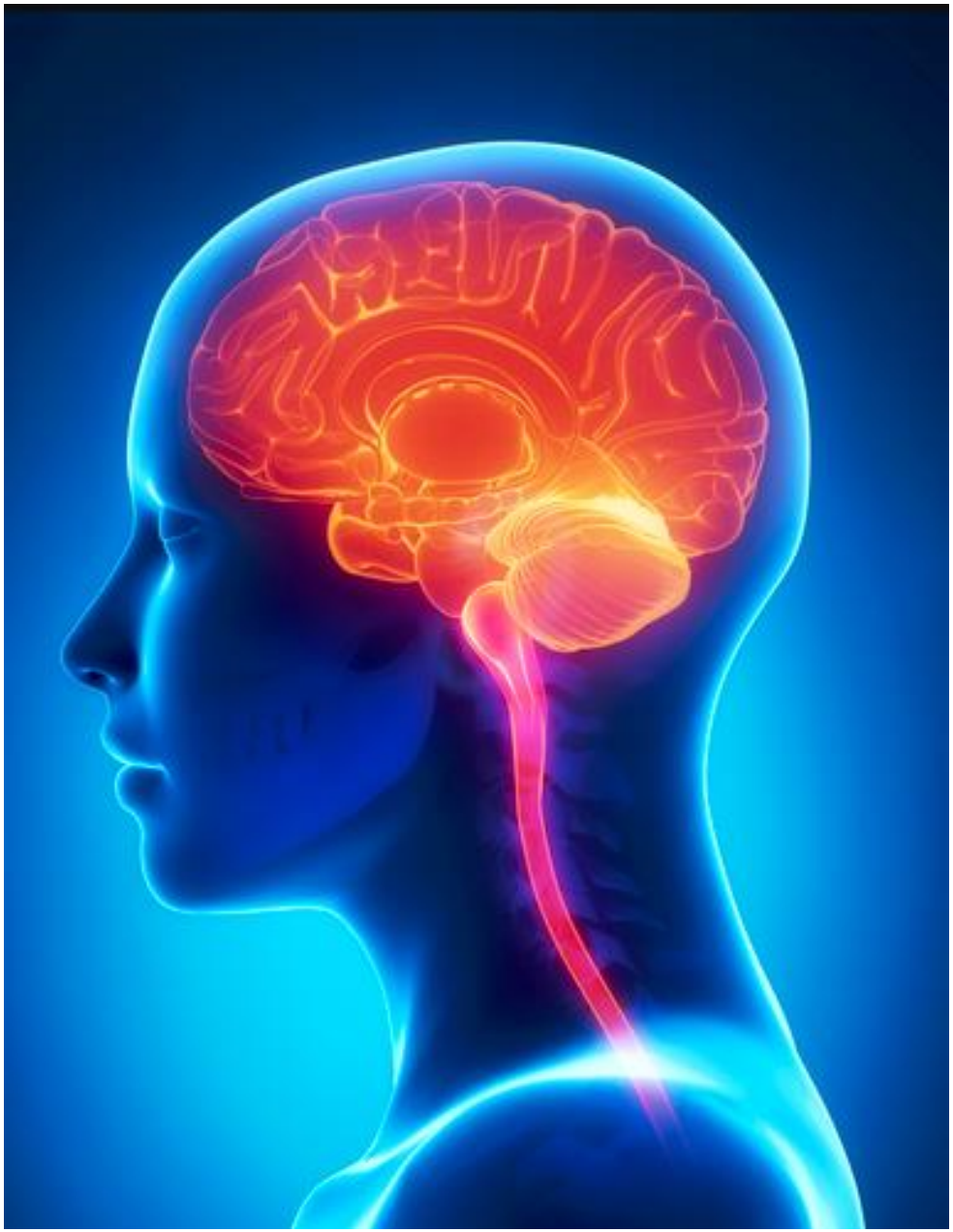
Introduction to Contemporary Neuroscience

Will discuss basic principles of the nervous system functioning and the recent advances and findings from human brain mapping.

(Reading: Zimmer, C., & Clark, R. (2014). Secrets of the brain. Nat. Geogr, 28-58.)

Klára Marečková, Ph.D., M.Sc.

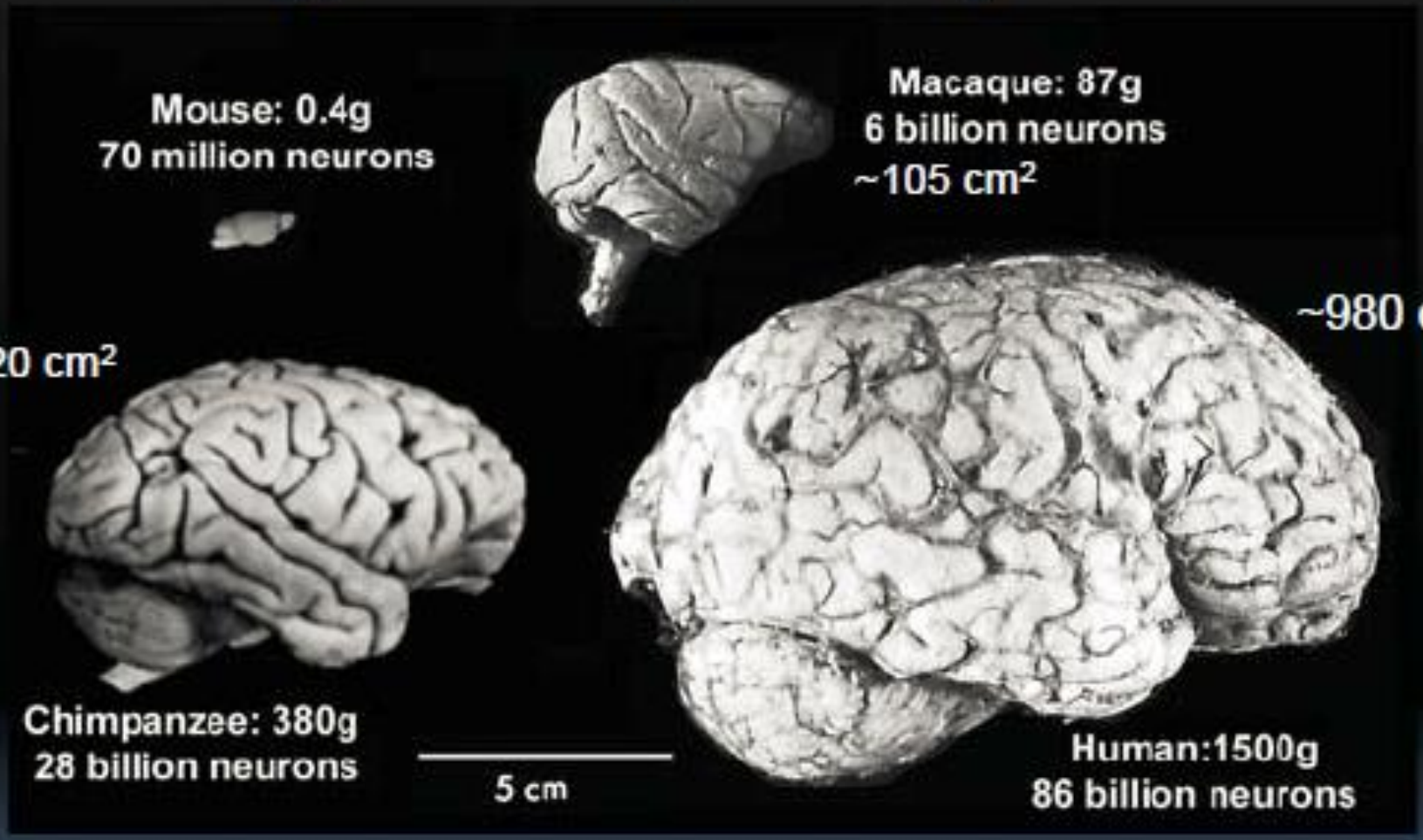


„The human brain is a three-pound wad of flesh able to explore the universe, imagine a better world, and ponder its own nature. Armed with far more sophisticated imaging techniques, scientists today are reaching toward an ultimate understanding of what makes us us.“

(Visible Human Brain Project).

What do we know about the human brain?

Big, medium, and tiny brains



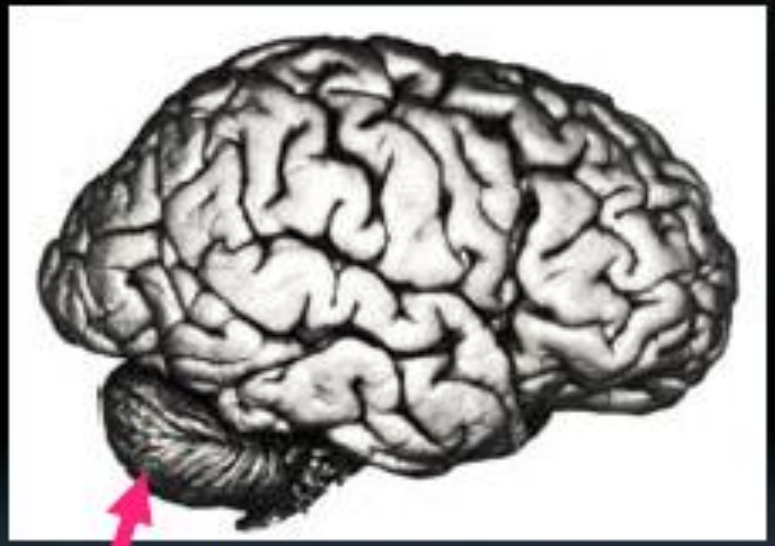
- Human vs mouse: >1,000-fold difference in size and # neurons
- " vs. macaque: >10-fold
- " vs. chimpanzee: ~3-fold

Human Brain Numbers

Whole brain: 1500g; 86 billion neurons[1]

Cerebral cortex:

- ~80% of brain mass (GM + WM)
- 16 billion neurons (~20%)
- 150 trillion synapses (~10,000/neuron)
- 160,000 km myelinated WM axons (~1 cm/neuron)



Cerebellum:

- 10% of brain mass
- 69 billion neurons (80%)

Rest of brain:

- 8% of brain mass
- 0.7 billion neurons (0.8%)

Human Brain Numbers

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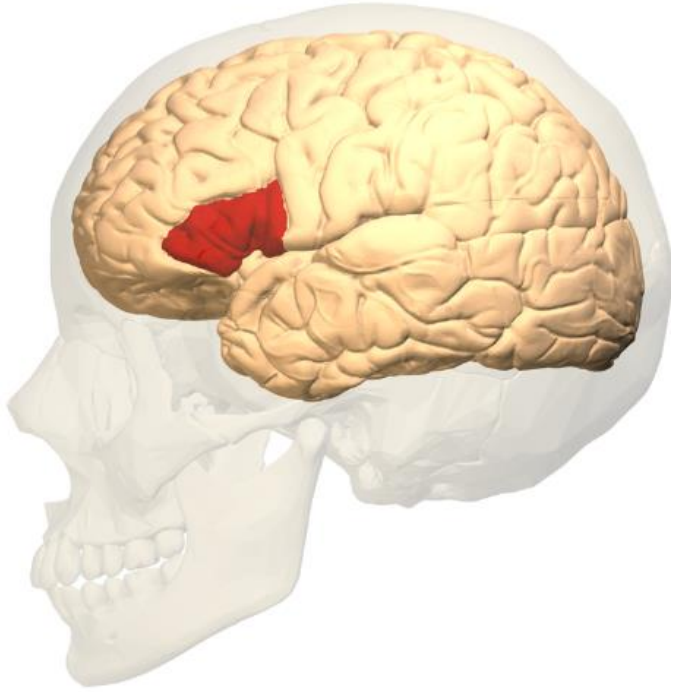
1820s: Mind located in the brain

- Founder of experimental brain science; through the study of ablations on animals, he was the first to prove that the mind was located in the brain, not the heart.

1860s: Localization of brain function

- brains of patients suffering from aphasia contained lesions in a particular part of the cortex, in the left frontal region. This was the first anatomical proof of localization of brain function.



1906 Nobel Prize in Physiology and Medicine

Camillo Golgi

Santiago Ramón y Cajal

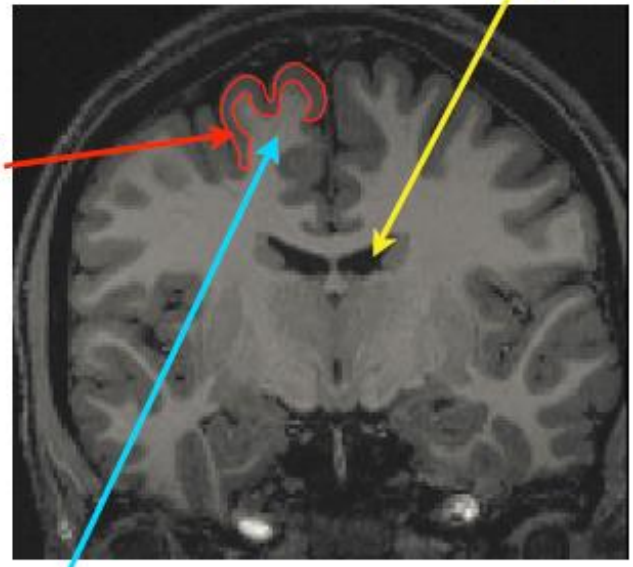
Neuron as the functional unit of the brain.

