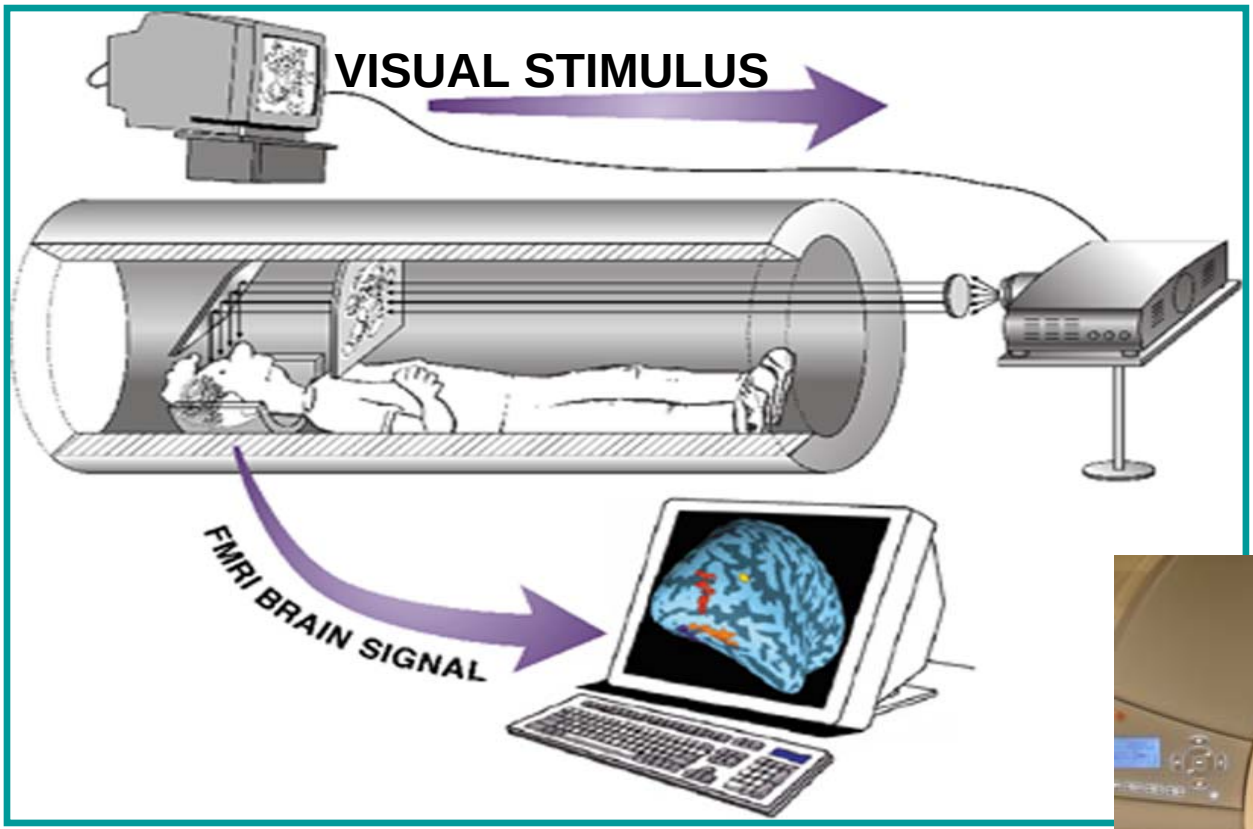




Video games & dopamine

RECORDING

fMRI



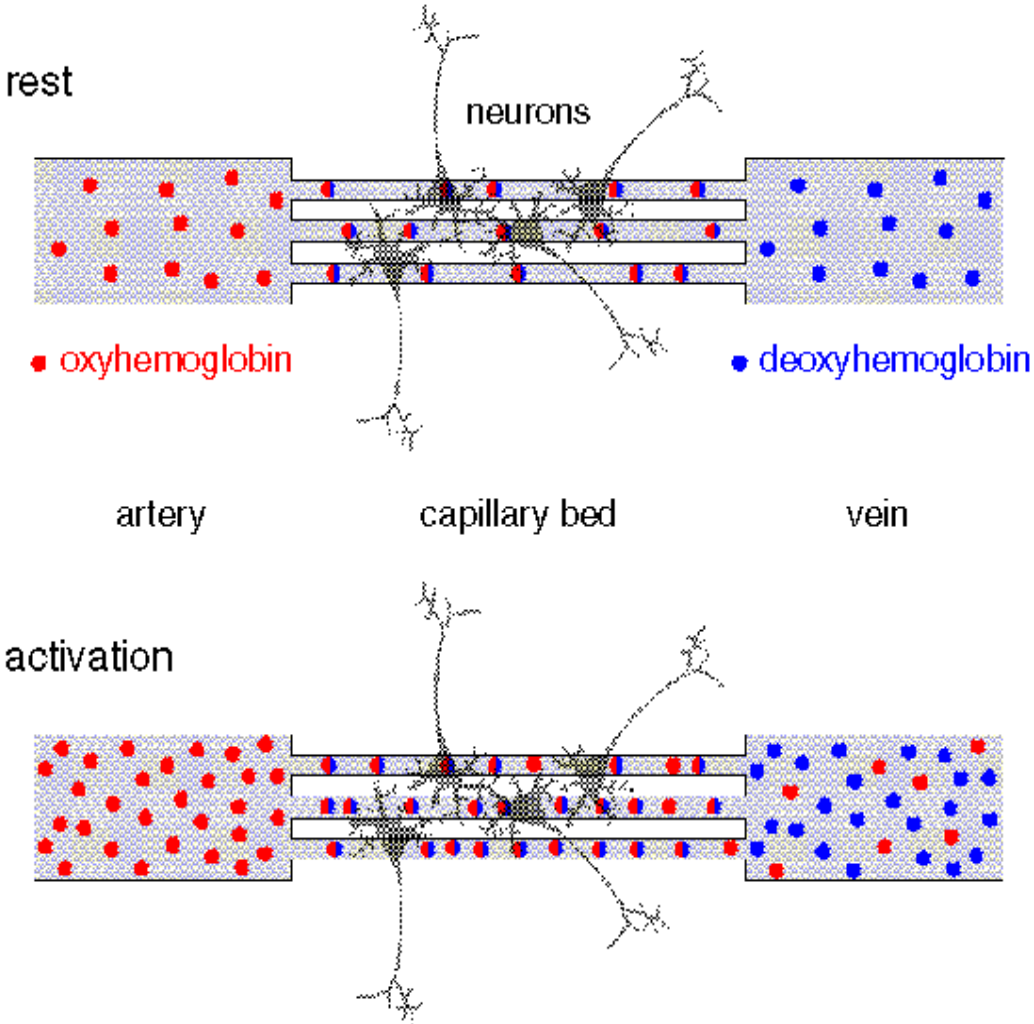
RECORDING

fMRI Principles

- like MRI, take advantage of magnetic properties of molecules
- HOWEVER, focus on hemoglobin
- Hemoglobins are in the blood and carry O_2
- Hemoglobins become deoxygenated when O_2 is absorbed
- deoxygenated hemoglobin more sensitive to magnetic field than oxygenated hemoglobin

