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The Brain 10 Years Later

Daniel A. Drubach, MD
Departments of Neurology and Psychiatry
Mayo Clinic and College of Medicine

- Brain Structure
- Functional Systems
- Perpetual change
- Perception
- Social Networks
- Default and Attentional States
- Sleep and Dreaming
- Universal Human Functions

1. Brain Structure

frontiers
IN HUMAN NEUROSCIENCE

REVIEW ARTICLE

* This article is part of a Research Topic

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Front. Hum. Neurosci., 09 November 2009 | doi: 10.3389/neuro.09.031.2009

The human brain in numbers: a linearly scaled-up primate brain

Suzana Herculano-Houzel*

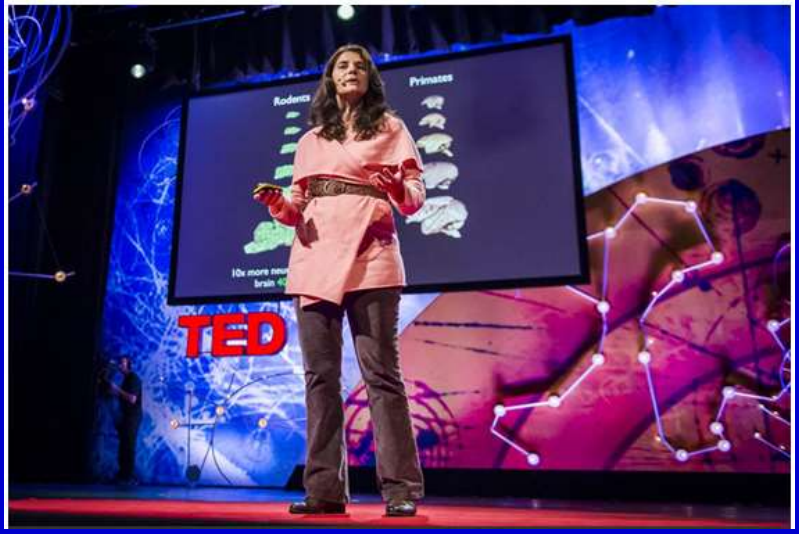
Instituto de Ciências Biomédicas, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brasil

Brain neurons

86	human[30]
33	gorilla[33]
23	elephant[32]
21	false killer whale[3]
6	macaque[28]
1	marmoset[28]

Lessons from brain soup: Suzana Herculano-Houzel at TEDGlobal 2013

Posted by: Kate Torgovnick
June 12, 2013 at 12:15 pm EDT

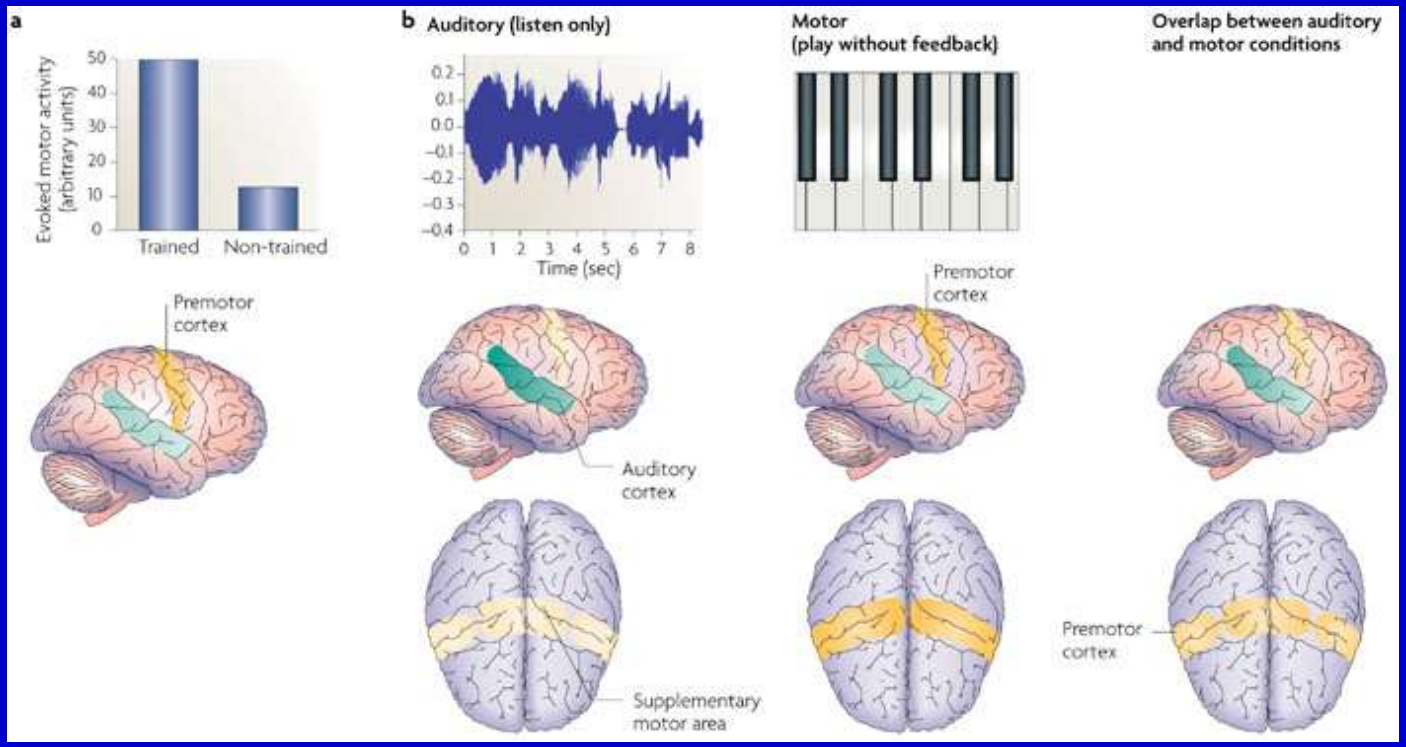


The Brain

- Weights approximately 3 pounds
- A “universe” containing
  - 86 billion neurons
  - 120 billion glial cells (disputed)
  - Each neuron communicates with at least 1000 and up to 10000 other neurons simultaneously
- The brain consumes 25% of the body’s “energy budget”

2. Functional System

- The brain is organized into functional system. A system consists of the totality of neurons and other cells which ‘’associate” to perform a specific function (reading, speaking, perceiving a stimulus, aggression)
- Components of this system are widely spread throughout the brain
- Components of one system (neuron) can participate in innumerable other systems