The brain is full of neurons. These are organised into two types of "tissues":

- Grey Matter
- White Matter

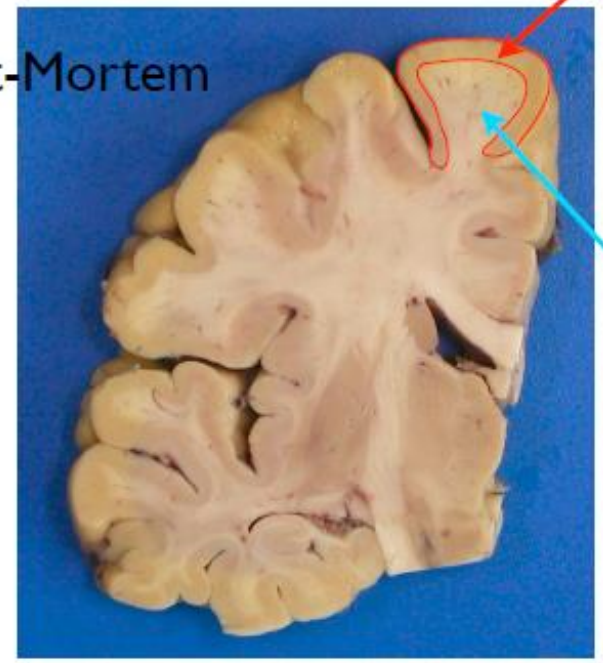
Grey Matter

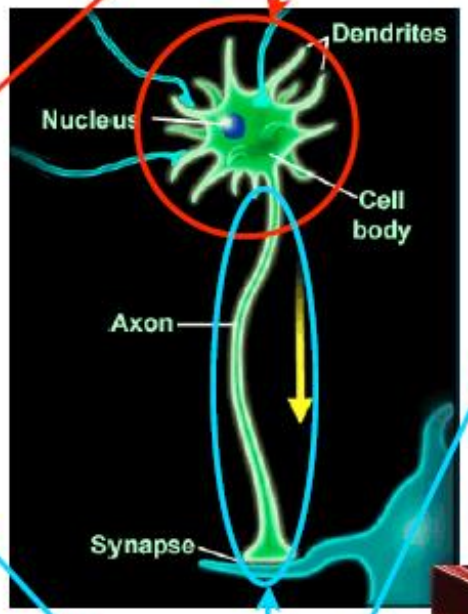
CSF



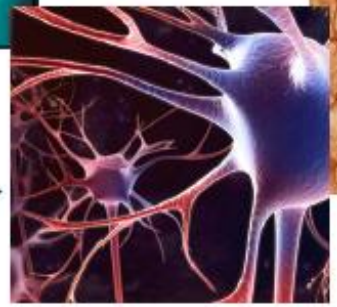
MRI

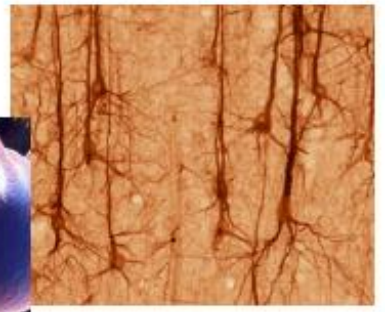
Post-Mortem





Neurons

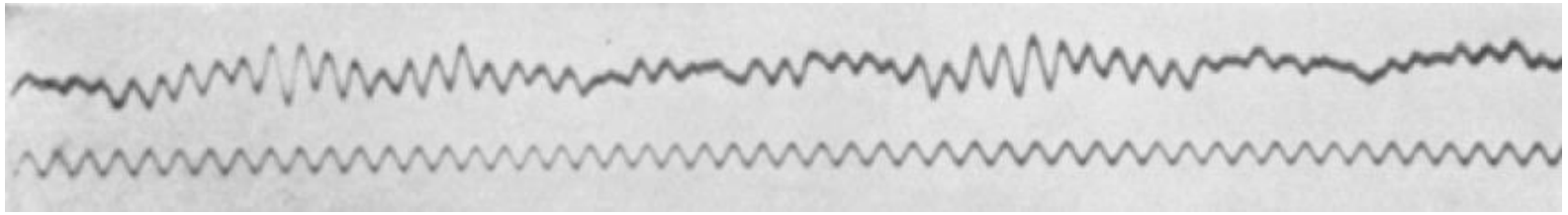




White Matter

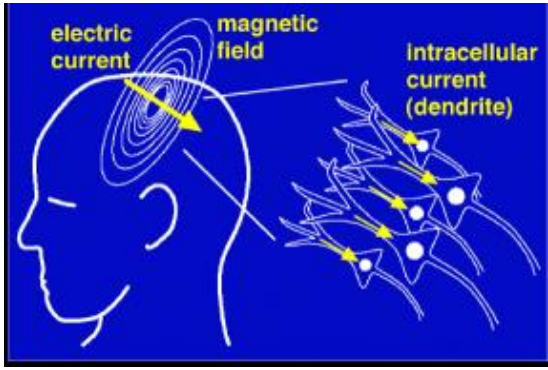
1924: first human EEG

- Hans Berger invented electroencephalogram and recorded first human EEG



- The electrodes attached to the subject's scalp transmit the electrical signals produced by the brain to the EEG monitor. Since these electrical signals are very small (of the order of 10s of microvolts) the EEG acts as an amplifier, typically amplifying them by 10,000 times, as well as a device to measure them.

1968: first MEG recordings



- David Cohen first measured MEG signals

- The brain's magnetic field, measuring at 10 femotesla (fT) for cortical activity and 10^3 fT for the human alpha rhythm, is considerably smaller than the ambient magnetic noise in an urban environment, which is on the order of 10^8 fT or 0.1 μT.
- The essential problem of biomagnetism is, thus, the weakness of the signal relative to the sensitivity of the detectors, and to the competing environmental noise. Since the magnetic signals emitted by the brain are on the order of a few femtoteslas, shielding from external magnetic signals, including the Earth's magnetic field, is necessary. Appropriate magnetic shielding can be obtained by constructing rooms made of aluminium and mu-metal for reducing high-frequency and low-frequency noise, respectively.

First Departments of Neuroscience

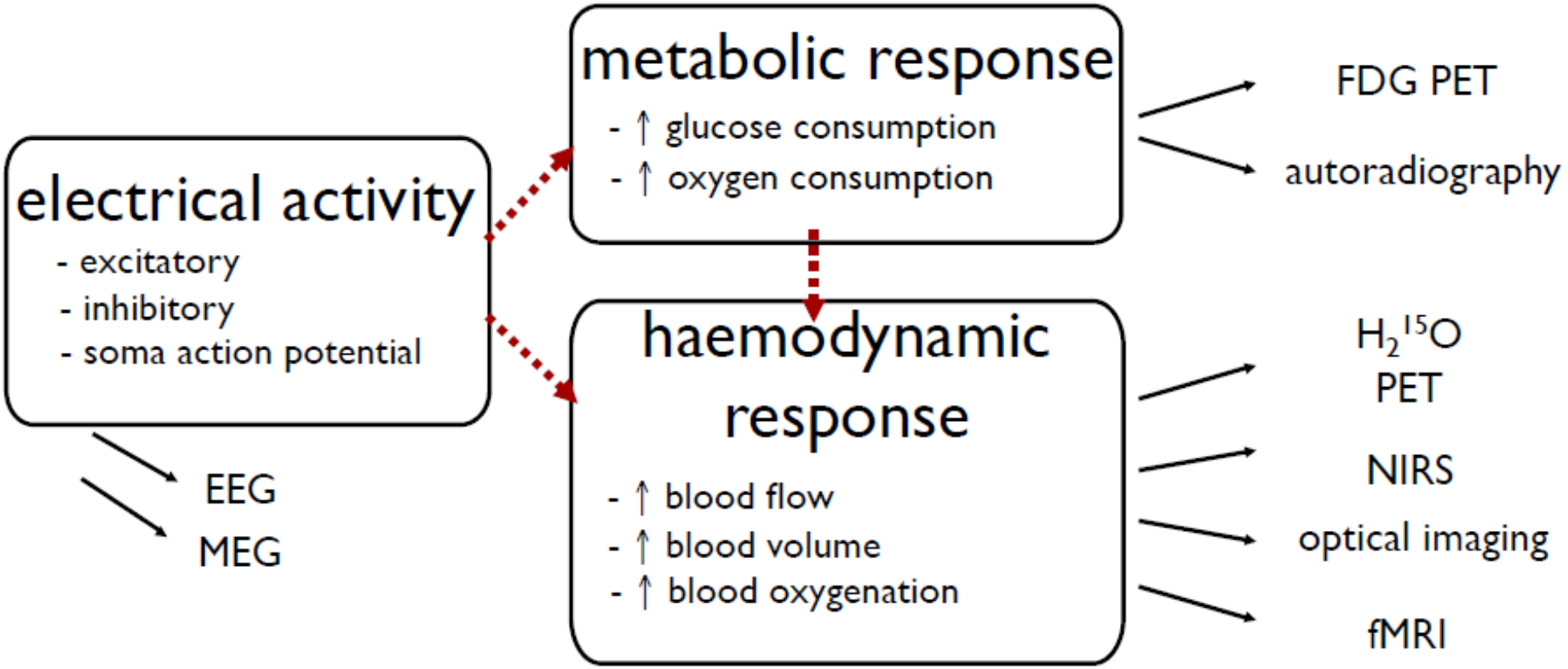
1950s

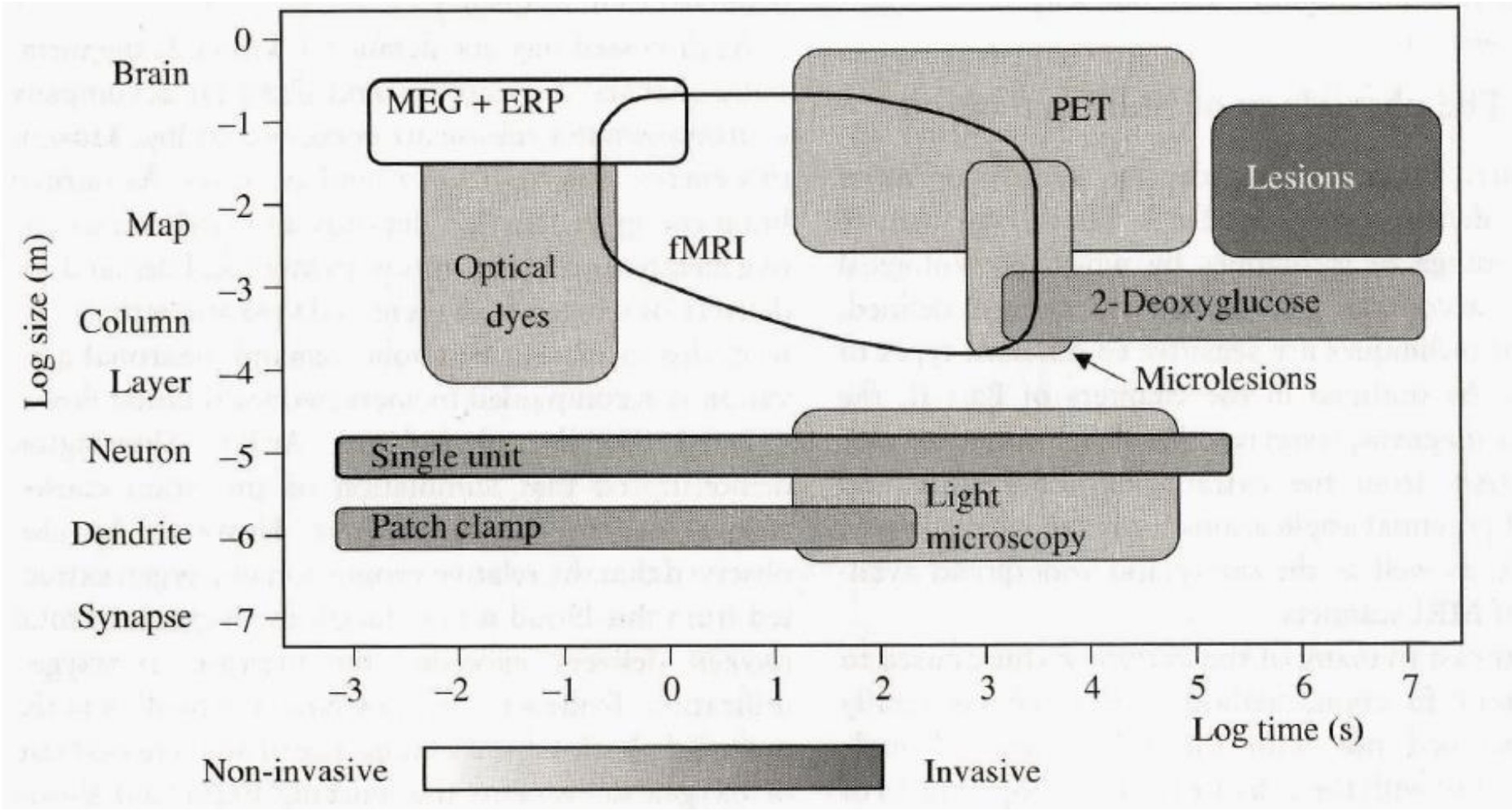
1960s

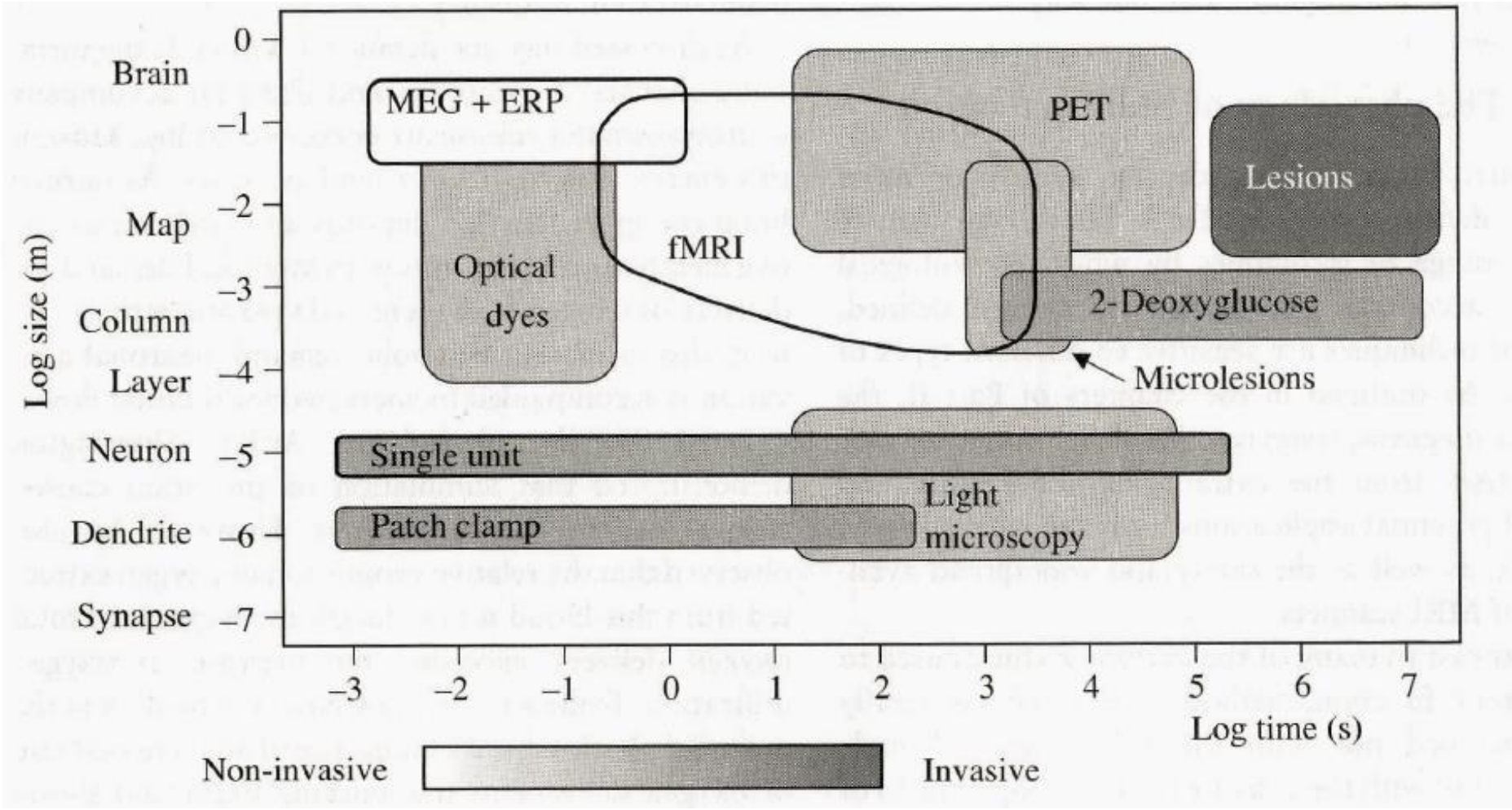
2003 Nobel Prize in Physiology and Medicine

- Paul Lauterbur and Sir Peter Mansfield received the 2003 Nobel Prize in Physiology and Medicine for discoveries concerning Magnetic Resonance Imaging (and fast imaging allowing functional magnetic resonance imaging)

Physiological Measures




Brain
Map
Column
Layer
Neuron
Dendrite
Synapse
Log size (m)
0
–1
–2
–3
–4
–5
–6
–7
MEG + ERP
PET
Lesions
fMRI
Optical dyes
2-Deoxyglucose
Microlesions
Single unit
Light microscopy
Patch clamp
–3
–2
–1
0
1
2
3
4
5
6
7
Log time (s)
Non-invasive
Invasive



Most powerful scanners record activity down to the scale of a cubic millimeter – a sesame seed's worth of tissue. But within that space, hundreds of thousands of neurons are firing.