RECORDING

fMRI Principles



- increased blood flow to active region

- hemoglobins become deoxygenated as neurons use up the supplies of O_2

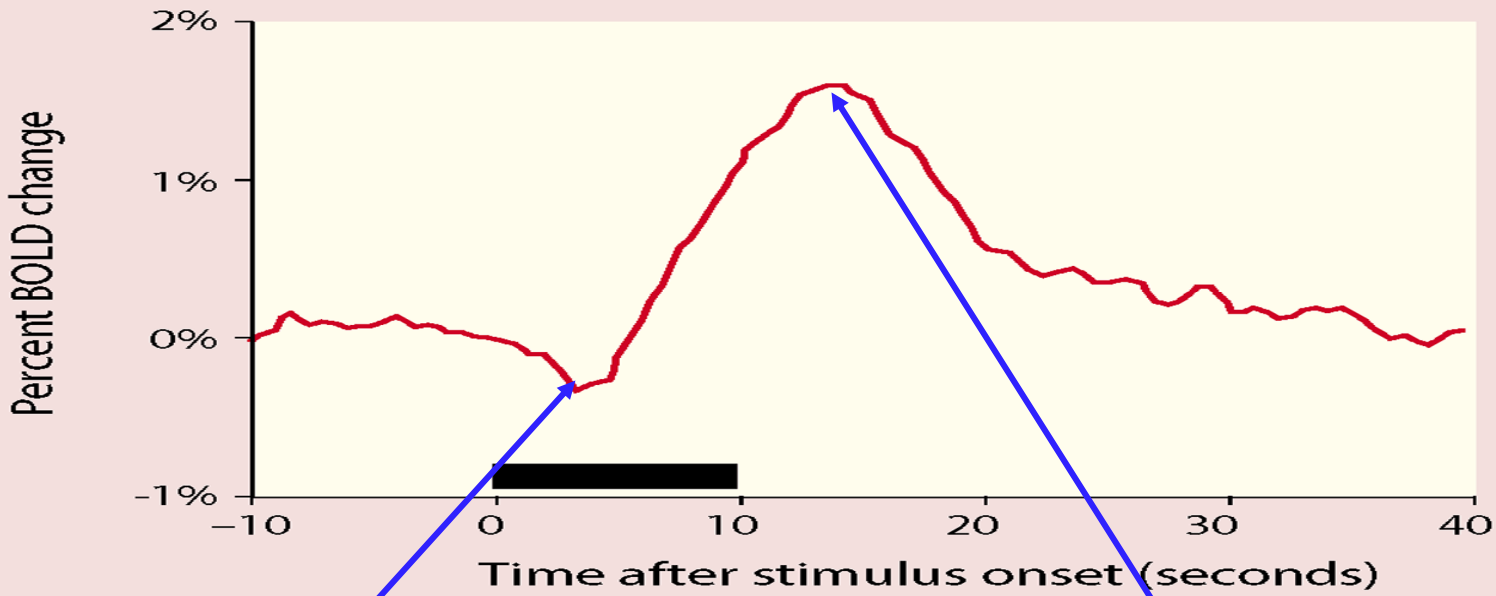
- fMRI measures ratio of Oxy:Deoxy

- Blood Oxygenation Level Dependent effect (BOLD effect)

? If neurons using up oxygen, why does BOLD signal *increase*?

RECORDING

fMRI Principles



- initial dip DOES reflect use of oxygen

- but signal too small to detect

- later rush of blood to area; arteries overcompensates, providing more oxygen than needed - MUCH LARGER SIGNAL

RECORDING

fMRI - issues

Strengths

- good spatial resolution (2-3mm)
- non-invasive (no injection)
- widely available
- can be used to assess many cognitive tasks

Limitations

- poor temporal resolution (6s, better than PET, worse than ERP/MEG)
- expensive ($4 million, $300-$1000 per scan)
- correlational, not causal

High level social cognition -

Paradigm to study *Empathy*

Observation or imagination of another person in a particular emotional state automatically activates a representation of that state in the observer

(Preston & de-Waal, 2002)