Zatorre, et a; Nature reviews (8) 2007

3. Perpetual Change; Brain plasticity

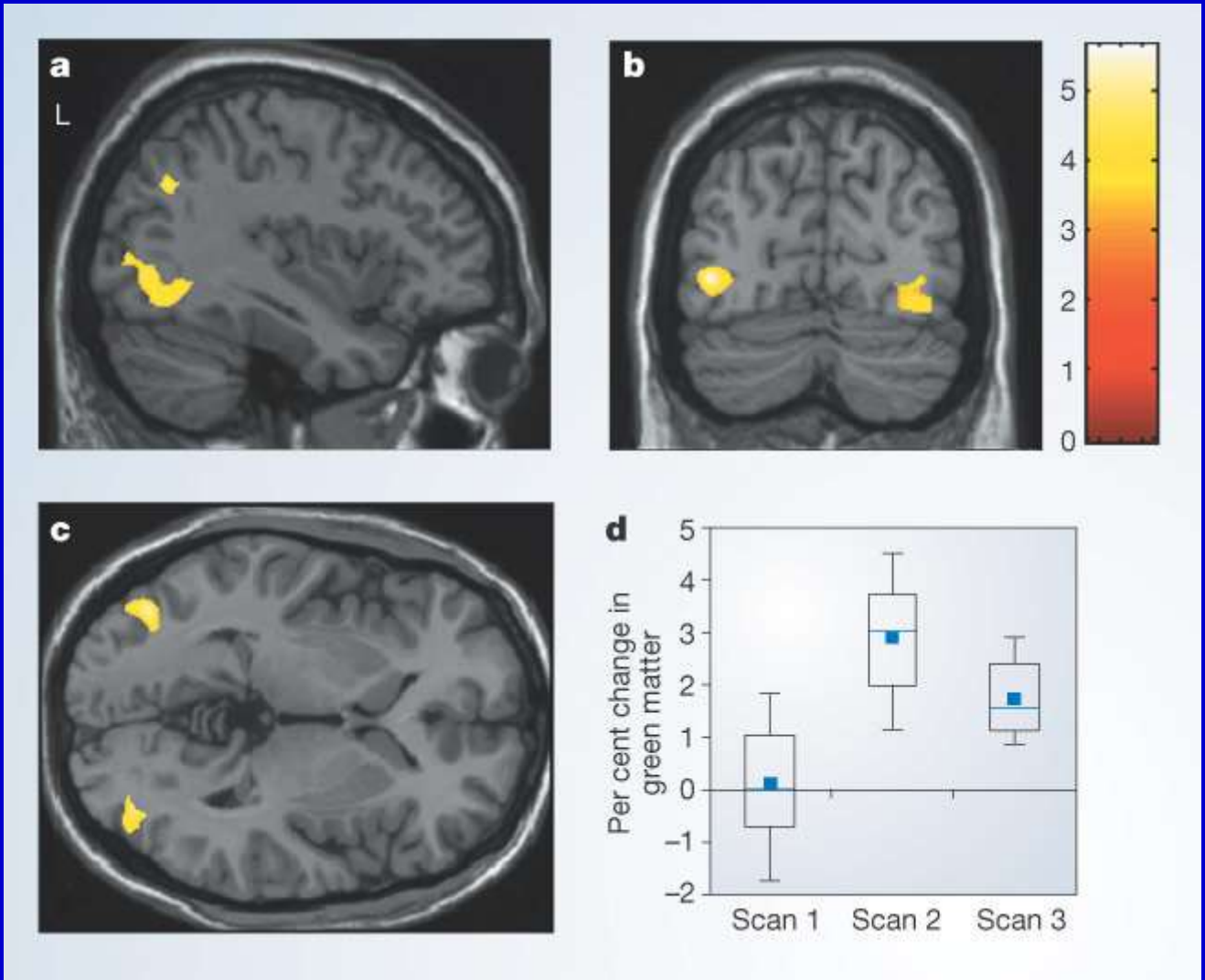
- The brain is a resilient system that is in a constant state of structural flux
- This inherent characteristic of the brain has been denominated brain plasticity
- Brain Plasticity results in a constant reorganization of neural structures with ongoing creation and elimination of neuronal networks

Purposes of Plasticity

- Fulfill a need imposed by the individual’s unique circumstances
- Plasticity allows experience, life circumstances and individual's wishes to acts as a guide, relieving the necessity to hard-wire the brain for all potential circumstances

Plasticity Drivers

- Reorganization after injury to (hopefully) maximize function
- Developmental milestones (gait, fine motor movements, language
- Experience, demands, etc.