Revolutions in Cartography

EARTH

Classical maps

Book atlases

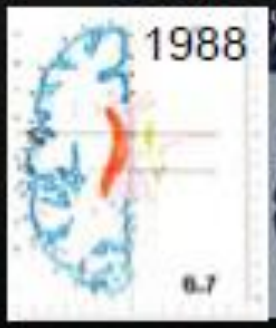
Satellite imagery

Google Earth

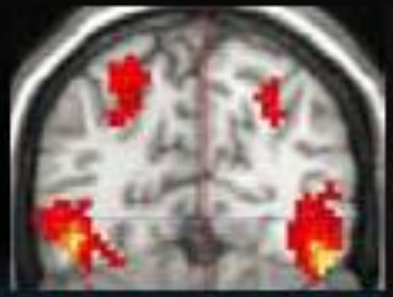
BRAIN

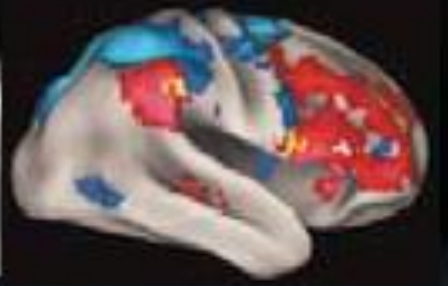
Classical maps

Talairach atlas

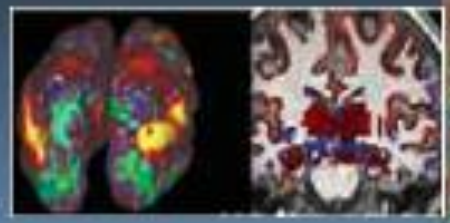


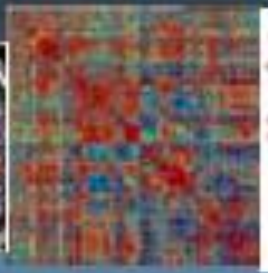
~2005: MRI; volumes + surfaces





2015 and beyond: Connectomics



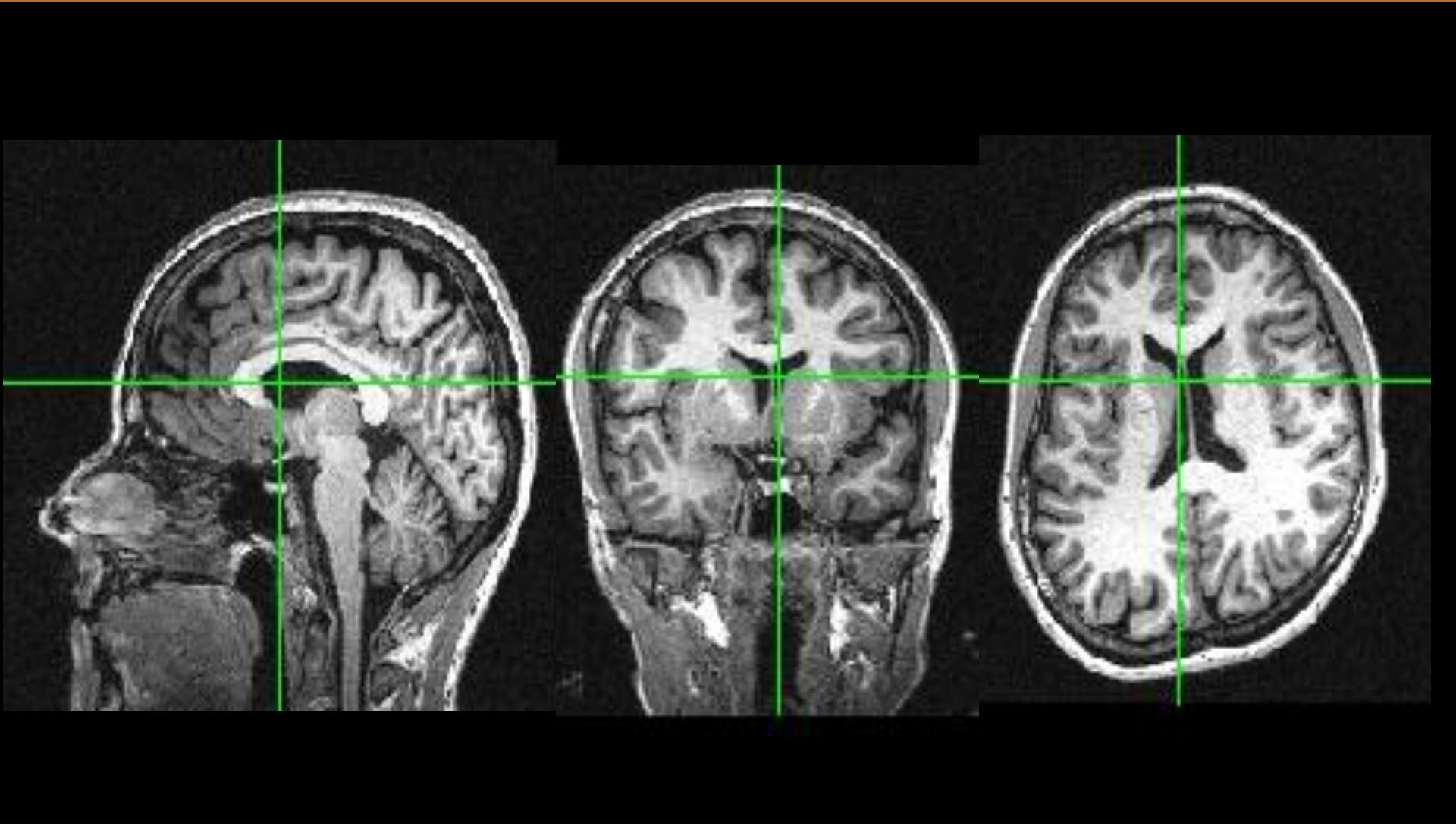


„The brain is a world consisting of a number of unexplored continents and great stretches of unknown territory.“

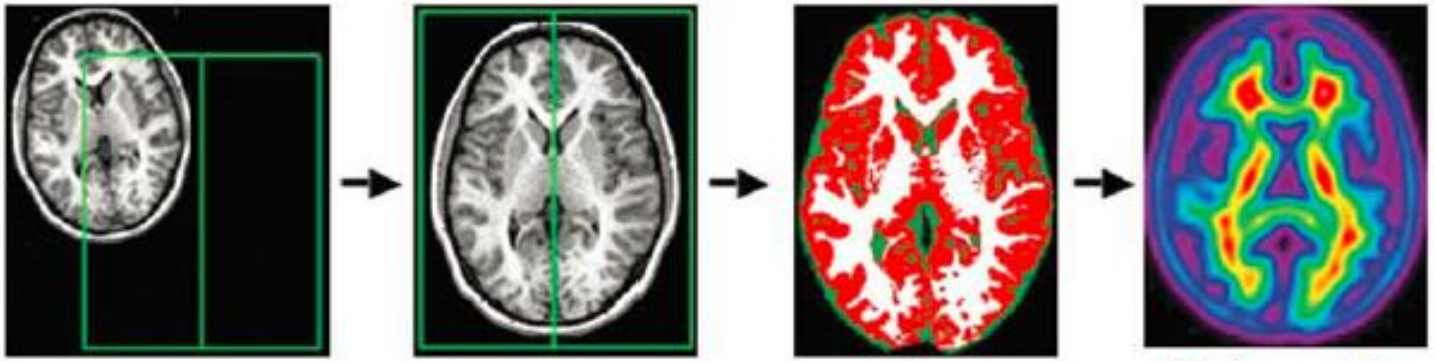
Contemporary Neuroscience

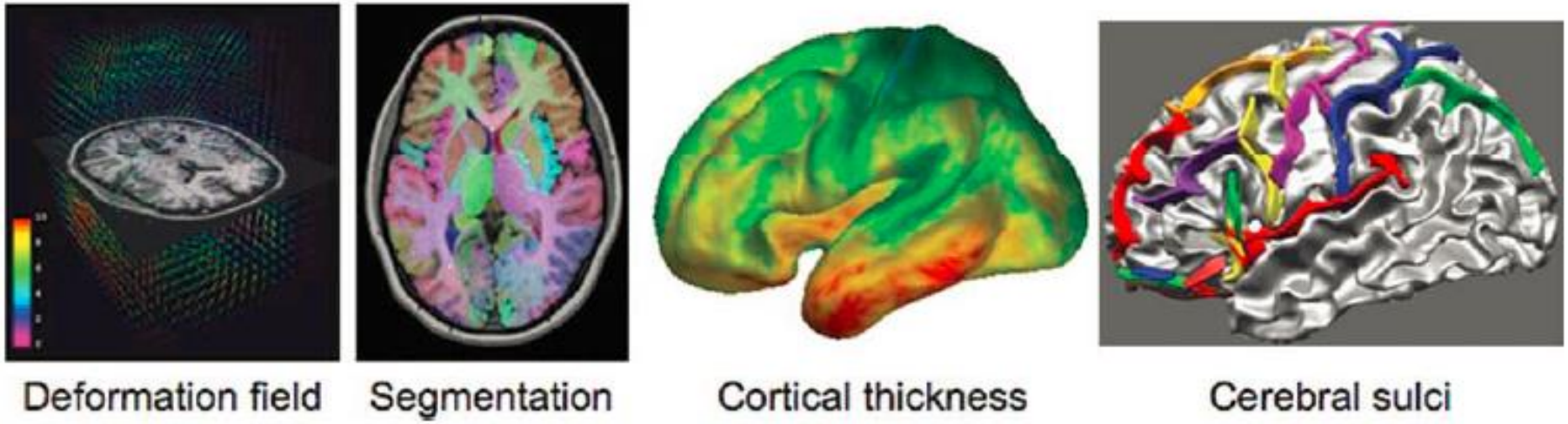
- Molecular Neuroscience –
  - biochemistry of the nervous system
- Cellular Neuroscience –
  - cell biology of the nervous system
  - Structure/function at the level of individual neurons
- Systems Neuroscience –
  - how do neural circuits work?
  - Sensory systems, motor systems, etc.
- Behavioral Neuroscience –
  - how do systems of the brain interact to produce behavior?
  - Source of dreams? Mind altering drugs (foods)?
- Cognitive Neuroscience –
  - How does the activity of the brain create the mind?
  - Descartes' Problem - self-awareness, mental imagery, language

Magnetic Resonance Imaging (MRI)