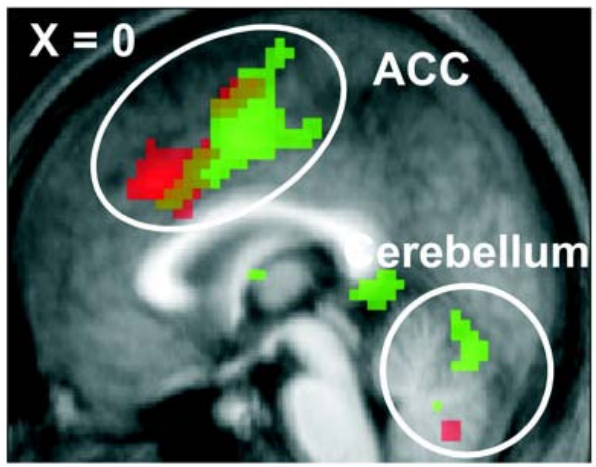
Empathy

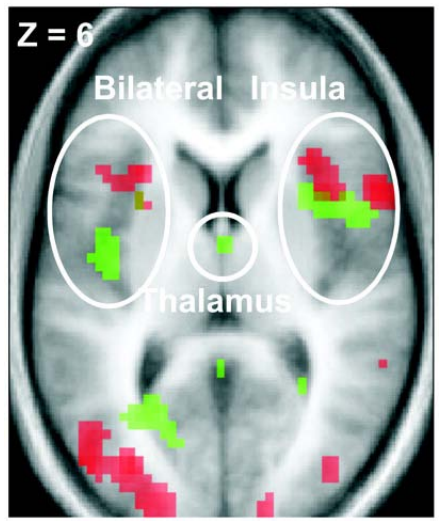
Pain-sensitive activation

Pain > No Pain

"self" *(Experiencing)*

"other" *(Observing one's partner)*





Trust Games

-*cooperate or defect*?