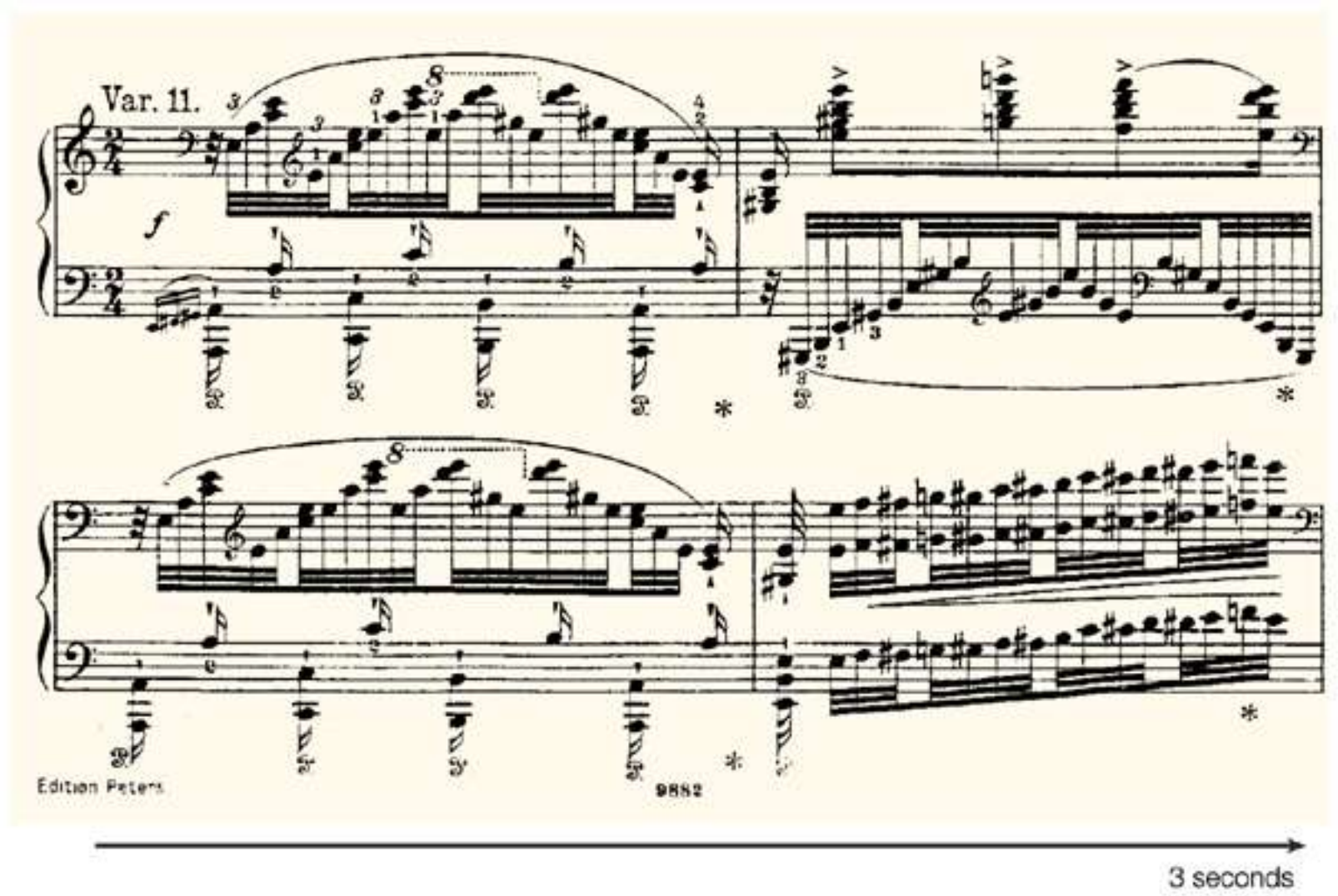
Learning to juggle

Tools for Self Creation
Plasticity Drivers

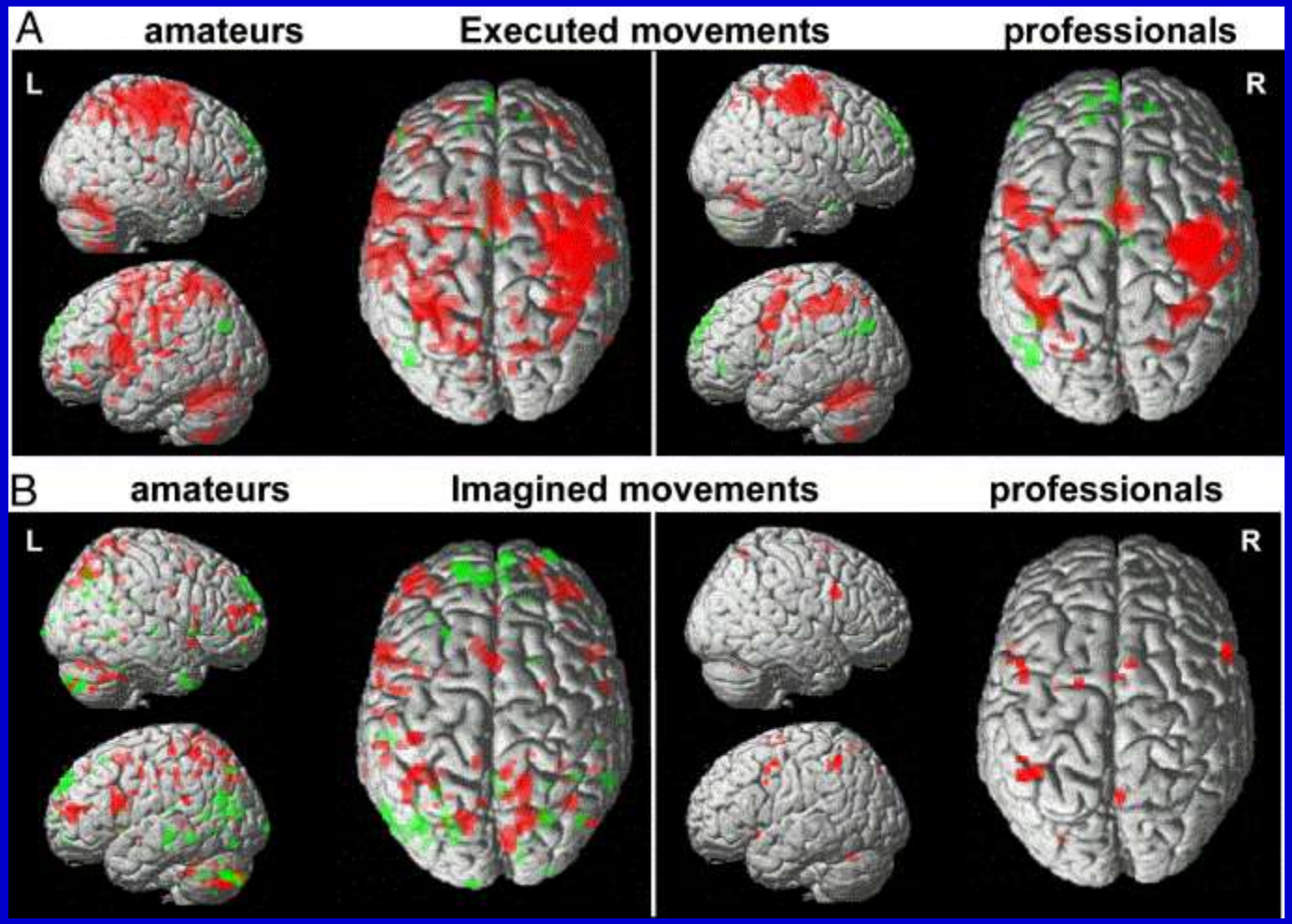
- Doing
- Perception and Exposure
- Learning
- Thought
- Imagination

Perceptual Plasticity

- Experience and learning can enlarge the “perceptual range”
- Musicians can identify more notes per minute in a musical piece than non musicians
- Artists can identify more shades of yellow than non artists
- Trained bird watchers can identify more birds in a particular area than non bird watchers'



Paganini-Etude, by Franz Liszt. 1800 notes per minute



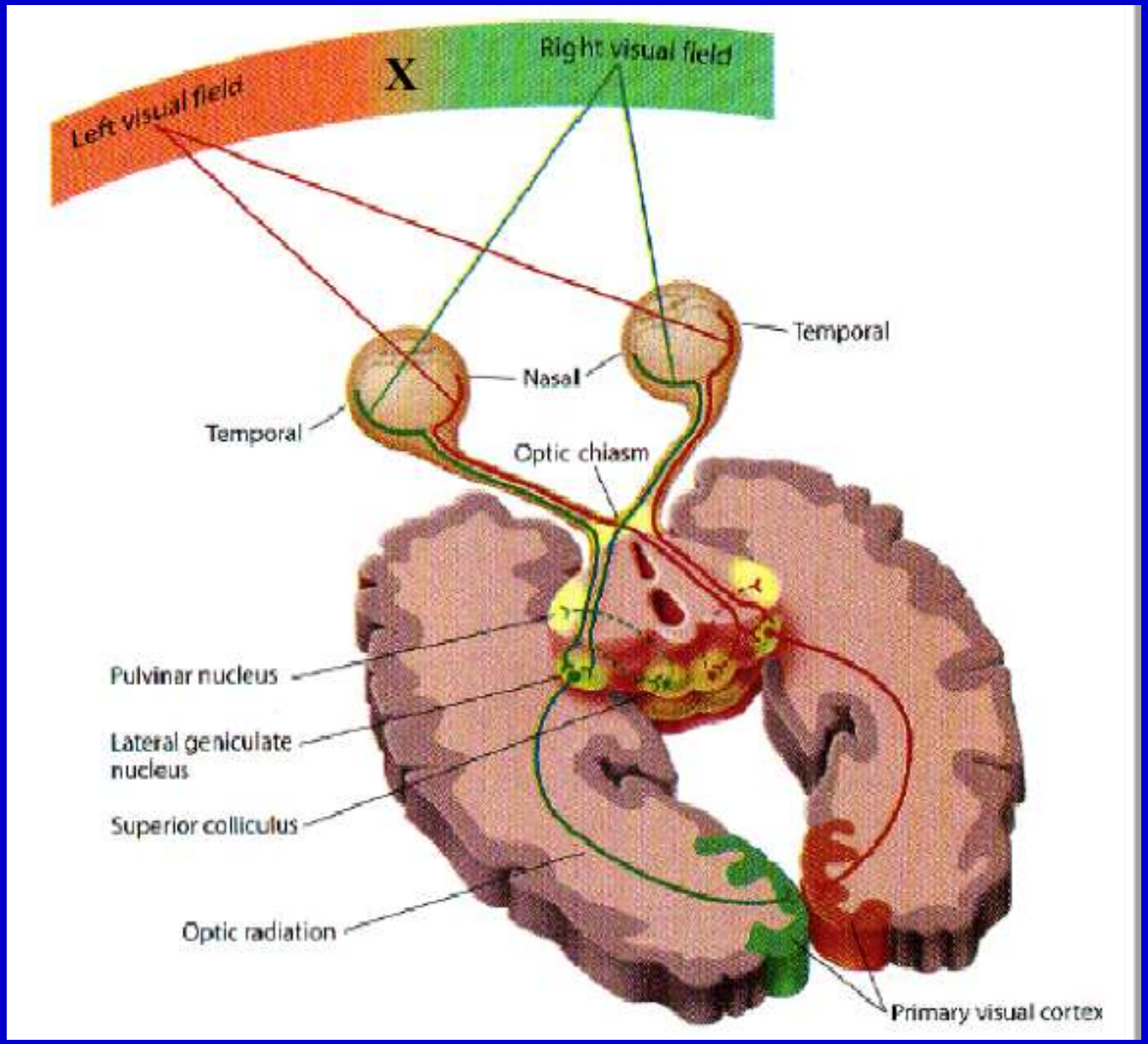
Lotze, M., et al., *The musician's brain: functional imaging of amateurs and professionals during performance and imagery.* Neuroimage, 2003. **20**(3): p. 1817-29.