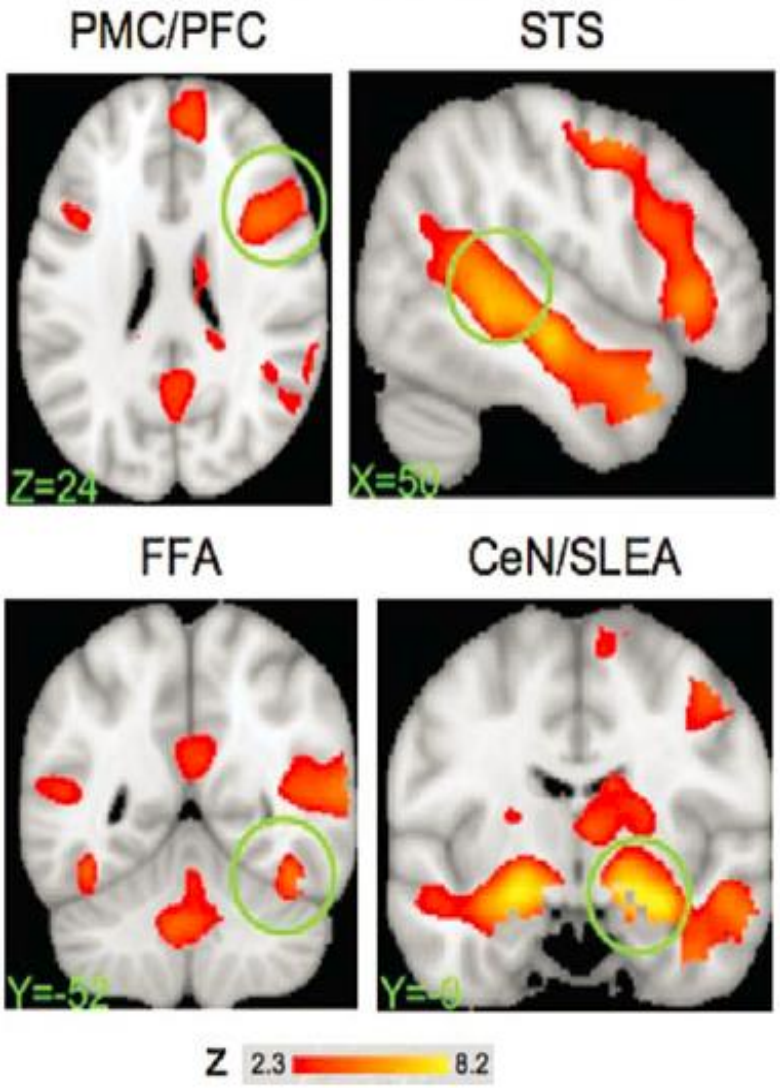
Brain Structure

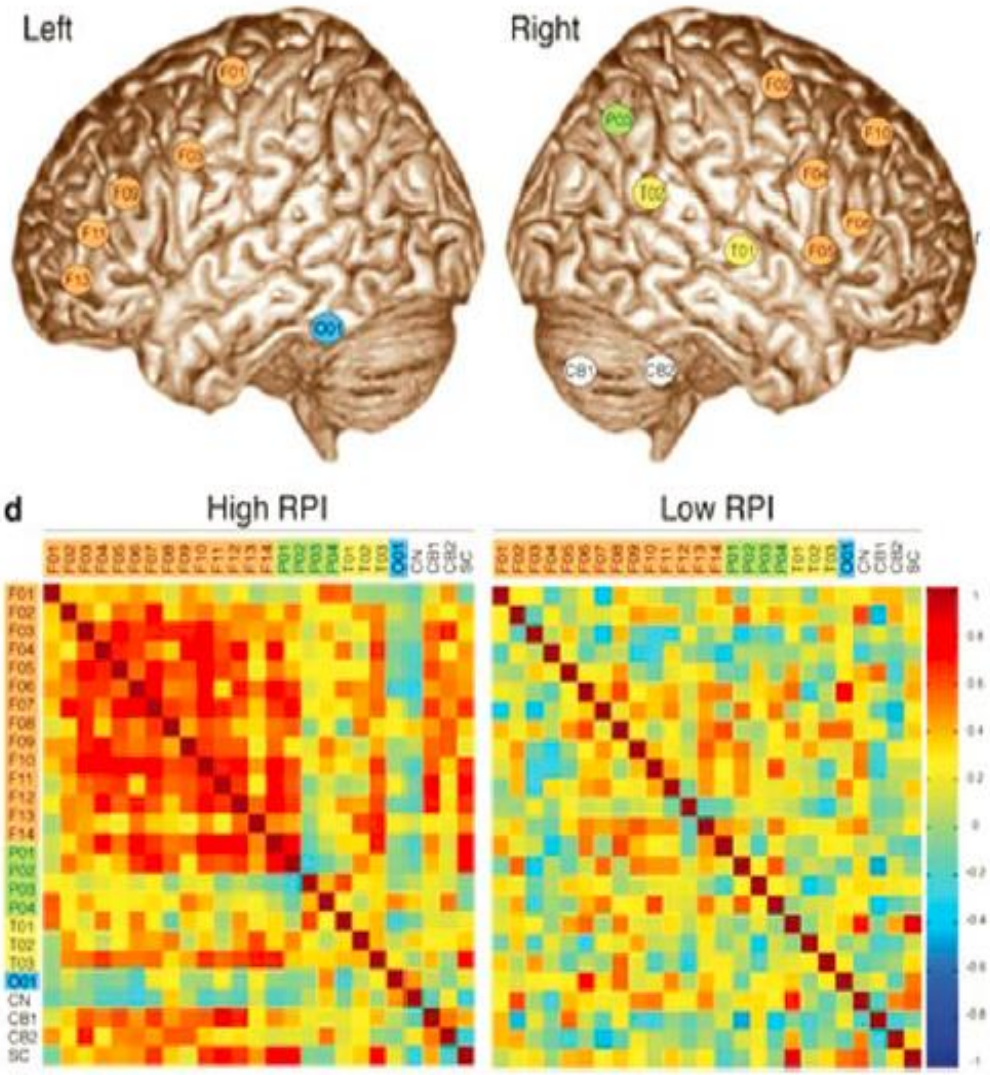




Paus, 2010

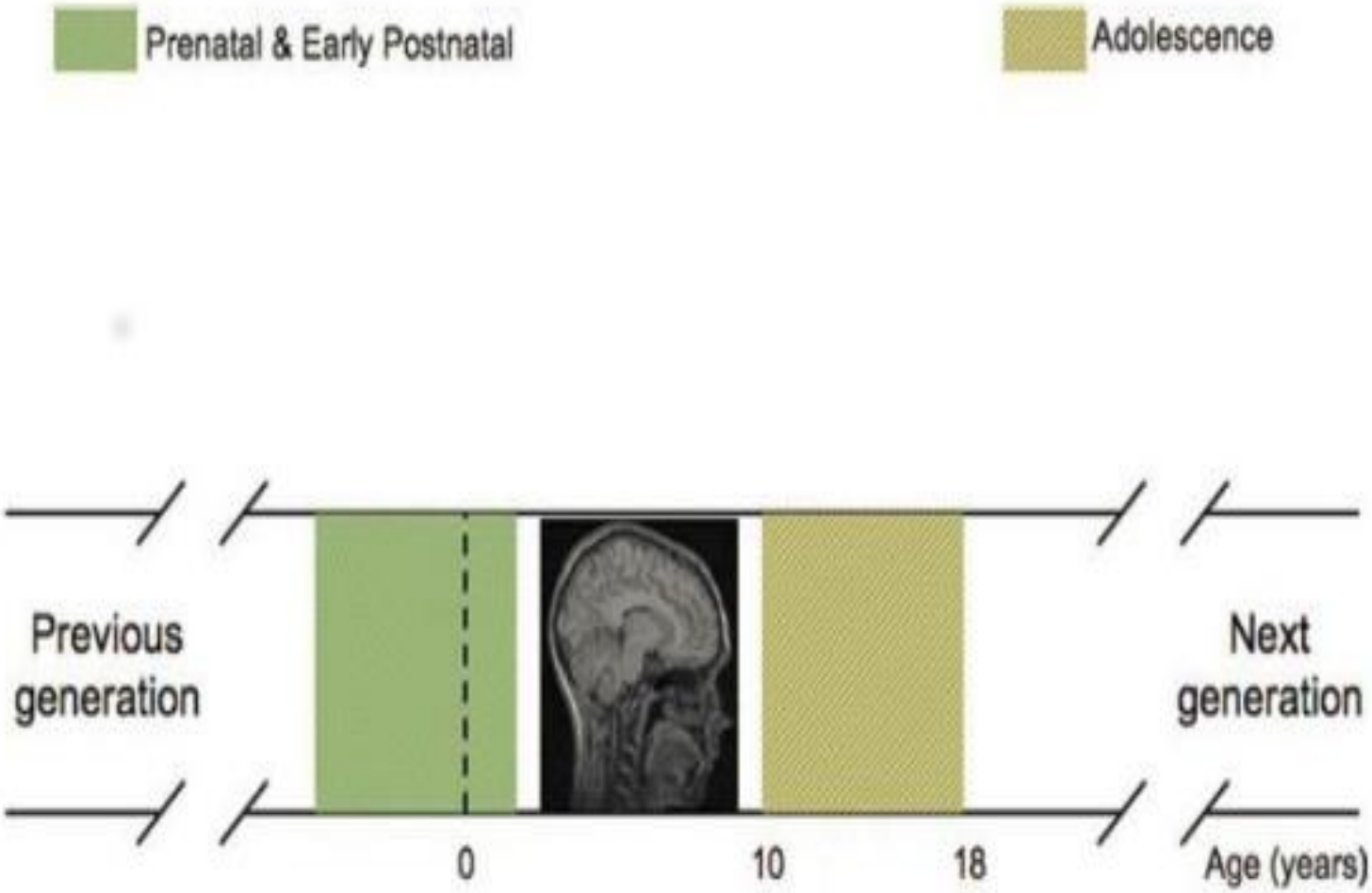
Brain Function





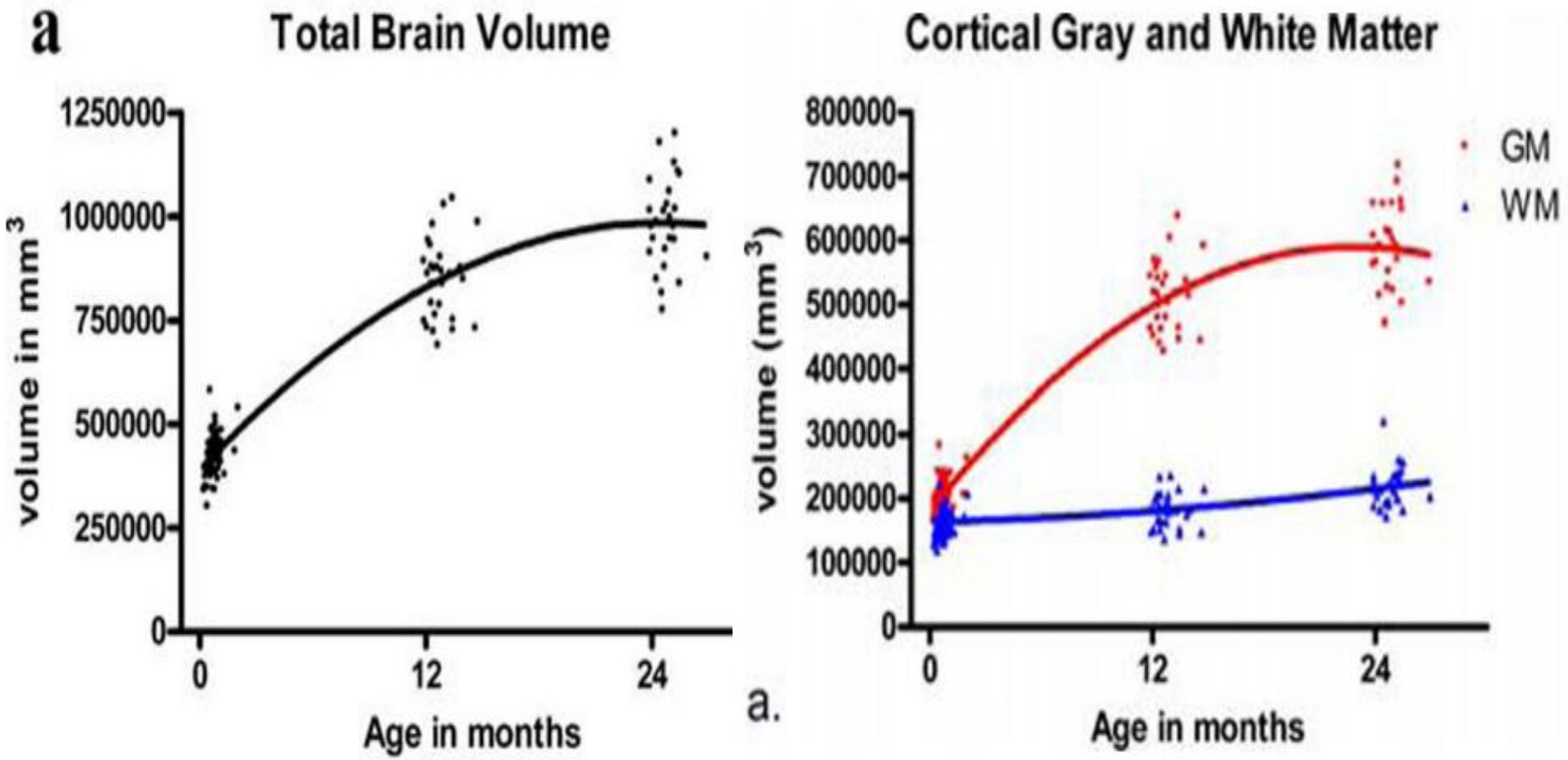
Paus, 2010

What are the factors that shape our brains and generate the impressive interindividual variability?



Paus, 2010

Brain Development in First 2 Years of Life

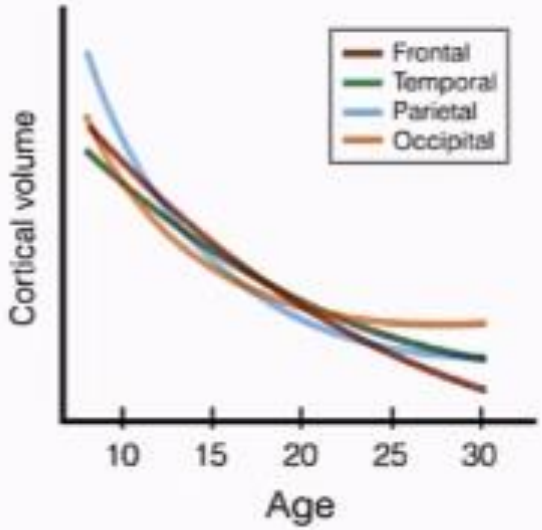


Knickmeyer et al., 2008

Brain Development during Adolescence

Brain development

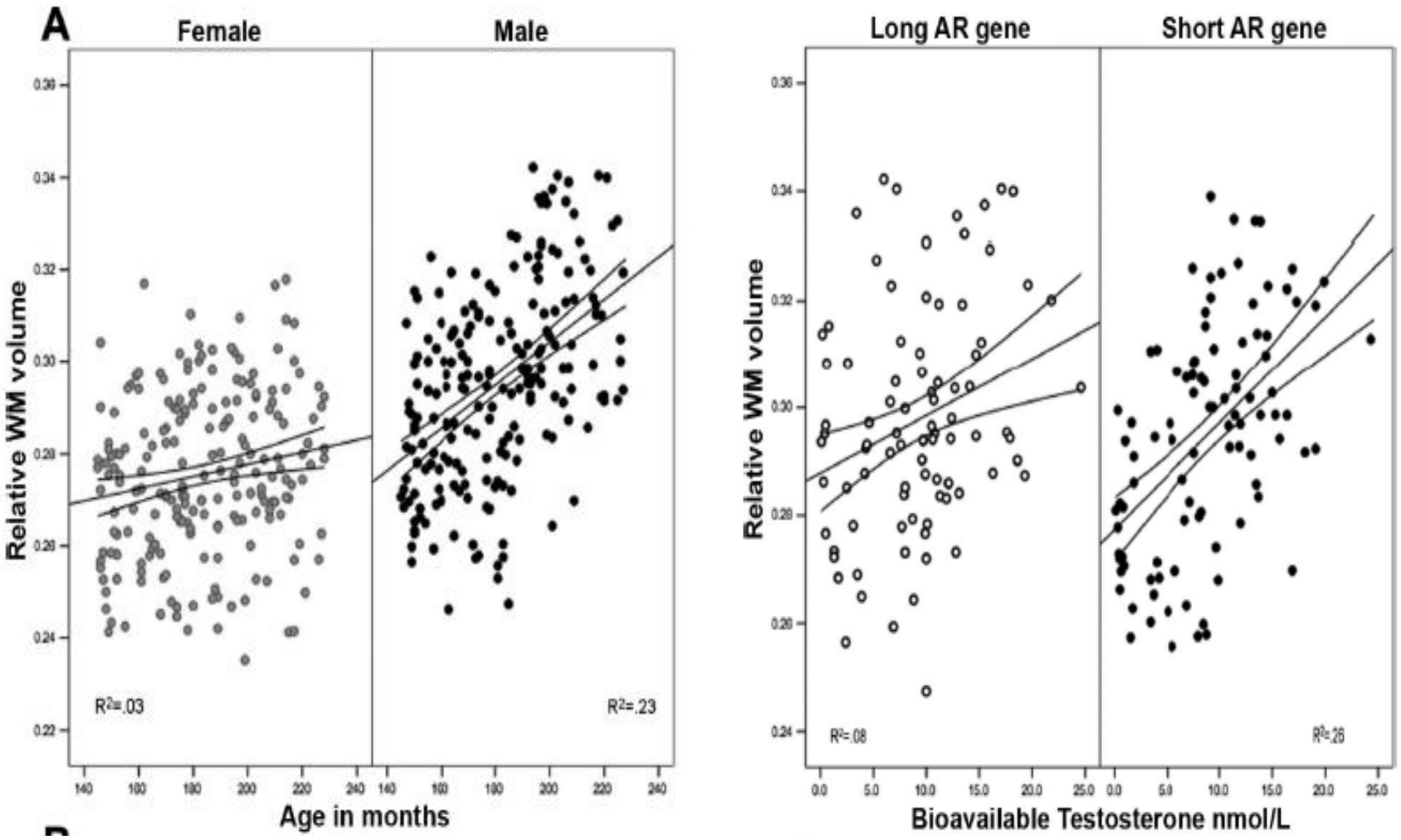
Adolescence is a time of dynamic brain development