Ultimatum Game

Two players – split a sum of money

Proposer & Responder

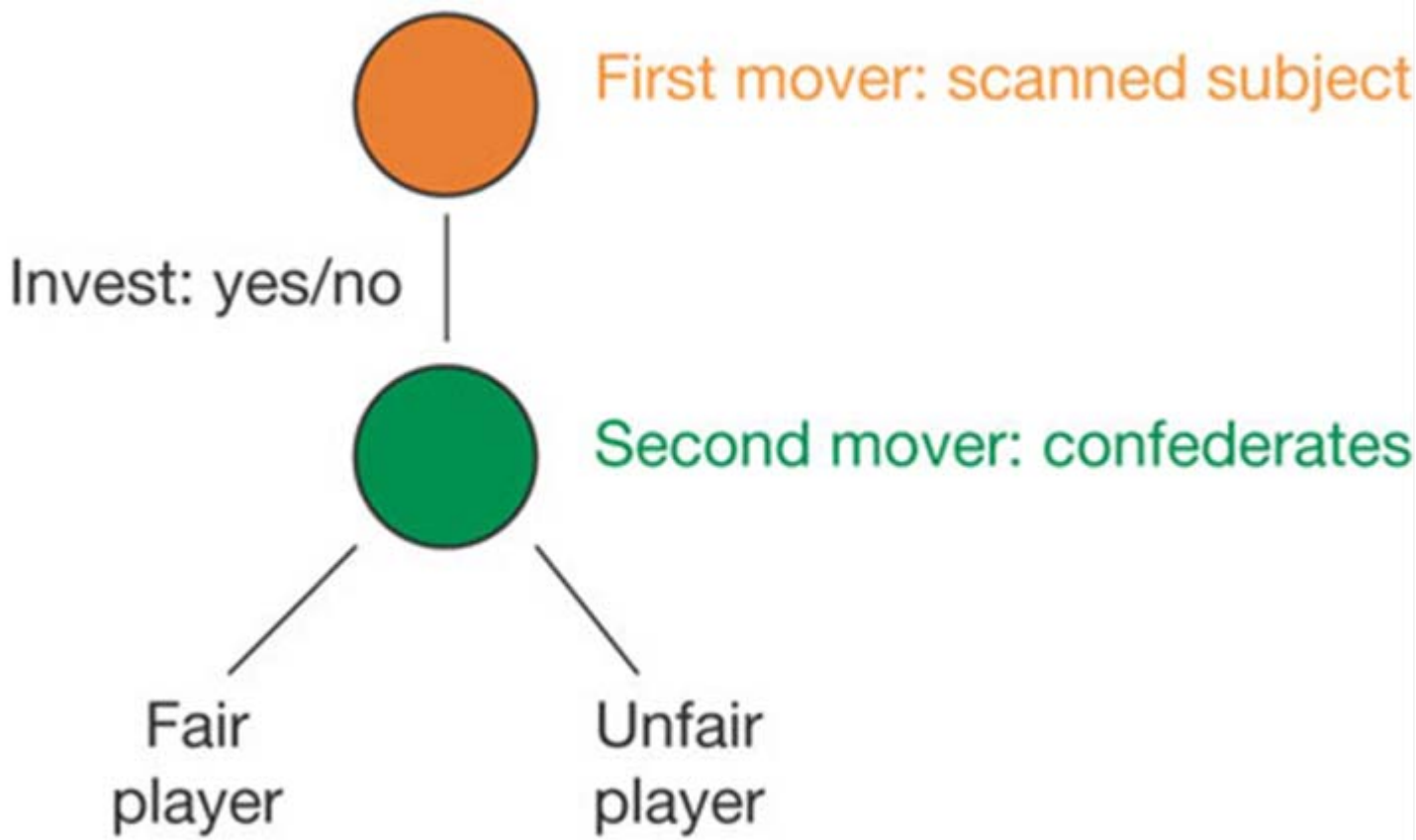
Rejection – no money for anyone

Modal offer – 50%

Low offers (20%) have 50% chance of rejection (fairness)

Empathy

Perceived Fairness of Others



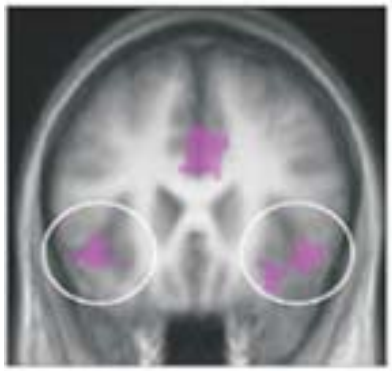
Empathy

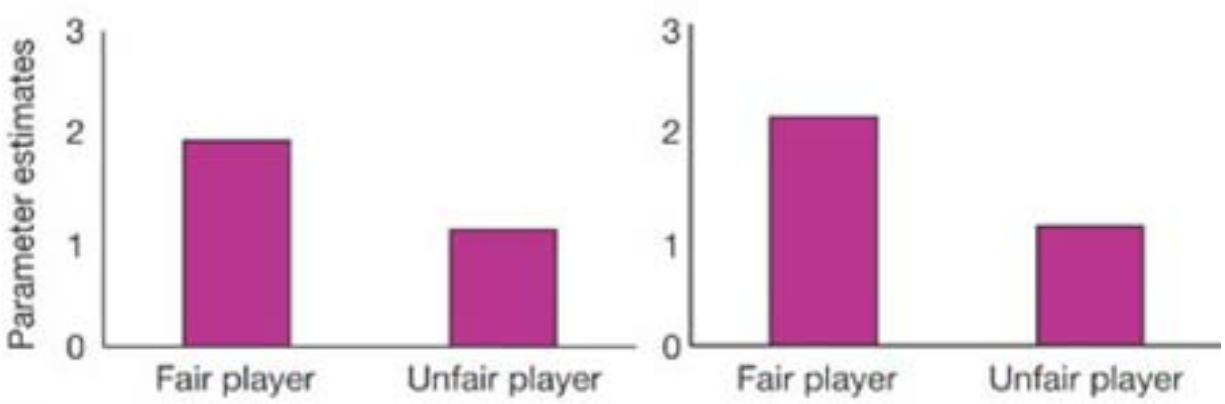
Perceived Fairness of Others

insula

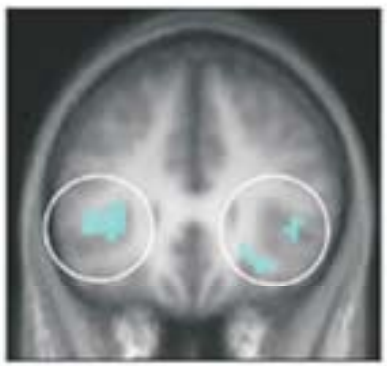
Feeling: Pain > No Pain
Conj.
Seeing other: Pain > No Pain