3. Perception

- The process that transforms sensory information into a meaningful experience.
- Transforms
  - Sounds into a symphony
  - Light waves into sunsets
  - Tastes into gourmet experience
  - Smells into perfumes

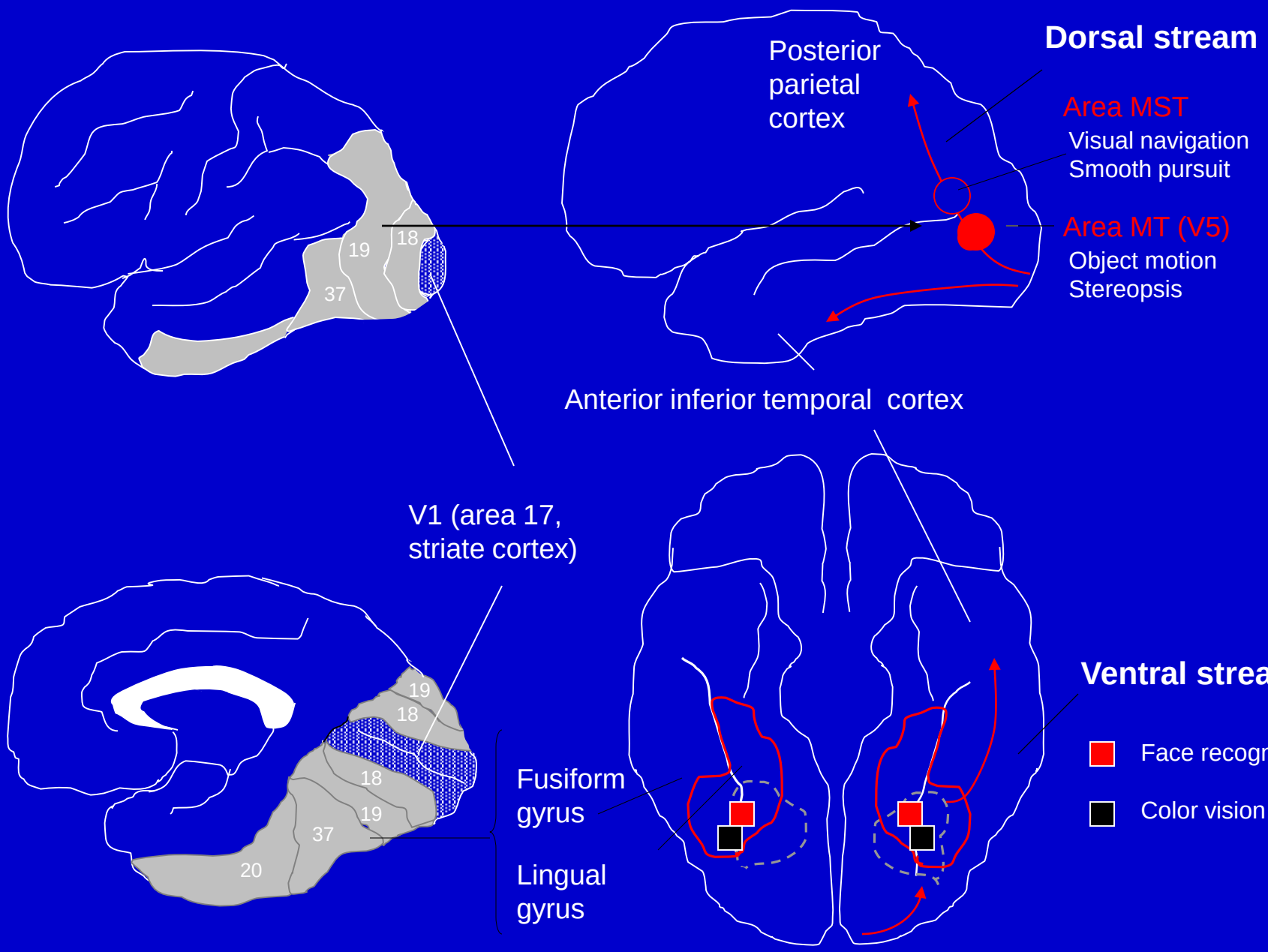
Sensorial modalities

- Vision
- Audition
- Gustation
- Olfaction
- Sensory
- “Mind”


Left visual field
X
Right visual field
Temporal
Nasal
Temporal
Optic chiasm
Pulvinar nucleus
Lateral geniculate nucleus
Superior colliculus
Optic radiation
Primary visual cortex

Steps to Perception

- Transduction of into neural impulses (performed by “sensory organs” (receptors)
- Transport of neural impulses from receptors to brain (sensory pathways)
- Transformation of neural impulses into meaningful experience
- Each of these steps takes time


Dorsal stream
Posterior parietal cortex
Area MST
Visual navigation
Smooth pursuit
Area MT (V5)
Object motion
Stereopsis
19
18
37
Anterior inferior temporal cortex
V1 (area 17, striate cortex)
19
18
18
19
37
20
Fusiform gyrus
Lingual gyrus
Ventral stream
Face recognition
Color vision

Facts about perception Perception=Object on Subject

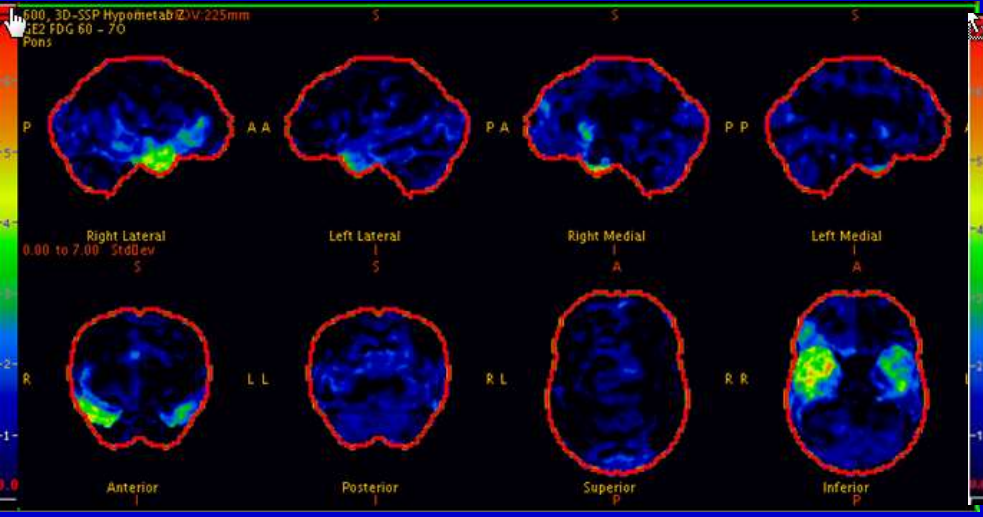
- We perceive the past, unable to perceive the present, always 500 milliseconds behind (analogous to looking at a star)
- “I have a longing, my dear sir, to catch a glimpse of things as they may have been before they show themselves to me” from Conversations with a Supplicant, by Franz Kafka