Redrawn from Ostby et al., 2009
In Somerville, 2016 *Neuron*

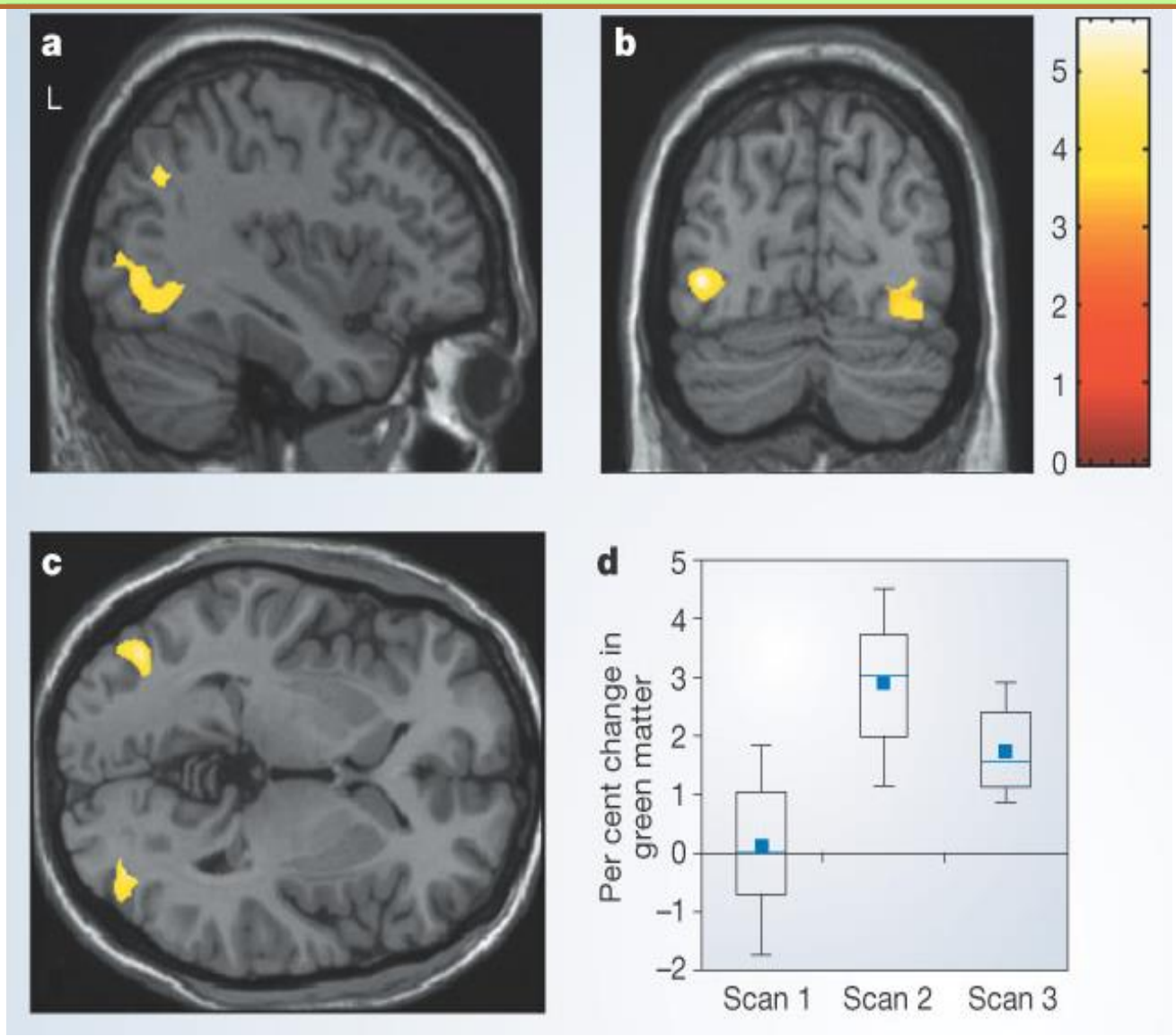
- Decline in gray matter
- Increase in white matter
- Shift in functional connectivity dynamics
- Neurotransmitter availability and receptor density