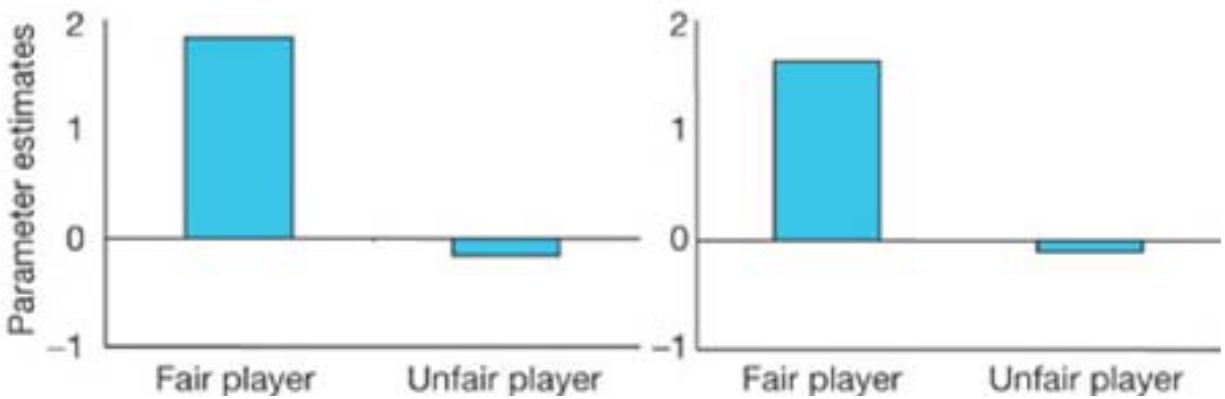
Women





Men





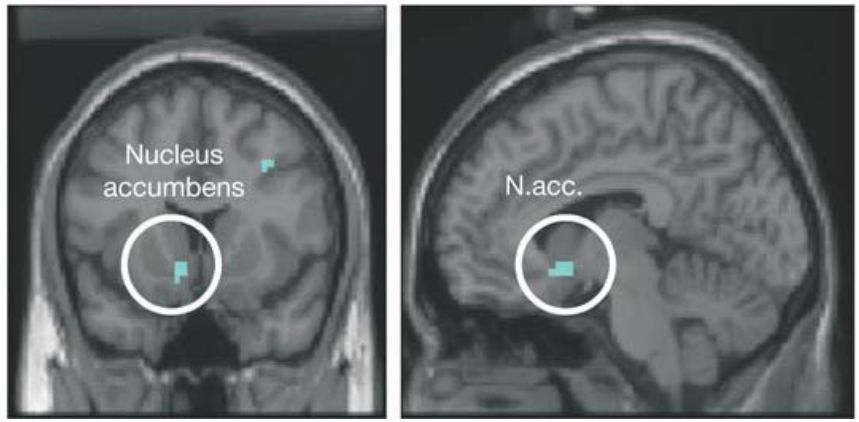
Empathy

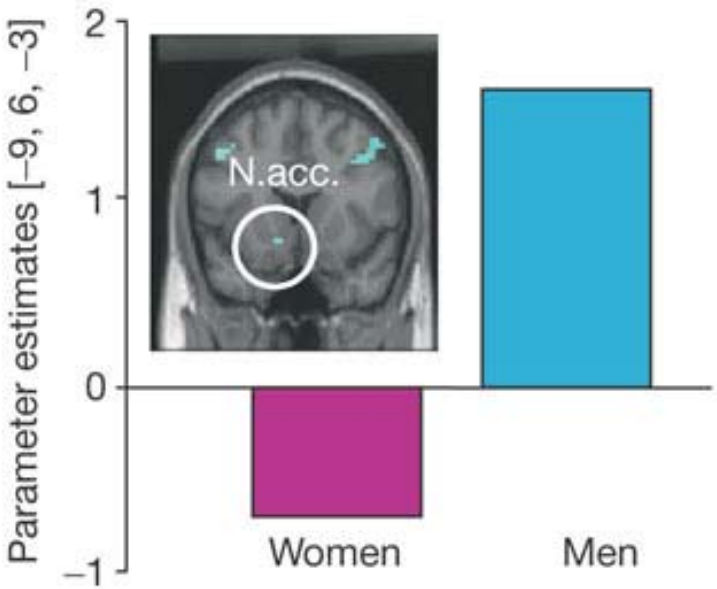
Perceived Fairness of Others – Gender Differences