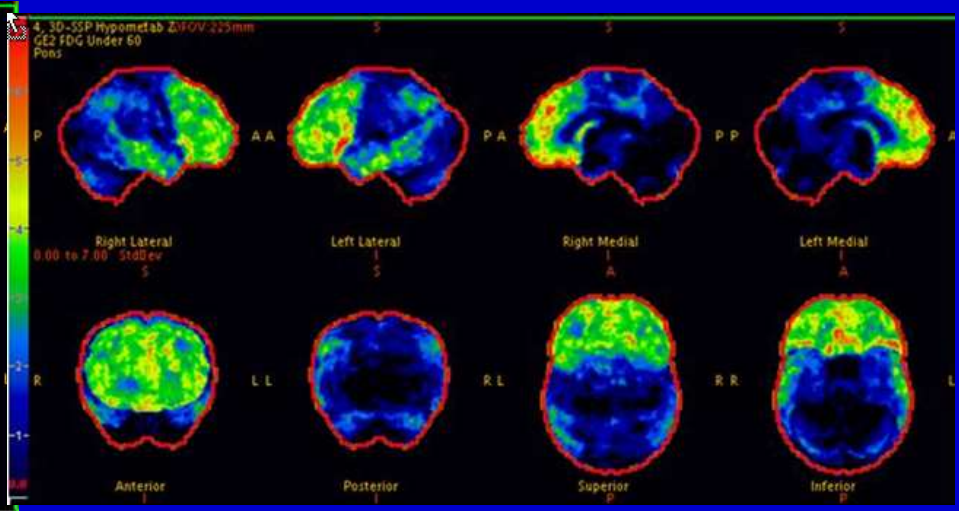
Facts about perception Perception=Object on Subject

- We perceive the past, unable to perceive the present, always 500 milliseconds behind (like looking at a star)
- There is no “objective” perception. (perception is not a reflection of a sensory stimulus but instead is its interpretation)
- There is no perceptual constancy (subject changes over time)

Perceptual Attributes

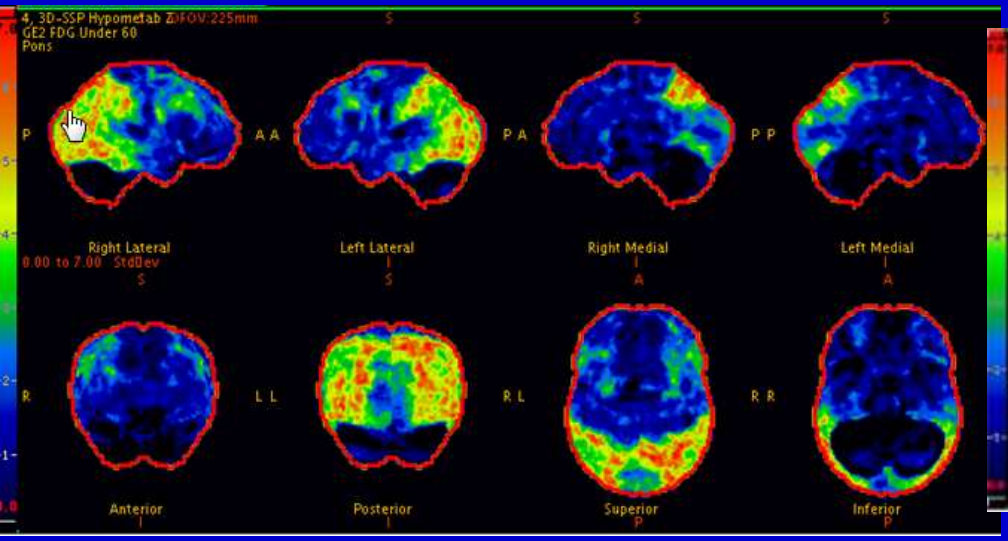
- Gnosis; what is it?
- Lexical symbol; What is it called?
- Spatial; Where is the object in relation to oneself and other objects. Is the object moving?
- Relevance; Determined by cultural factors, personal experience (genetics)

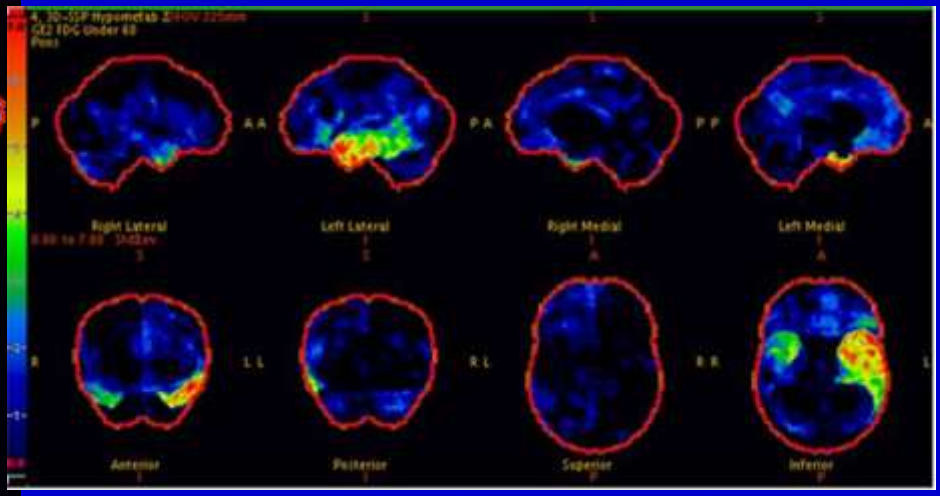




Gnosis Attribute,
Prosopagnosia

Relevance Attribute: “Indiference”,
Frontotemporal Dementia





Spatial Attribute
PCA

Lexical Attribute (PPA)

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Perceptual Binding

- Neural mechanism for unifying all areas of the brain involved in perceiving a specific object, so as to create a “wholesome” perception
- Binding occurs when there is synchronous depolarization at a specific frequency of every neuron involved in the perception of each specific attribute

Fasciculus the Stranger

- Perceptual Network A

Fasciculus the Friend

- Perceptual Network B
- Difficult (or impossible) to reverse to Network A
- He could become an enemy (Network C), but not reverse to Network A

4. Default and Salience Networks

Default Network

- Activated when we don't attend to internal or external stimulus and instead allow our mind to go "free"
- Deactivated when we attend to an internal or external stimulus