Brain Development during Adolescence



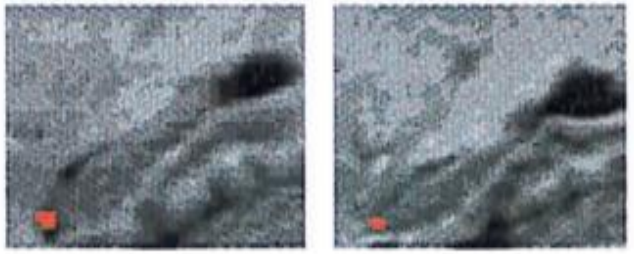
Perrin et al., 2008

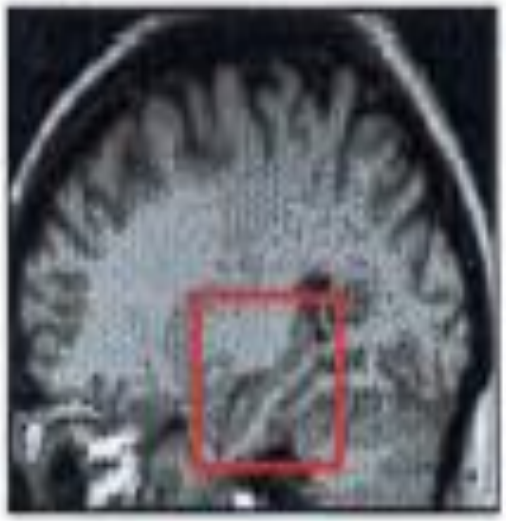
Brain Plasticity

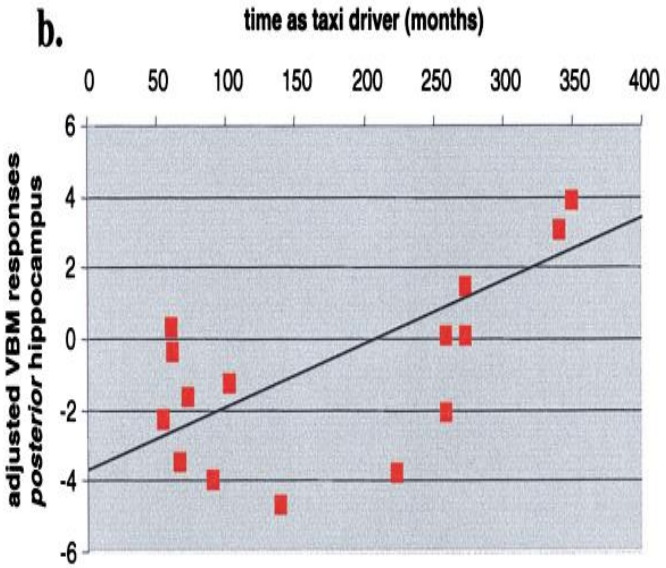


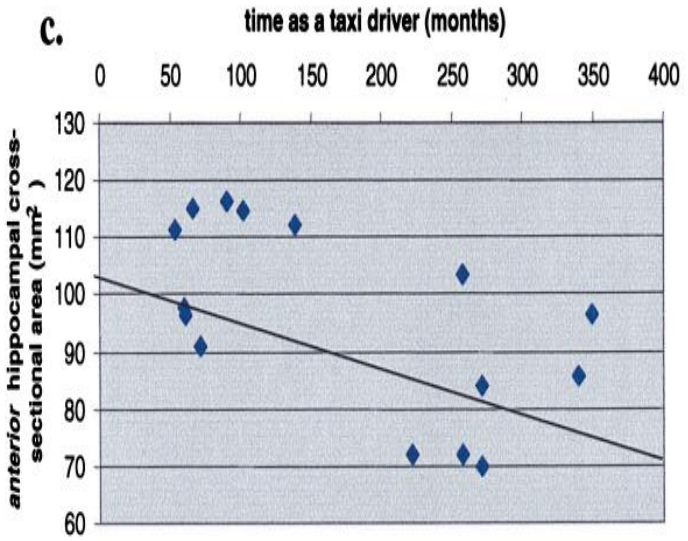
Draganski et al., 2004

Brain Plasticity

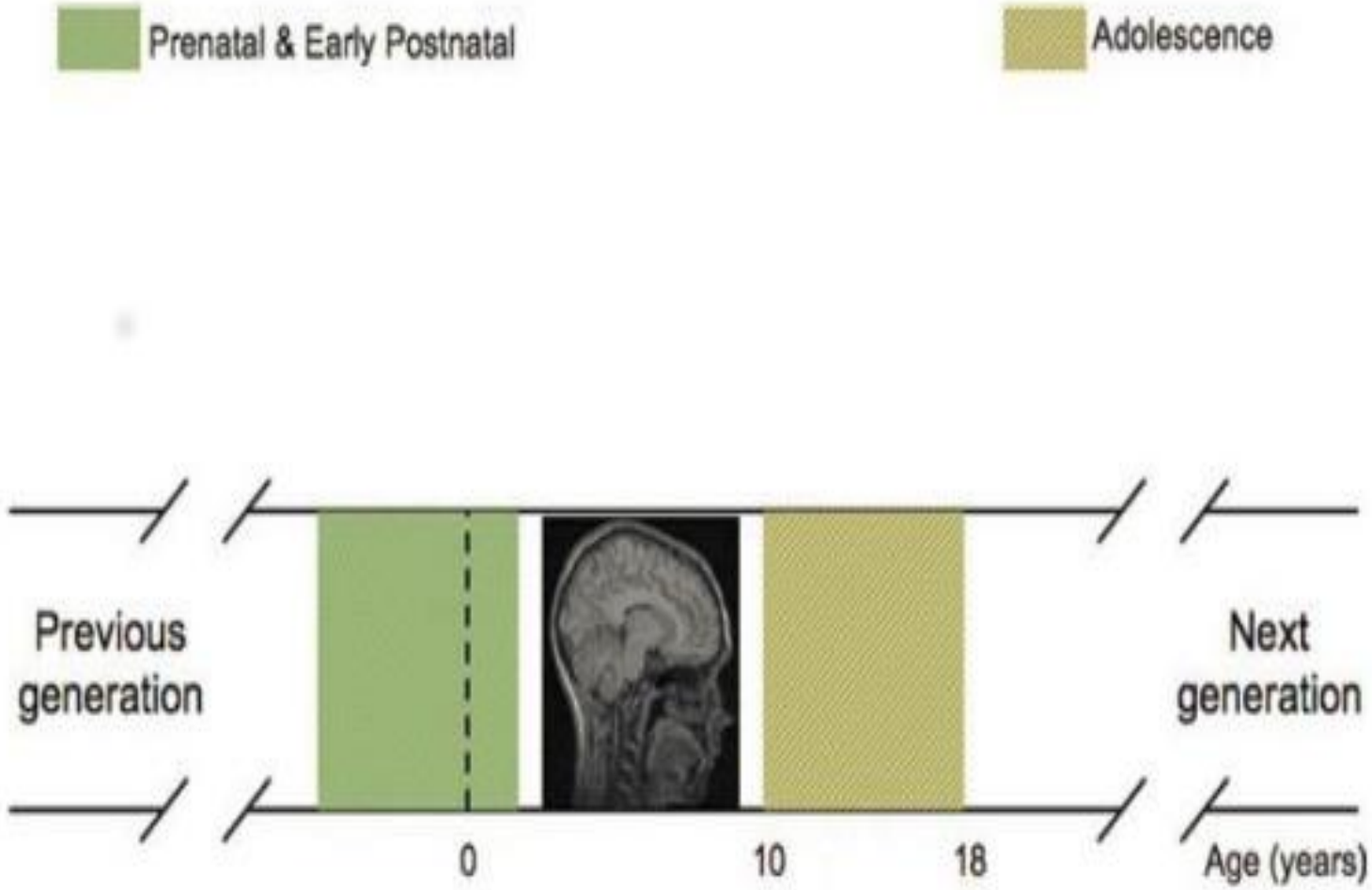




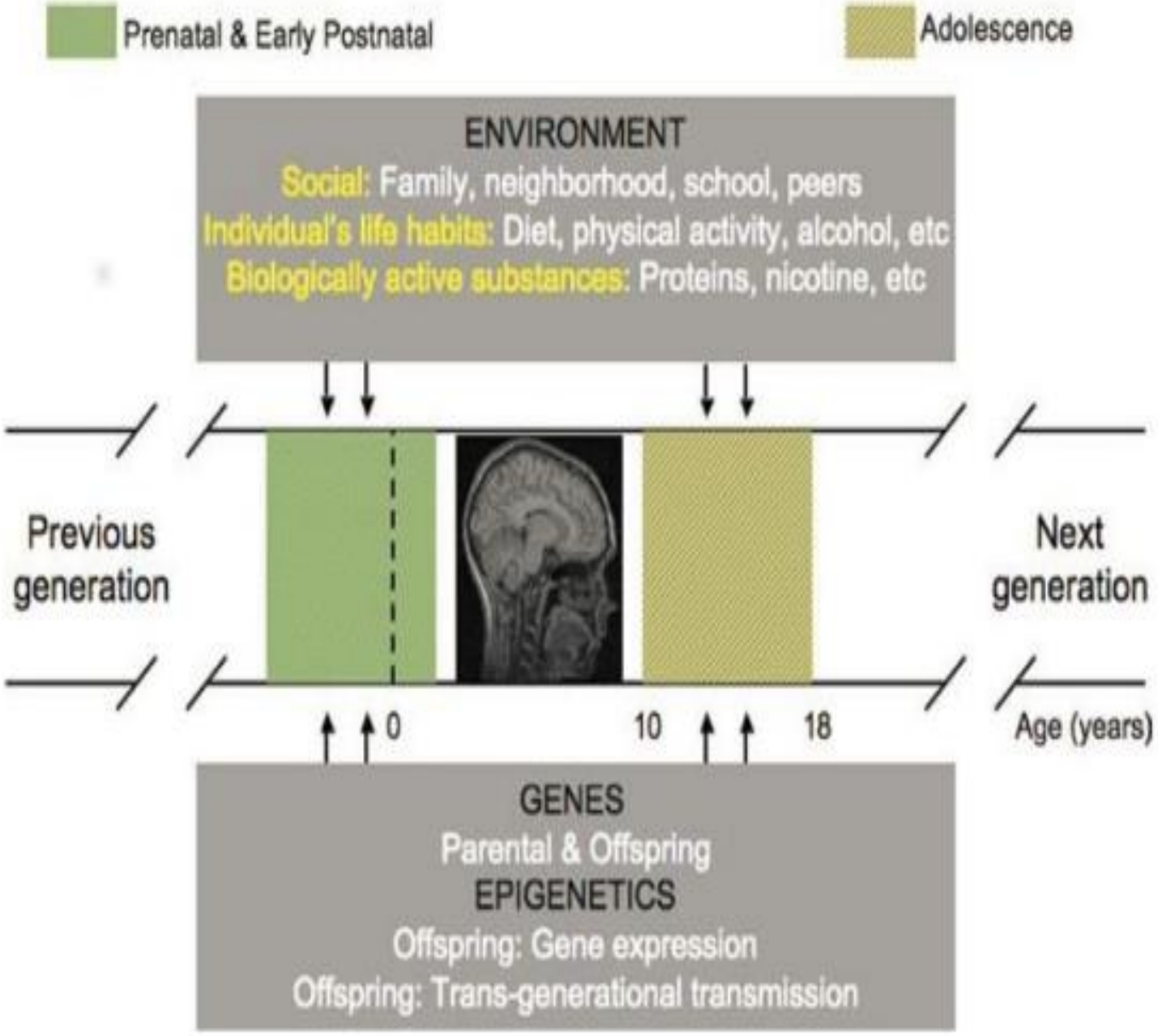




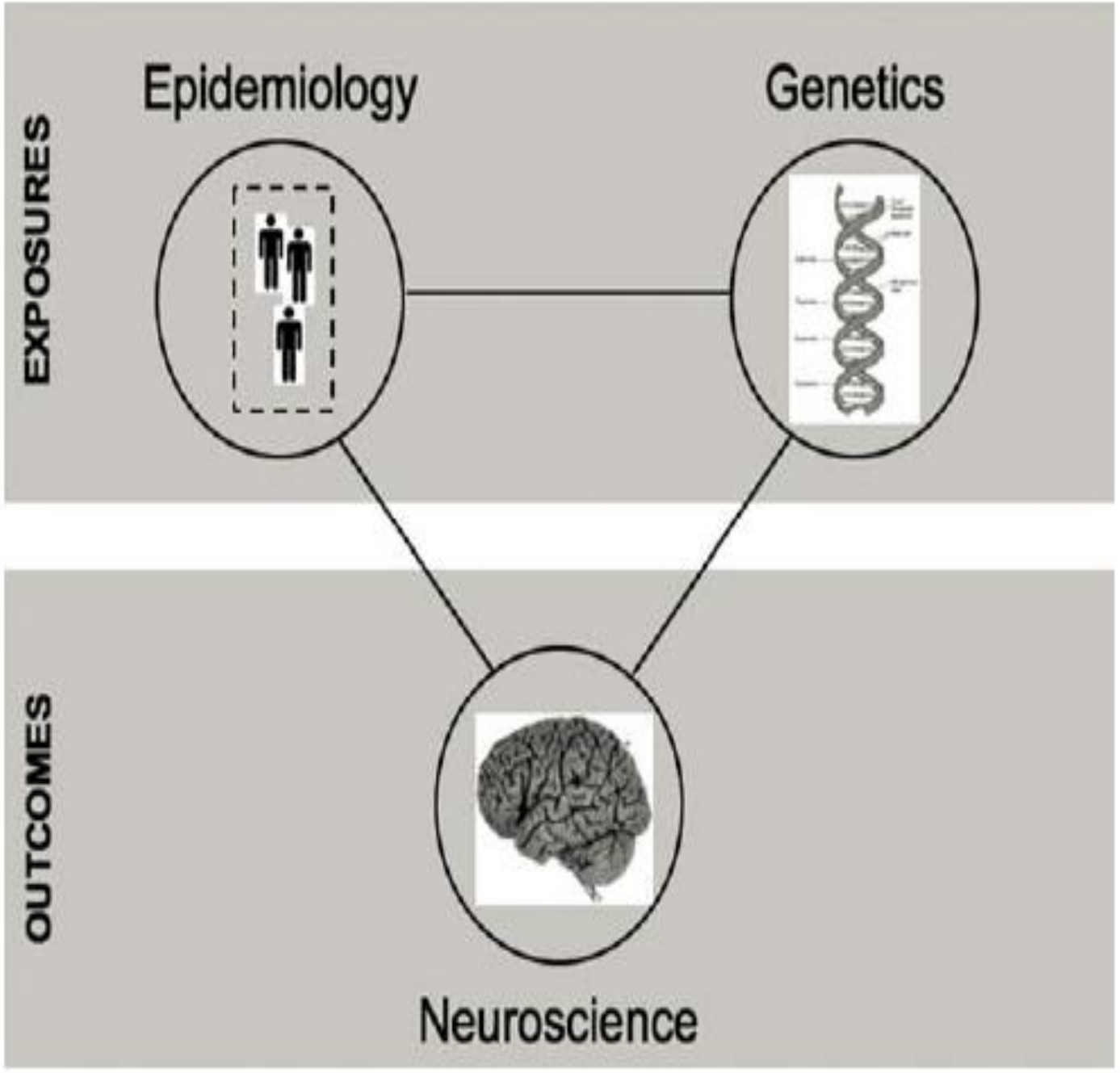
Maguire et al., 2000


Prenatal & Early Postnatal
Adolescence
Previous generation
Next generation
0
10
18
Age (years)

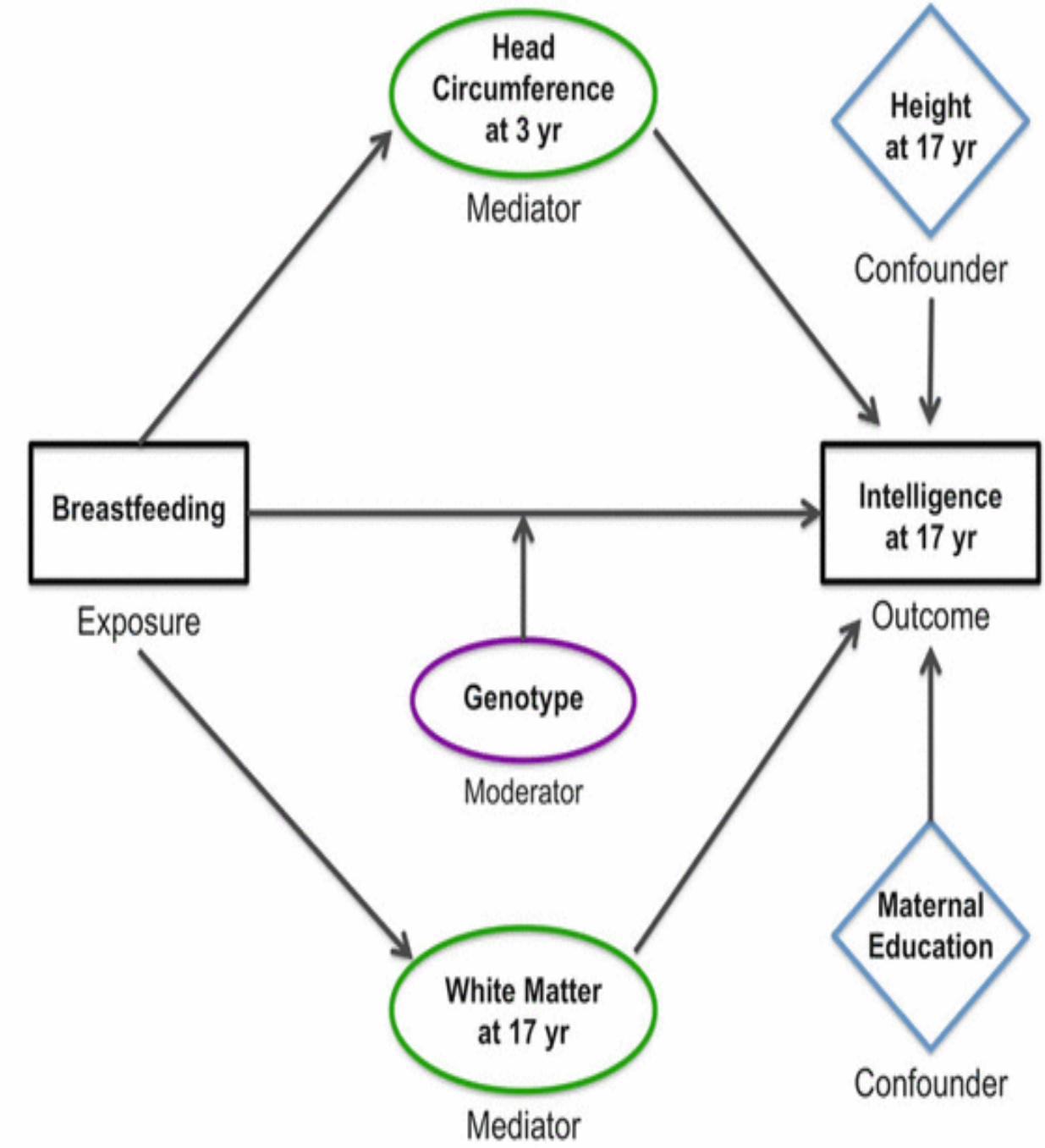
Paus, 2010


Prenatal & Early Postnatal
Adolescence
ENVIRONMENT
Social: Family, neighborhood, school, peers
Individual's life habits: Diet, physical activity, alcohol, etc
Biologically active substances: Proteins, nicotine, etc
Previous generation
Next generation
0
10
18
Age (years)
GENES
Parental & Offspring
EPIGENETICS
Offspring: Gene expression
Offspring: Trans-generational transmission

Paus, 2010

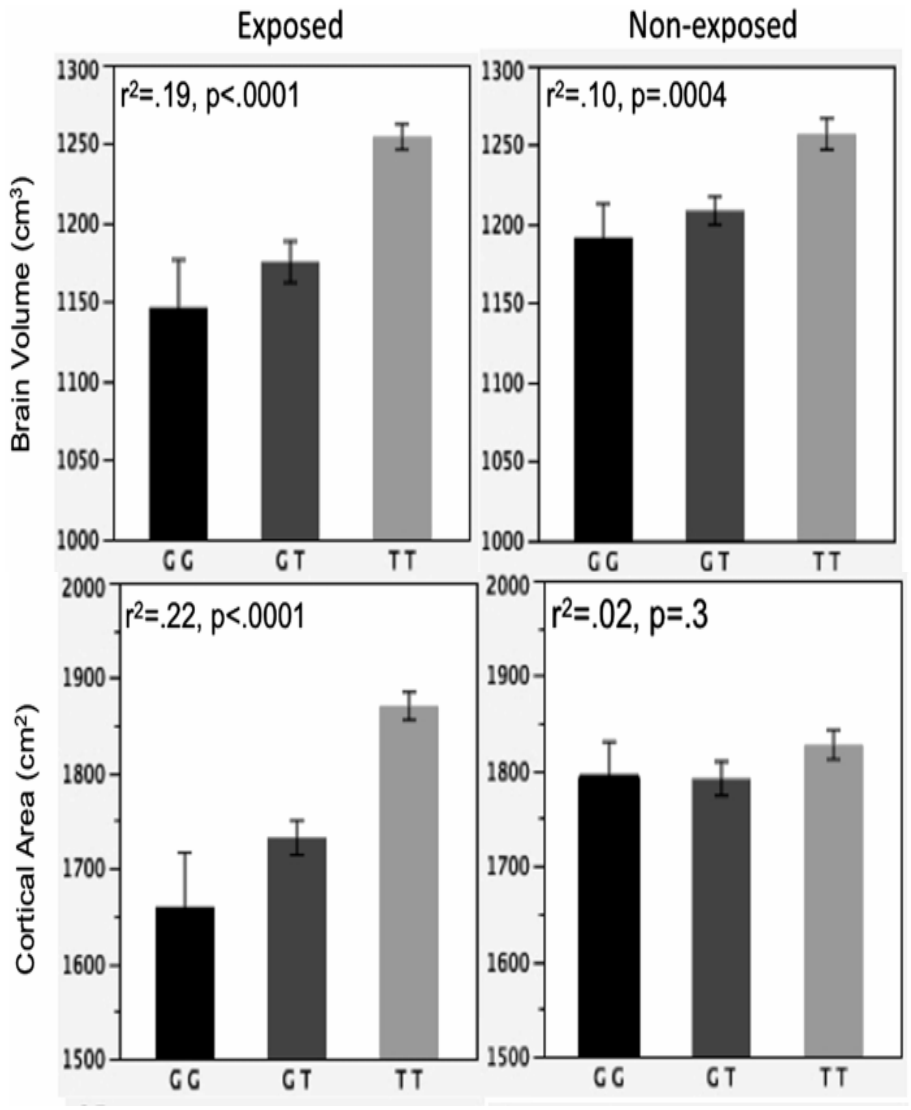


Paus, 2010


Head Circumference at 3 yr
Mediator
Height at 17 yr
Confounder
Breastfeeding
Exposure
Intelligence at 17 yr
Outcome
Genotype
Moderator
White Matter at 17 yr
Mediator
Maternal Education
Confounder

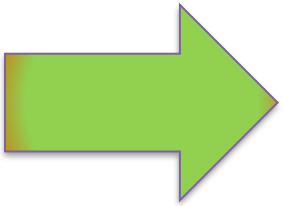
Paus, 2013

Brain Development during Adolescence



rs 716890 of KCTD8 gene

Paus et al., 2012



Medicine Today

- reactive
- one-size-fits-all model of care

Personalized Medicine

- predictive/preventive
- patient centric model of care

Toronto Trans-generational Brain and Body Centre

How environment and genes shape human brain & body across generations and cultures

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Home ▸ National and International Brain & Body Studies