Nucleus Accumbens

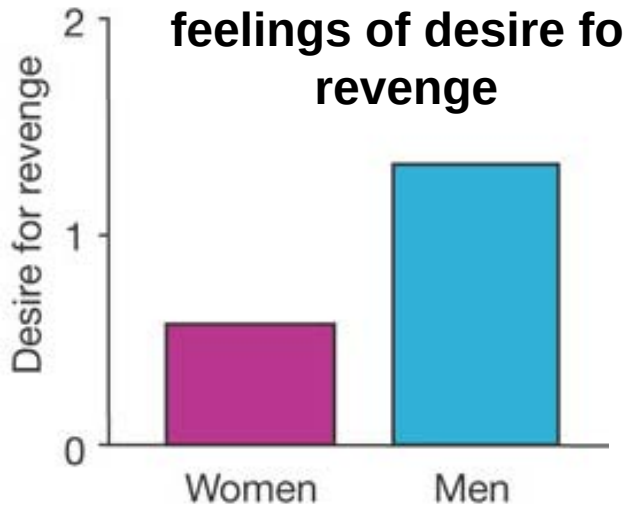
Seeing: Pain Unfair > Pain Fair

Increase in men but not women

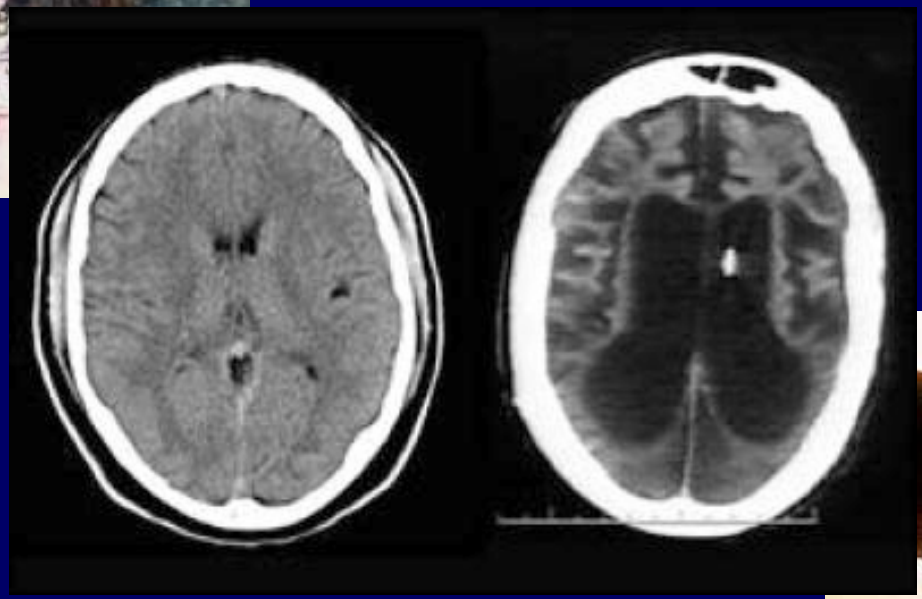




Men indicate stronger feelings of desire for revenge



Terry Schiavo

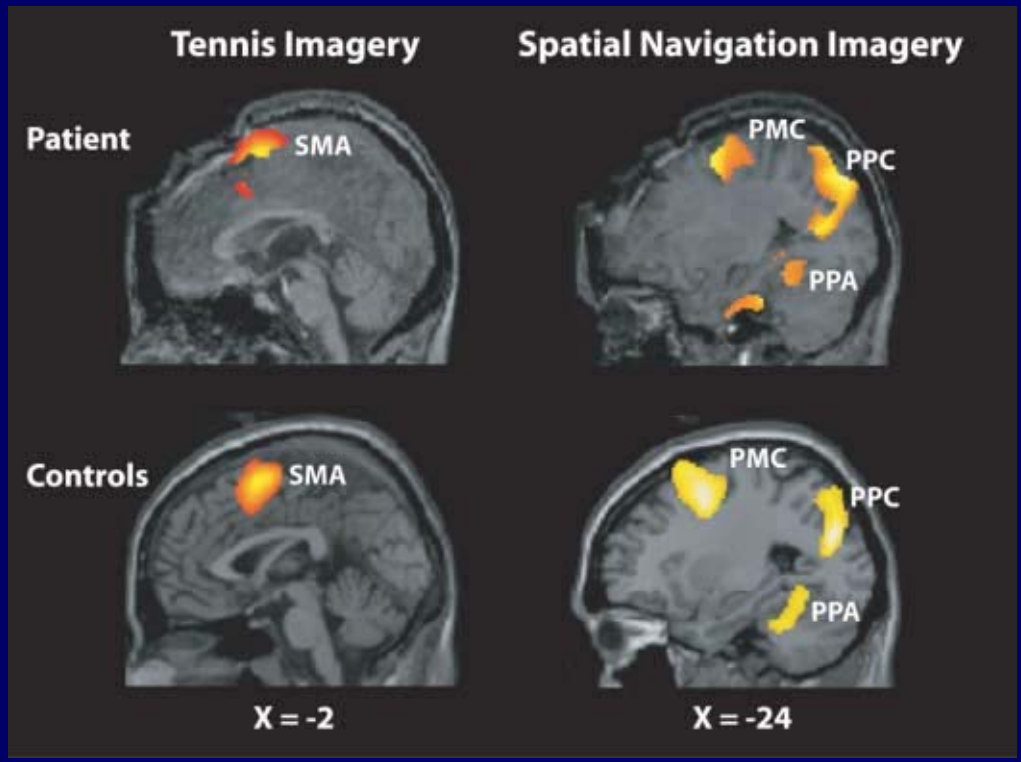


Cardiac arrest Feb 25, 1990; coma, vegetative state; 1998, husband petitioned to remove feeding tube; parents opposed; April 24, 2001 tube removed, but reinserted several days later; many court decisions; President Bush signed legislation to keep her alive; disconnected March 18, 2005 and died March 31, 2005

Vegetative State

- emerge from coma, appears to be awake, but no sign of awareness
- 2005, 23 year-old woman, road traffic accident, severe traumatic brain injury, 5 months later unresponsive but preserved sleep-wake cycles
- two mental imagery tests
  - neuroimaging - imagery activates relevant and specific perceptual and memory systems
    - playing tennis
    - visit all rooms of your house, starting with front door

Imagery-Specific Activations



Patient and group of 12 healthy volunteers imagined playing tennis or moving around a house

Owen et al., Science, 2006

OUTLINE

1) **Lesion**
2) **Stimulation**
3) **Recording**
   - **a. Structure**
   - **b. Function**
     - **i. Electrical/Magnetic**
       - **- EEG**
       - **- MEG**
     - **ii. Metabolic**
       - **- PET**
       - **- fMRI**

Goals: • ***introduce techniques***
• ***present strengths and limitations***

9.00SC Introduction to Psychology
Fall 2011