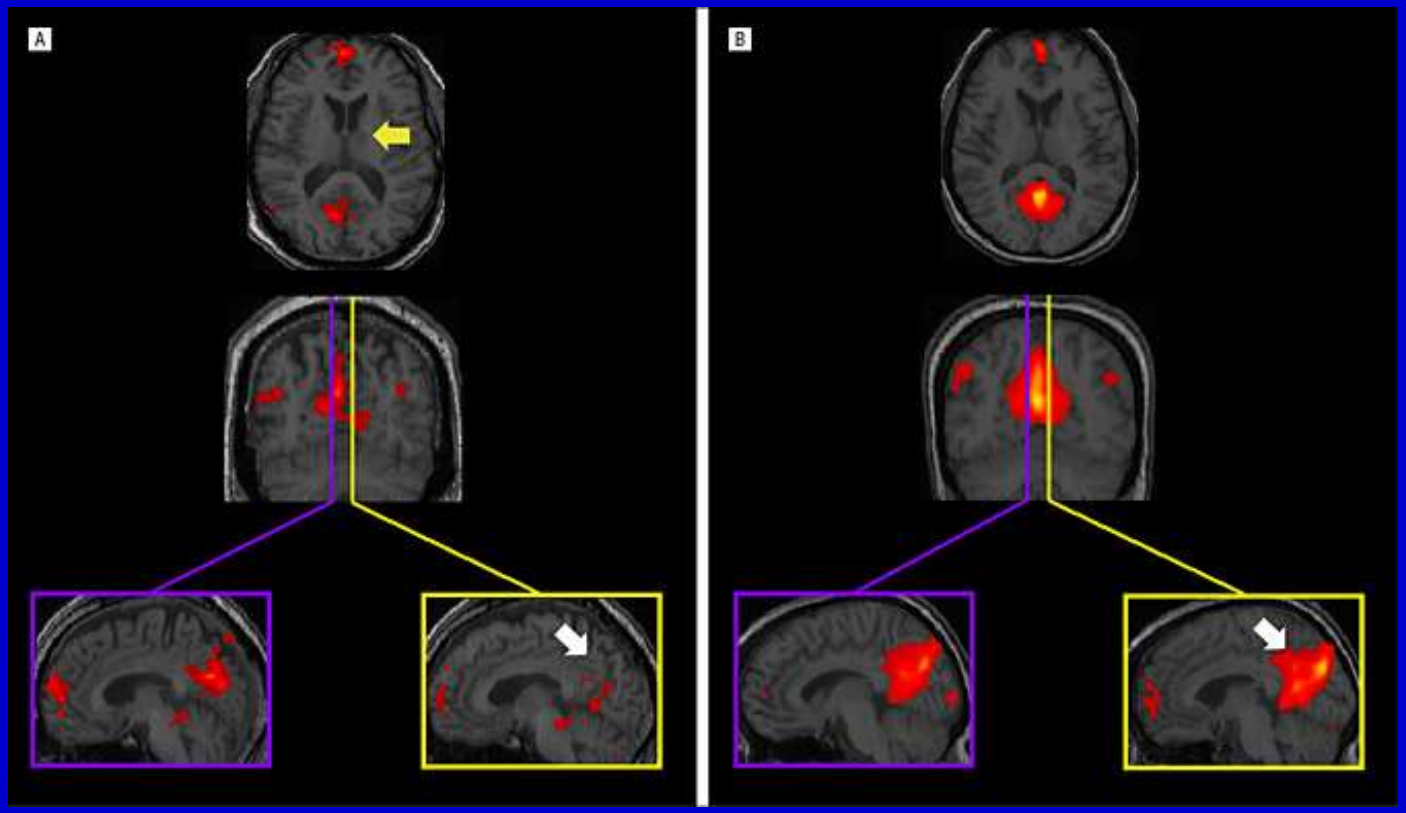
Salience Network

- Activated when we attend to an internal or external stimulus
- Deactivated when we do not attend to an external or internal stimulus

Default Mode Network

- more active during passive rest than during attention-demanding tasks.
- Interaction with the “self” rather than the external world
- active in self centered thought (planning about the future, seeing oneself in a particular situation)
- posterior cingulate cortex (PCC), medial prefrontal cortex, inferior parietal lobule, lateral temporal cortex, and hippocampal formation.

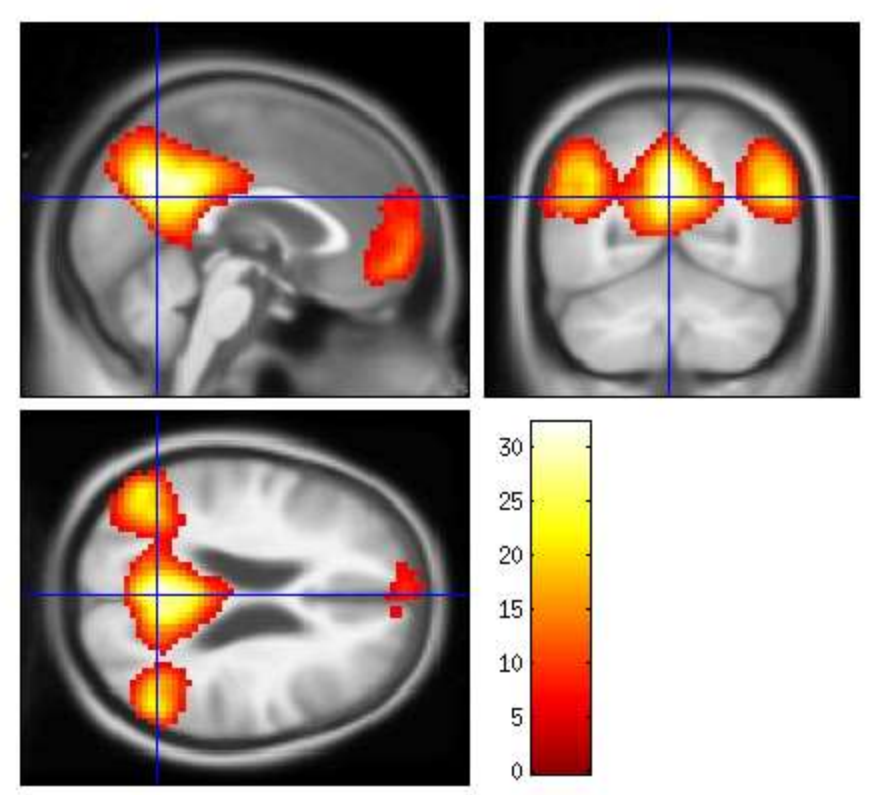
Resting-state functional magnetic resonance imaging analyzed with independent component analysis demonstrates the default mode network (DMN)



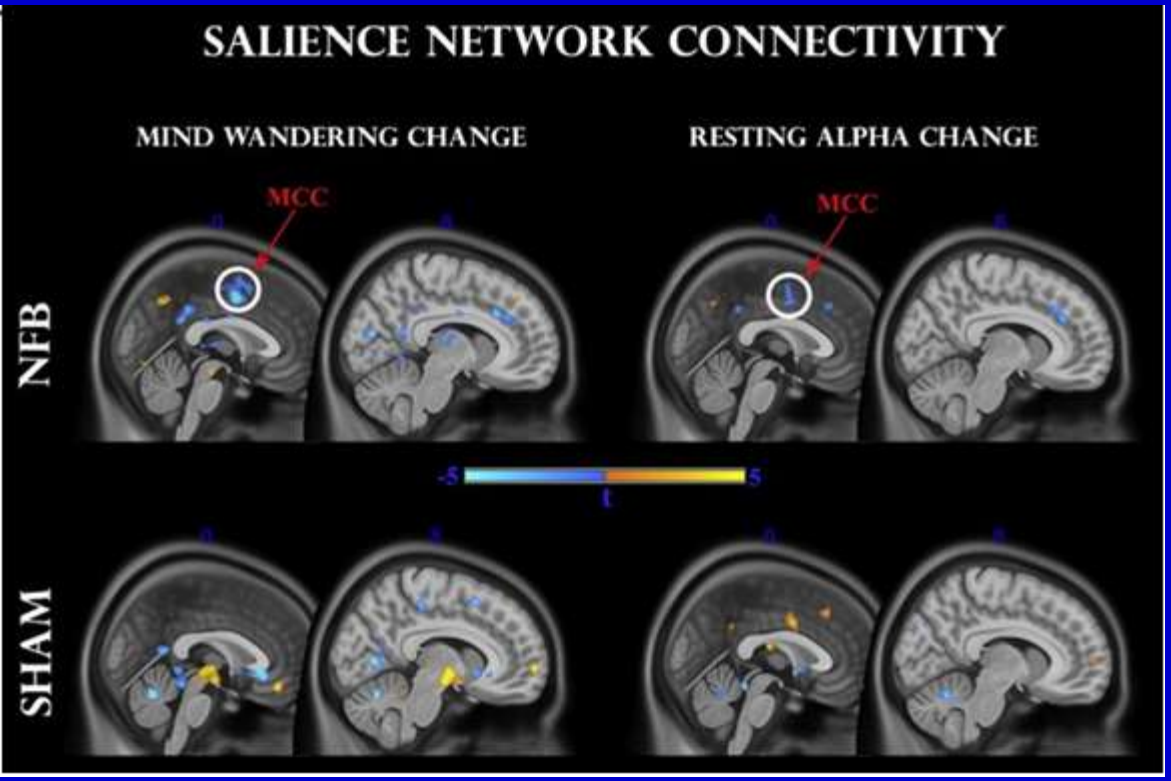
Jones, D. T. et al. Arch Neurol 2010;0:archneurol.2010.259v1-6.