National and International Brain & Body Studies

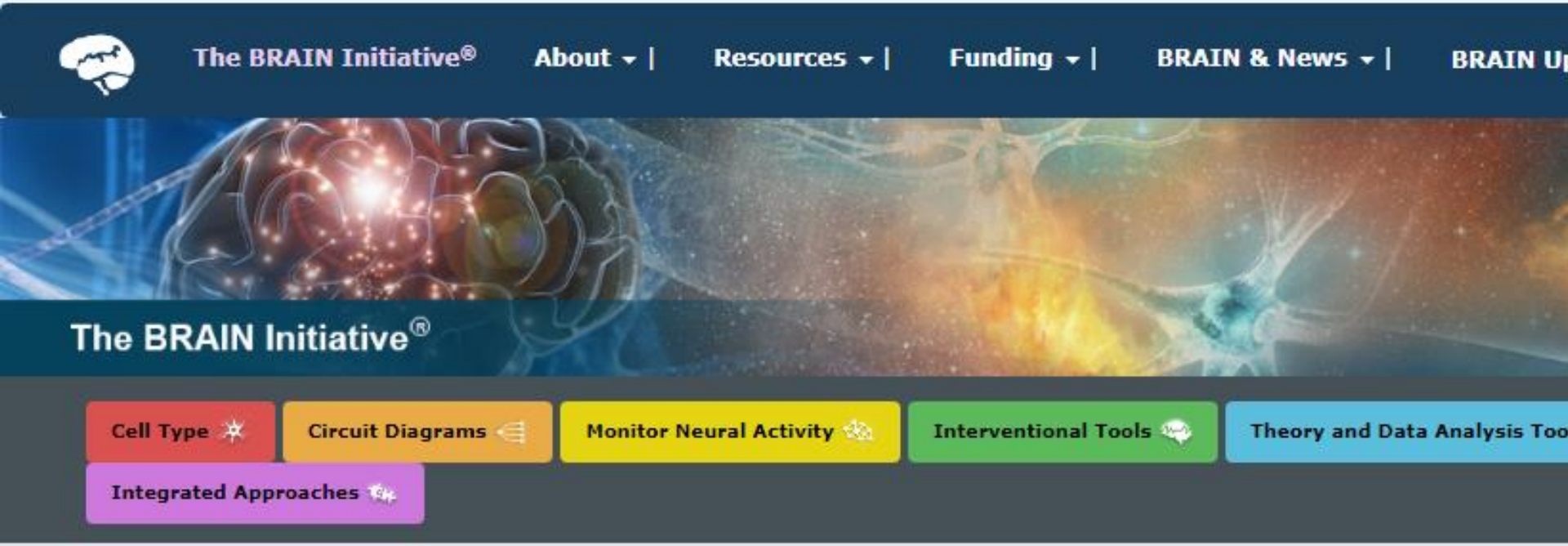
Saguenay Youth Study

IMAGEN

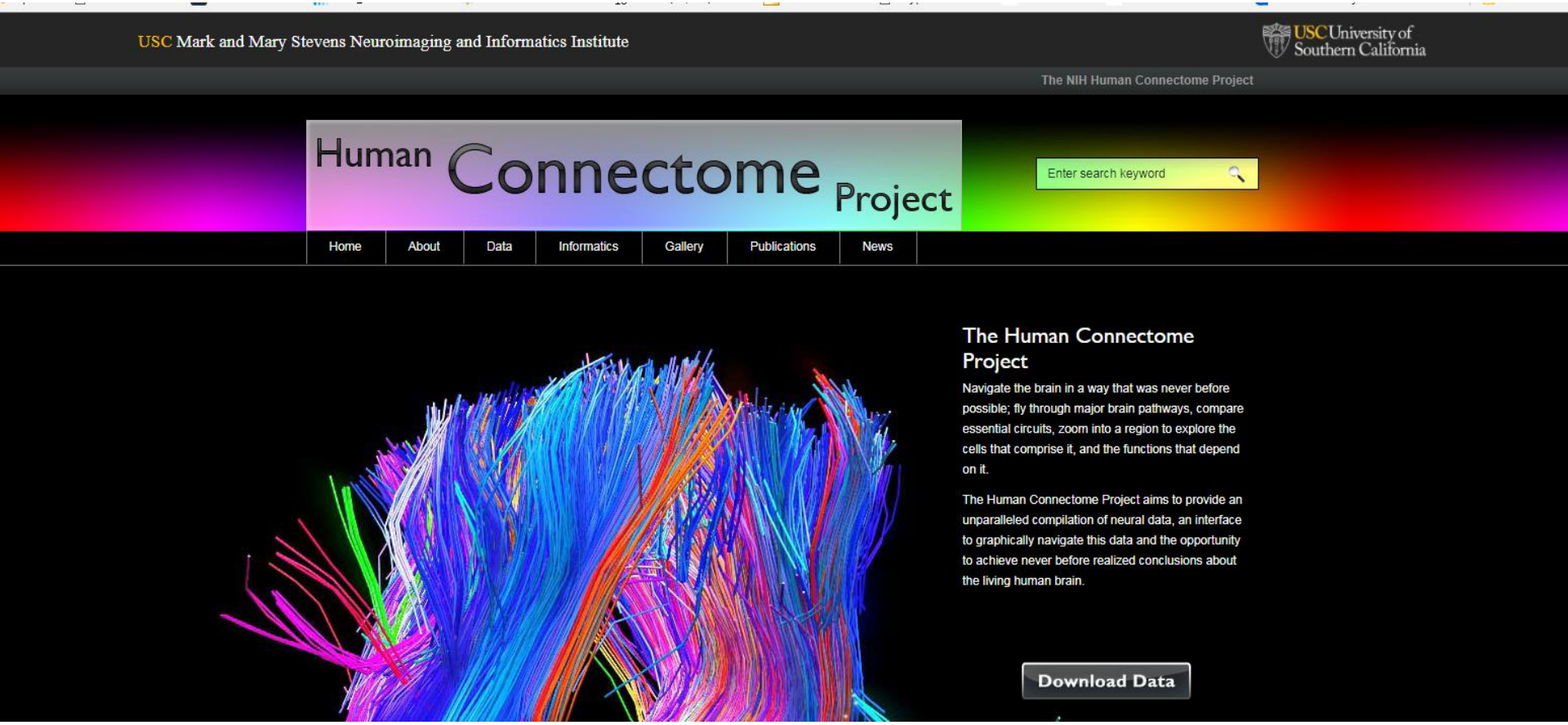
Oulu/Lapland, Finland

Avon Longitudinal Study of Parents and Children

Learning to prevent and thrive!



- Announced by Barack Obama in spring 2013
- BRAIN 2025: A Scientific Vision – first half to design tools and technology, second half to use them to make fundamental discoveries about how brain circuits work and what goes wrong in disease https://www.youtube.com/watch?v=1T5q9NSa3kM



https://www.youtube.com/watch?v=i2W570VgV6I

HEALTHY ADULT CONNECTOMES

The Human Connectome Project (HCP) has tackled one of the great scientific challenges of the 21st century: mapping the human brain, aiming to connect its structure to function and behavior.

HCP Young Adult

PI: Kamil Ugurbil, David Van Essen

- 1200 Subjects, Age 22-35
- 3T MR, 7T MR, MEG
- Washington U. in Saint Louis, U. of Minnesota, U. of Oxford, Saint Louis U., Indiana U., U. d'Annunzio, Ernst Strungmann Institute, Warwick U., Radboud U. Nijmegen, U. of California at Berkeley

Get Data

Current Data Releases (All Data Releases)

Jul 21, 2017: S1200 Extensively Processed fMRI Data

Mar 01, 2017: 1200 Subjects Data Release

LIFESPAN CONNECTOME DATA

HCP Lifespan Projects are acquiring and sharing multimodal imaging data acquired across the lifespan, in four age groups (prenatal, 0-5, 6-21, and 36-100+). The scanning protocols are similar to those for the WU-Minn Young Adult HCP, except shorter in duration.

Learn More

HCP Aging

PI: Beau Ances, Susan Bookheimer, Randy Buckner, David Salat, Stephen Smith, Melissa Terpstra, Kamil Ugurbil, David Van Essen, Roger Woods

- 1200 Subjects, Age 36-100+
- 3T MRI
- Washington University, University of Minnesota, Massachusetts General Hospital, Harvard University, University of California Los Angeles, Oxford University

Info

Recent News (All Study News)

Nov 13, 2017: HCP Aging Releases Task fMRI Scripts

HCP Development

PI: Deanna Barch, Susan Bookheimer, Randy Buckner, Mirella Dapretto, Stephen Smith, Leah Somerville, Kathleen Thomas, David Van Essen, Essa Yacoub

- 1350 Subjects, Age 5-21
- 3T MRI
- Washington University, University of Minnesota, University of California at Los Angeles, Harvard University, Oxford University

Info

Recent News (All Study News)

Nov 13, 2017: HCP Development Releases Task fMRI Scripts

Lifespan Baby Connectome Project

PI: Jed Elison, Weili Lin

- 500 Subjects, Age 0-5
- 3T MR
- University of North Carolina, University of Minnesota

Info

Lifespan Developing Human Connectome Project

PI: David Edwards, Jo Hajnal, Daniel Rueckert, Stephen Smith

- 1500 Subjects, Age 20-44 weeks post-conception
- MR
- King's College London, Imperial College London, Oxford University

Info

CONNECTOMES RELATED TO HUMAN DISEASE

HCP Disease studies apply HCP-style data collection protocols toward subject cohorts at risk for, or suffering from, diseases or disorders affecting the brain, with a goal of providing comparable data to healthy HCP subjects across the lifespan.

Learn More

CRHD Alzheimer's Disease Connectome Project

PI: Barbara Bendlin, Shi-Jiang Li

- 300 Subjects, Age 55-90
- 3T MRI, PET
- Medical College of Wisconsin, University of Wisconsin

Info

CRHD Amish Connectome Project

PI: Elliot Hong, Peter Kochunov

- 450 Subjects, Age 18-85
- 3T MRI
- University of Maryland

Info

CRHD Changes in Visual Cortical Connectivity Following Central Visual Field Loss

PI: Kristina Visscher

- 100 Subjects, Age 18-89
- 3T MRI, Retinal Imaging (OCT and SLO)
- University of Alabama

Info

CRHD Connectomes Related to Anxiety & Depression

PI: John Gabrieli, Susan Whitfield-Gabrieli

- 225 Subjects, Age 14-15
- 3T MRI, 7T MRI
- Massachusetts Institute of Technology, Massachusetts General Hospital, McLean Hospital, Boston University

Info

CONNECTOME SOFTWARE RELEASES

Connectome software has been developed that fully supports browsing, downloading, exploring and analyzing of HCP data. Connectome software will be downloadable as individual components with full documentation on installing and using the tools.

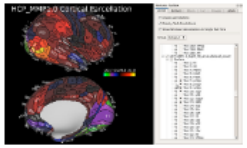
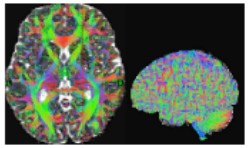
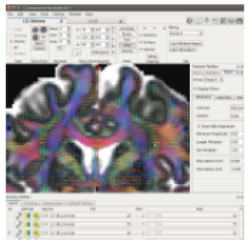
Connectome Workbench

v 1.3.2

Connectome Workbench is an open source, freely available visualization and discovery tool used to map neuroimaging data, especially data generated by the Human Connectome Project.

Download

Screenshots

Resources

>> Learn More
>> Tutorial
>> Workbench Command Documentation

Connectome MR Pipeline

v 3.4.0

The HCP Pipelines product is a set of tools (primarily, but not exclusively, shell scripts) for processing MRI images for the Human Connectome Project. Among other things, these tools implement the Minimal Preprocessing Pipeline (MPP) described in Glasser et al. 2013.

Info

HCP MEG Pipelines

v 3.0

The analysis of MEG data in the Human Connectome Project is performed using FieldTrip, a MATLAB toolbox for MEG and EEG analysis, in combination with additional analysis scripts and functions that have specifically been written for the HCP.

Info

What is Open Science?

Opening Science

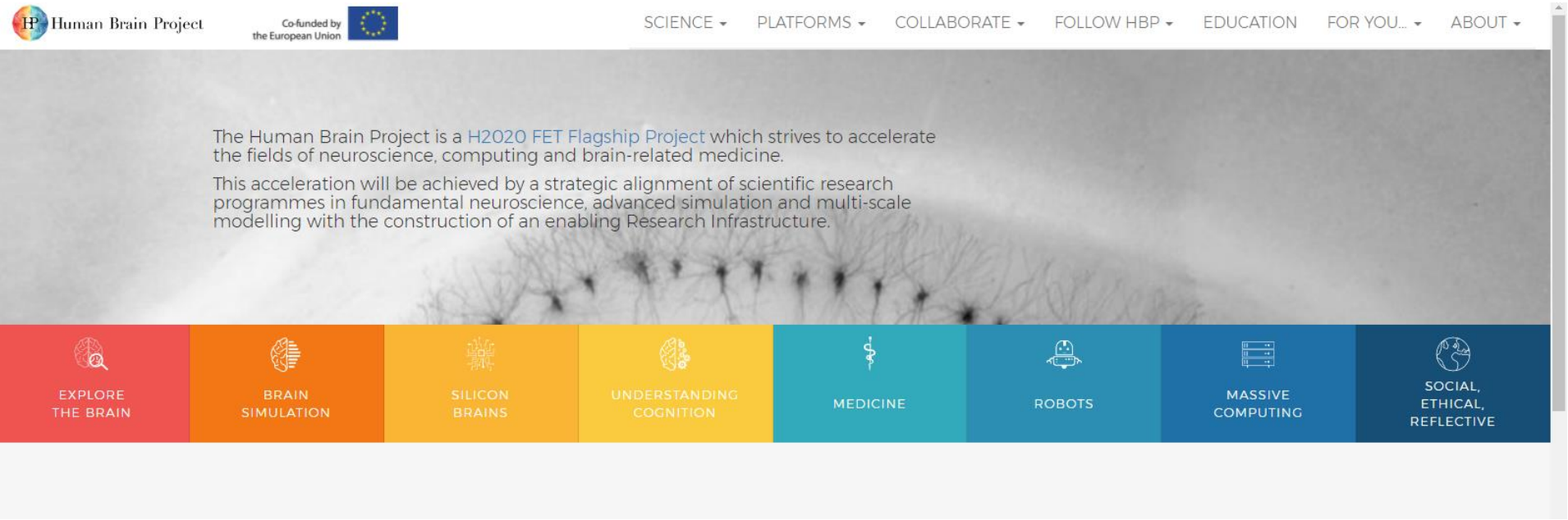
Open Science (OS) is the movement to make scientific research, data and their dissemination available to any member of an inquiring society, from professionals to citizens. It impinges on principles of scientific growth and public access including practices such as publishing open research and campaigning for open access, with the ultimate aim of making it easier to publish and communicate scientific knowledge. From development to dissemination of knowledge, several concepts belong under the umbrella term of 'Open Science'.

By broadening the principles of openness to the whole research cycle, OS fosters sharing and collaboration, bringing a systemic change to the way scientific research is done. The transition towards a comprehensive, effective open science is not an easy one; albeit challenging, a multifaceted cultural change remains essential to ensure scientific efforts have a real-world impact.

The Facilitate Open Science Training for European Research (FOSTER), a European-funded project, has developed an OS taxonomy tree in an attempt to map the open science field.

Paths to openness

Paths to OS focus on its value in improving research quality and transparency, the public ownership of science, data and resource sharing, and the policies to put in place to support the EU in this scientific revolution. We are heading for an increased OS policy: new journals with contemporary, innovative editorial formats, more effective data mining and plagiarism detection tools, embracing of best practices and ethics, improved data management, sharing practices, and social sharing.