ARCHIVES OF NEUROLOGY

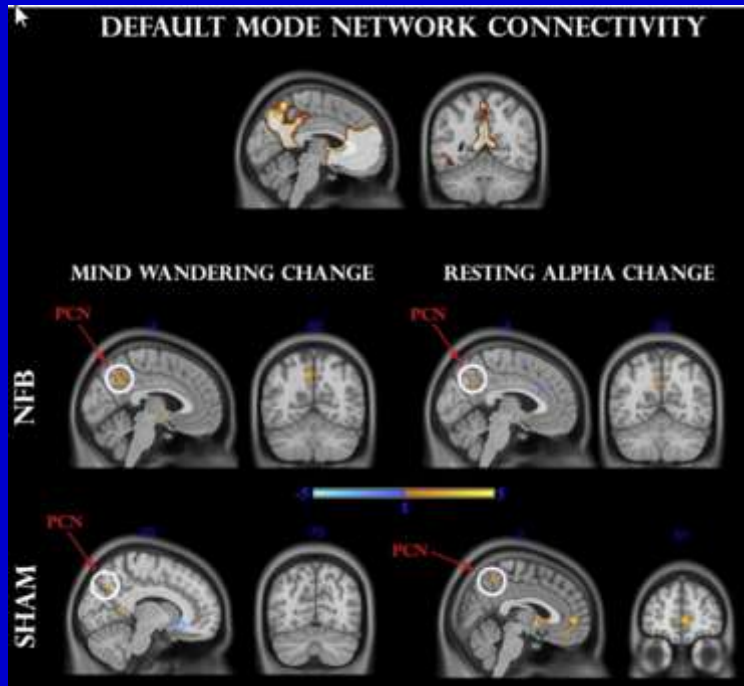
Default Cognitive Network



Default Cognitive Network



SALIENCE vs DEFAULT (YING AND YANG)



4. Sleep and Dreaming

- Sleep has an important role in health and in disease
  - Memory consolidation
- Dreams have content
  - REM Behavior Disorders

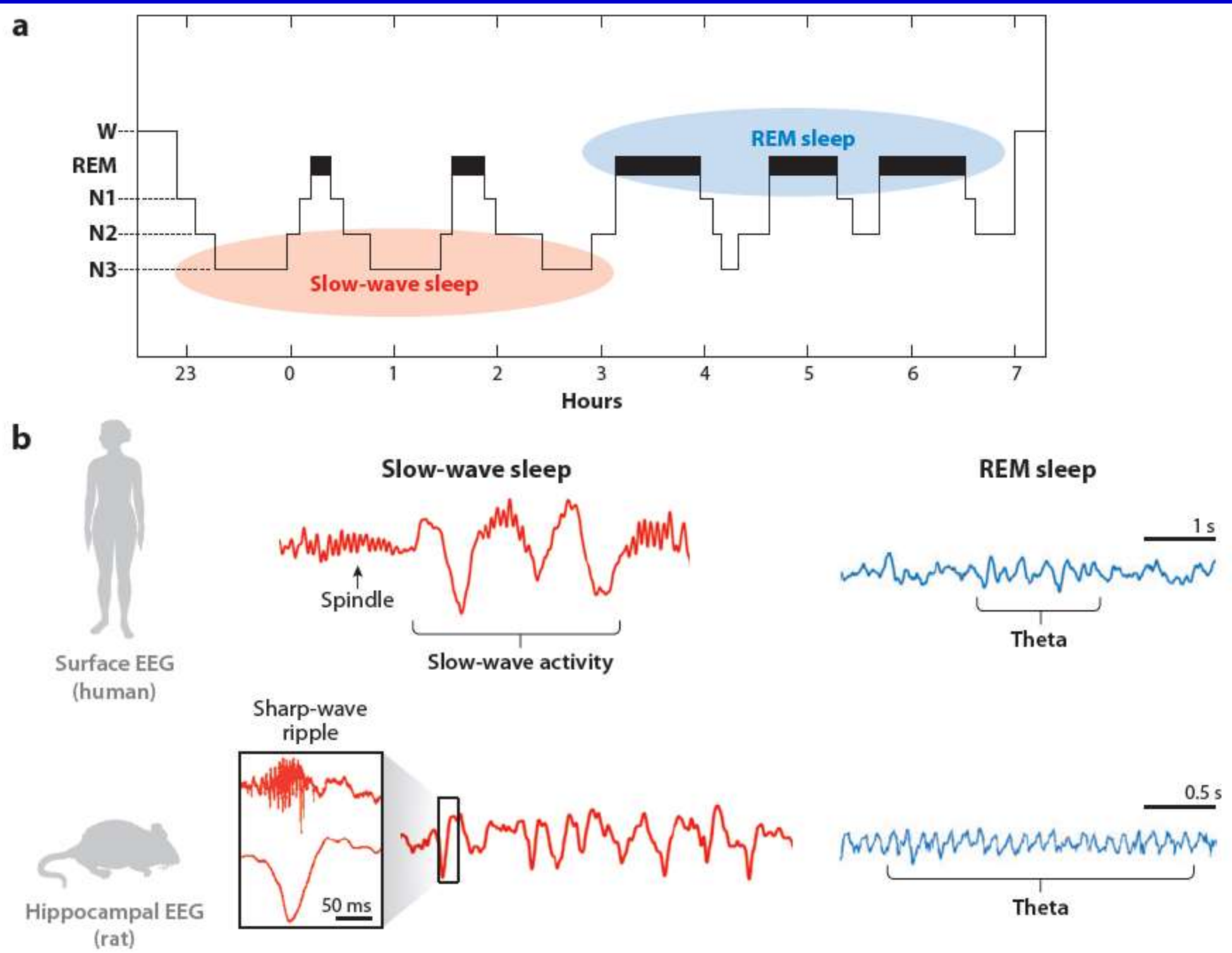
Sleep for Preserving and Transforming Episodic Memory

Marion Inostroza[1,2] and Jan Born[1]