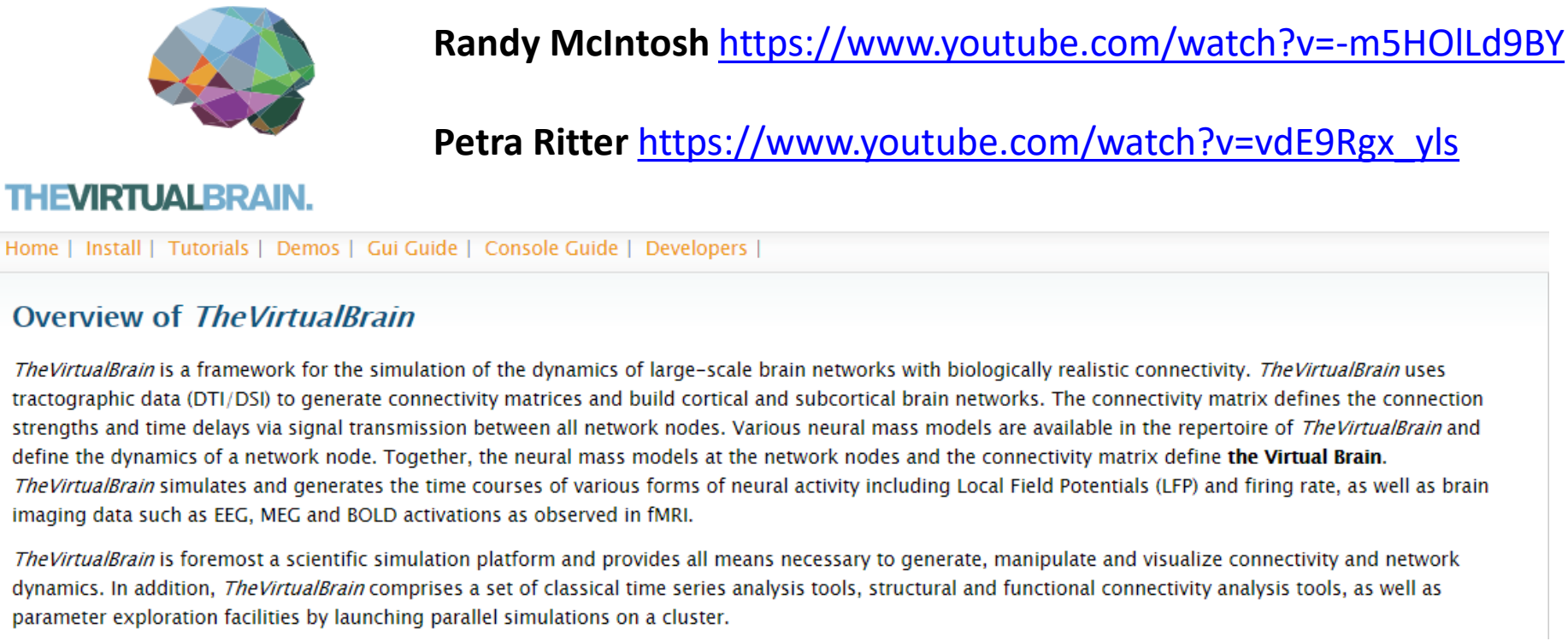


https://www.youtube.com/watch?v=JqMpGrM5ECo
https://www.youtube.com/watch?v=hm4XK02dFlU

Intro https://www.thevirtualbrain.org/tvb/zwei/home#

Randy McIntosh https://www.youtube.com/watch?v=-m5HOlLd9BY

Petra Ritter https://www.youtube.com/watch?v=vdE9Rgx_yls



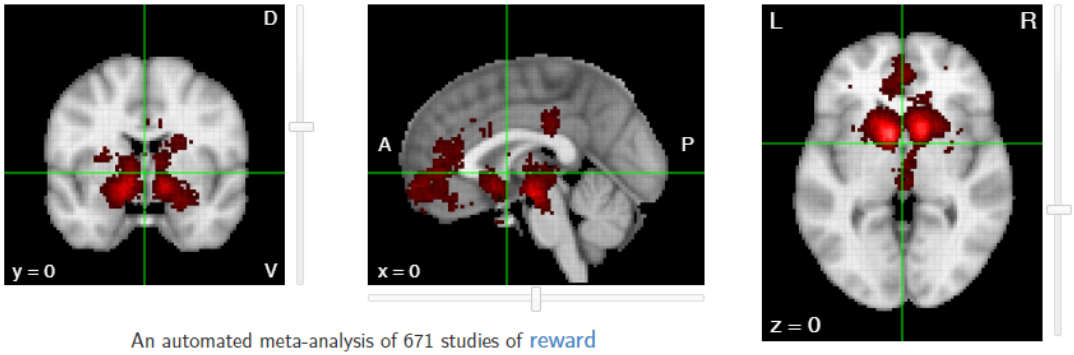
- Aims to create a large-scale neural simulation
- Our big vision is for future treatments to be tested on a patient's digital doppelganger.
- By entering data from an individual patient into the model, operators can produce personalized brain models.
- 'The Virtual Brain' will ensure access to a validated, well-documented software, thus avoiding a situation in which individual laboratories develop and work with their own in-house solutions.

Neurosynth.org (beta) Home Meta-analyses Studies Locations Decoder Code FAQs Sign in

neurosynth.org

Neurosynth is a platform for large-scale, automated synthesis of functional magnetic resonance imaging (fMRI) data.

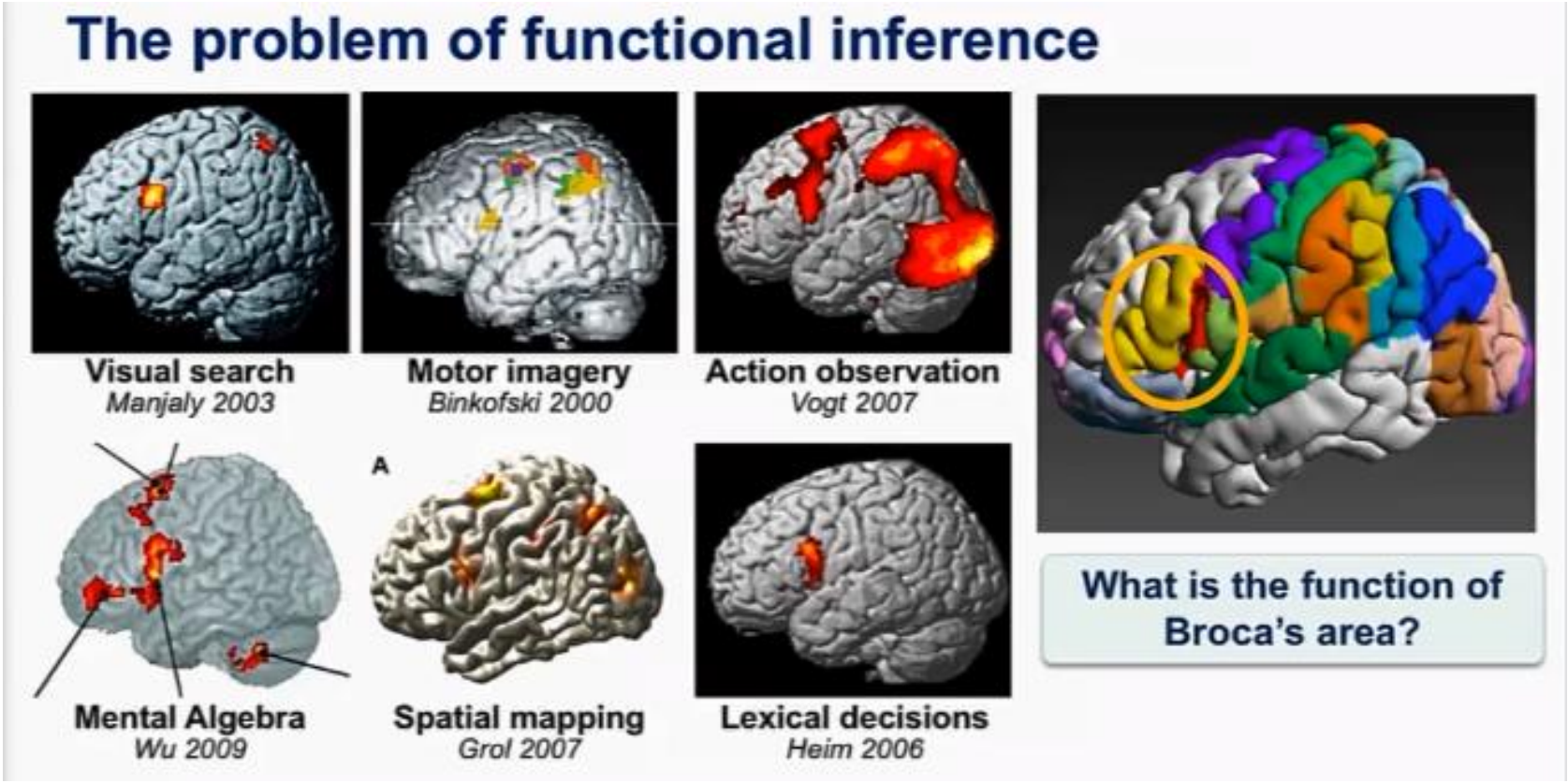
It takes thousands of published articles reporting the results of fMRI studies, chews on them for a bit, and then spits out images that look like this:



An automated meta-analysis of 671 studies of reward

http://www.neurosynth.org/locations/

Functional Inference



Article | 18 September 2017

Hypothalamic control of female aggression

Article | 18 September 2017

Dopamine induces soluble α-synuclein oligomers and nigrostriatal degeneration

Dopamine has long been thought to contribute to neurodegeneration in Parkinson's disease. The authors show that... show more

Danielle E Mor, Elpida Tsika [...] Harry Ischiropoulos

Announcement

Gut-brain axis web collection

A selection of articles covering key aspects of the gut–brain axis including immune, neuroendocrine and neural... show more

Current Issue | September 2017

NeuroImage

ISSN: 1053-8119

› Supports Open Access

Editor-in-Chief: Peter Bandettini

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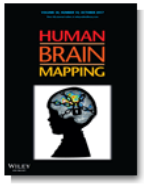
HUMAN BRAIN MAPPING

Human Brain Mapping



Edited By: Peter T. Fox, Jack L. Lancaster, and Gary Egan

Impact Factor: 4.53

ISI Journal Citation Reports © Ranking: 2016: 2/14 (Neuroimaging); 12/126 (Radiology Nuclear Medicine & Medical Imaging); 57/258 (Neurosciences)

Online ISSN: 1097-0193

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Volume 38, Issue 6

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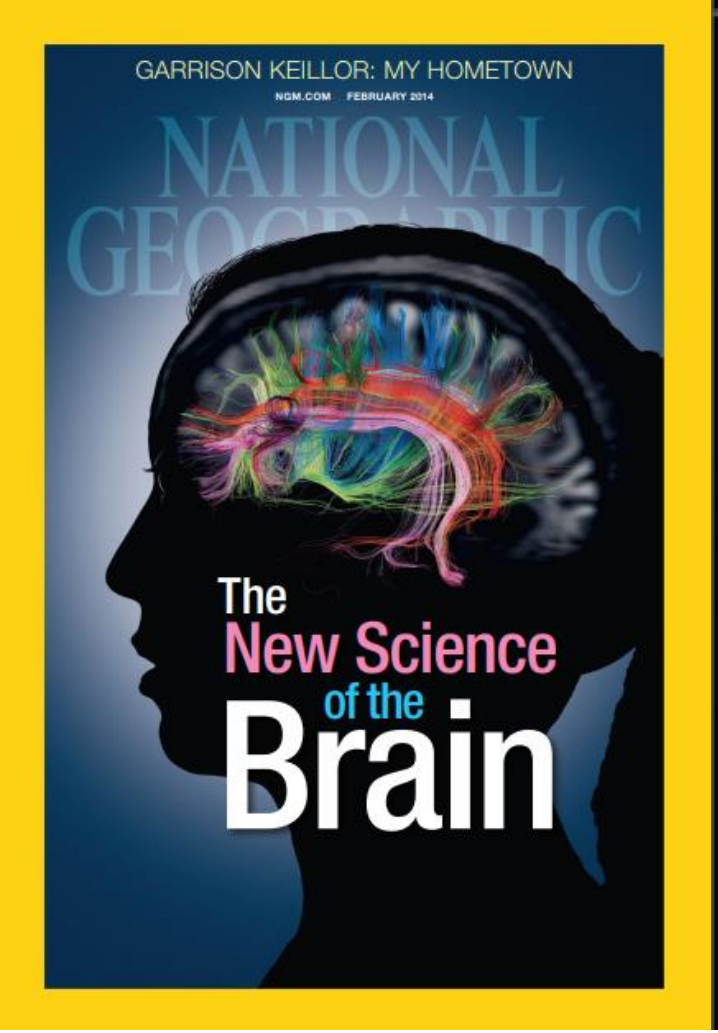

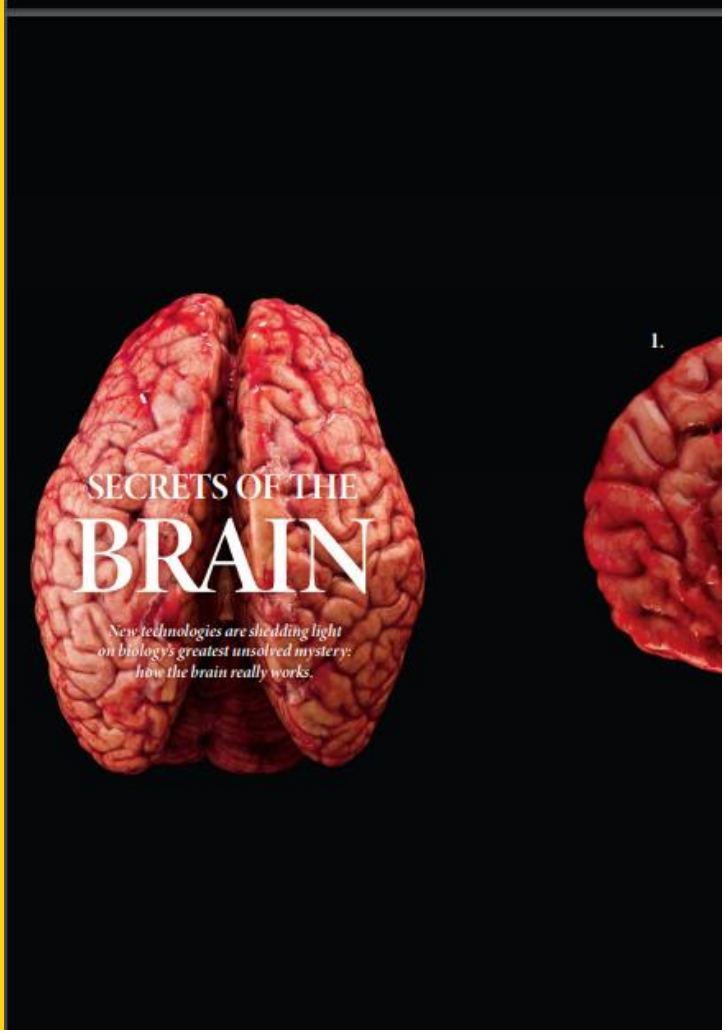

- New technologies are shedding light on biology's greatest unsolved mystery: how the brain really works.
- Try to volunteer for a study and wonder about the neuroscience research at your institute of choice.

Brain and Mind Research

Neuroscience programme aims to develop a unique workplace in the European context reaching from basic to transitional research of central nervous system; from animal studies to clinical, social and behavioural research of healthy and diseased brain, in particular dementia, epilepsy, movement disorders, schizofrenia, depression pain…. are studied with a core facility enabling most advanced structural, functional and metabolic brain mapping.

Research Groups

- Behavioural and Social Neuroscience - Milan Brázdil →
- Applied Neuroscience - Irena Rektorová →
- Multi-modal and Functional Neuroimaging - Ivan Rektor →

Clinical Studies

- Depression
- Bipolar
- Schizophrenia
- Healthy Controls

- Biomarkers (RDoC; focus on shared traits)

Cohort Studies

- Project VULDE, neuro-physio follow-up of ELSPAC

- Early biomarkers (focus on these traits)

Experimental Studies

- Sleep deprivation and its effects on axonal transport

- Origins and underlying mechanisms

Intervention -Prevention Studies

- Preventing mental illness in adolescents born preterm

- Prevention

Collaboration with Harvard Medical School

Marie Curie Project (FP7-2013-IEF)

Collaboration with Child Mind Institute and UofT

Possible European Project (H2020-Health)