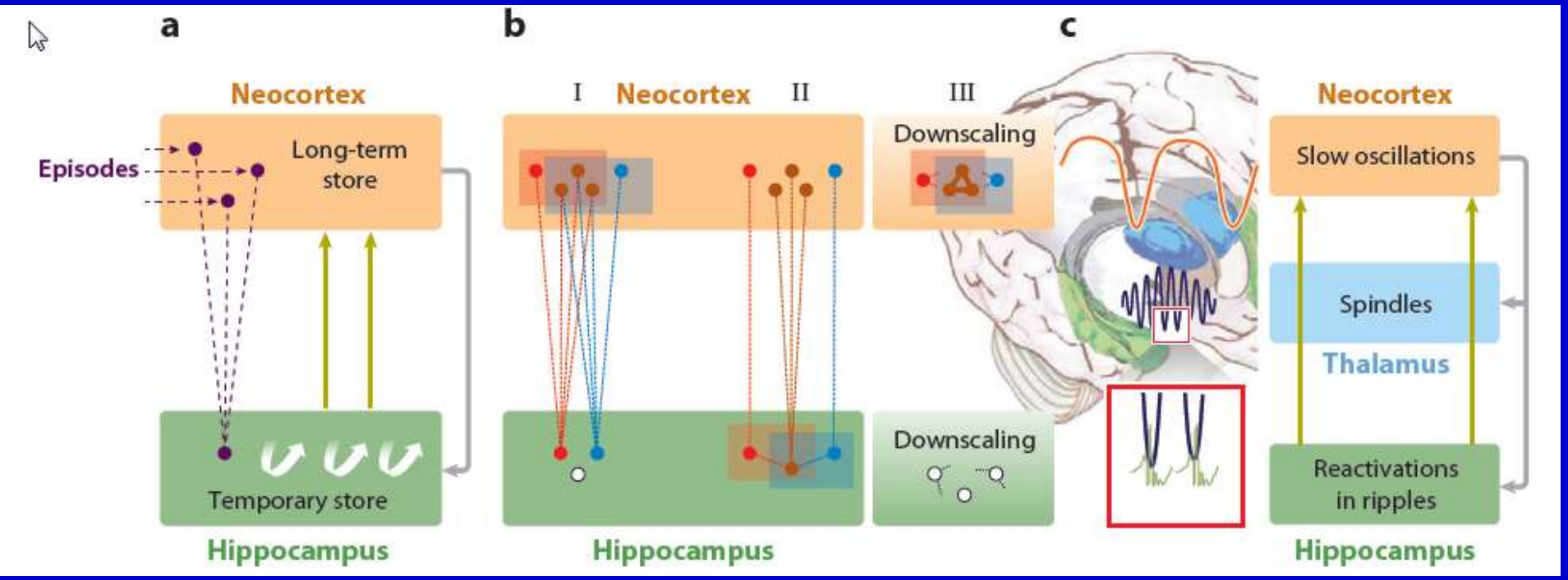
[1]Department of Medical Psychology and Behavioral Neurobiology and Centre for Integrative Neuroscience (CIN), University of Tübingen, 72076 Tübingen, Germany; email: jan.born@uni-tuebingen.de, marion.inostroza@uni-tuebingen.de

[2]Departamento de Psicología, Universidad de Chile, Santiago, Chile

Annu. Rev. Neurosci. 2013. 36:79–102


a
W
REM
N1
N2
N3
REM sleep
Slow-wave sleep
23
0
1
2
3
4
5
6
7
Hours
b
Surface EEG
(human)
Slow-wave sleep
Spindle
Slow-wave activity
REM sleep
1 s
Theta
Sharp-wave
ripple
50 ms
Hippocampal EEG
(rat)
0.5 s
Theta

ure 1


a
Neocortex
Episodes
Long-term store
Temporary store
Hippocampus
b
I
Neocortex
II
III
Downscaling
Downscaling
Hippocampus
c
Neocortex
Slow oscillations
Spindles
Thalamus
Reactivations in ripples
Hippocampus

70 year old male
severe RBD

5. Social Neurobiology

- Theory of Mind

Theory of Mind

- The cognitive ability that allows human beings to construe a mental representation of another person's mind so as to be able to perceive and predict their thoughts, feelings and behavior
- "Temporarily placing oneself in the other person's mind"
- "Walking in somebody else's shoes"

Joke

- Before you judge and criticize somebody, walk a mile in their shoes; that way when your criticize them, you will not only be a mile away, but you will also have a new pair of shoes.

Theory of Mind

- Putting our “current self’ in a potential situation in the future
- “How would I act if I were in a concentration camp and I could do something that would save my life but endanger another person”s?”
- Behavioral and Affective Forecasting

Theory of Mind

- Understand and predict how another person thinks, feels and behaves when faced with a particular situation
- Empathy: perhaps one of the most magnificent of human abilities
- Deceit: putting ourselves in the "mind of our enemies" so as to prepare an ambush

Possible additional function of theory of mind

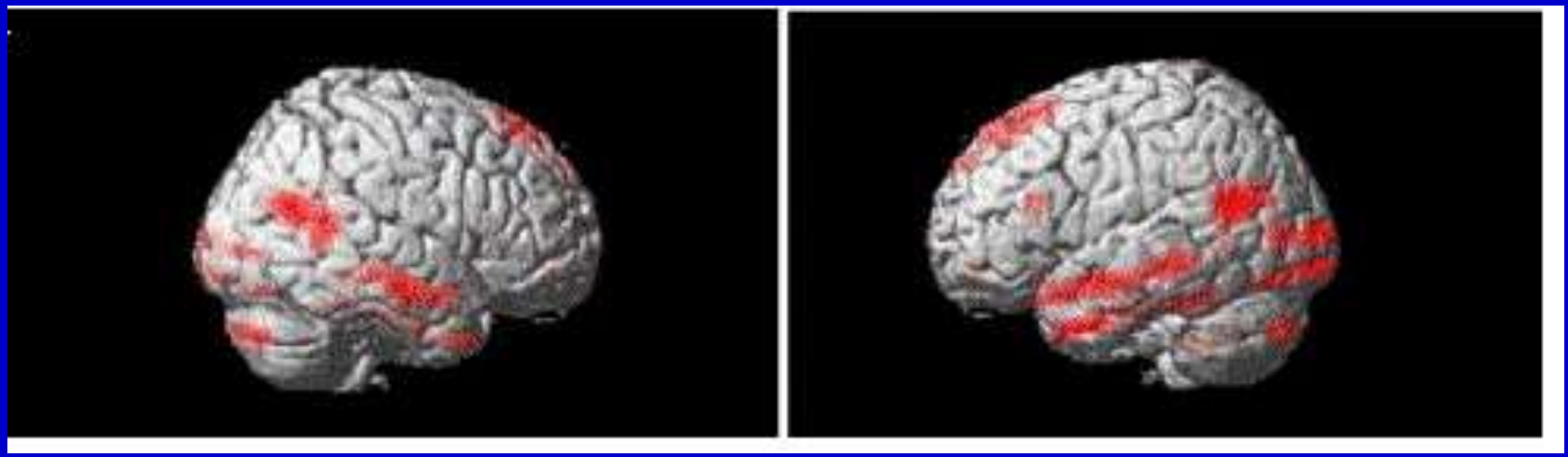
- Predict the intention and outcome of the "totality of the behavior" by observing only part of the behavior
- Arm raising an arm
  - Hailing down a taxi?
  - Striking at somebody else?

Theory of Mind and Development

- Become evident at age 4-5 (Reason unclear, but myelination and other factors have been implicated)
- Several tests have been utilized to measure TOM in children
- Failure to attain TOM functions is highly correlated with developmental disorders, including autism

Neurobiology of TOM

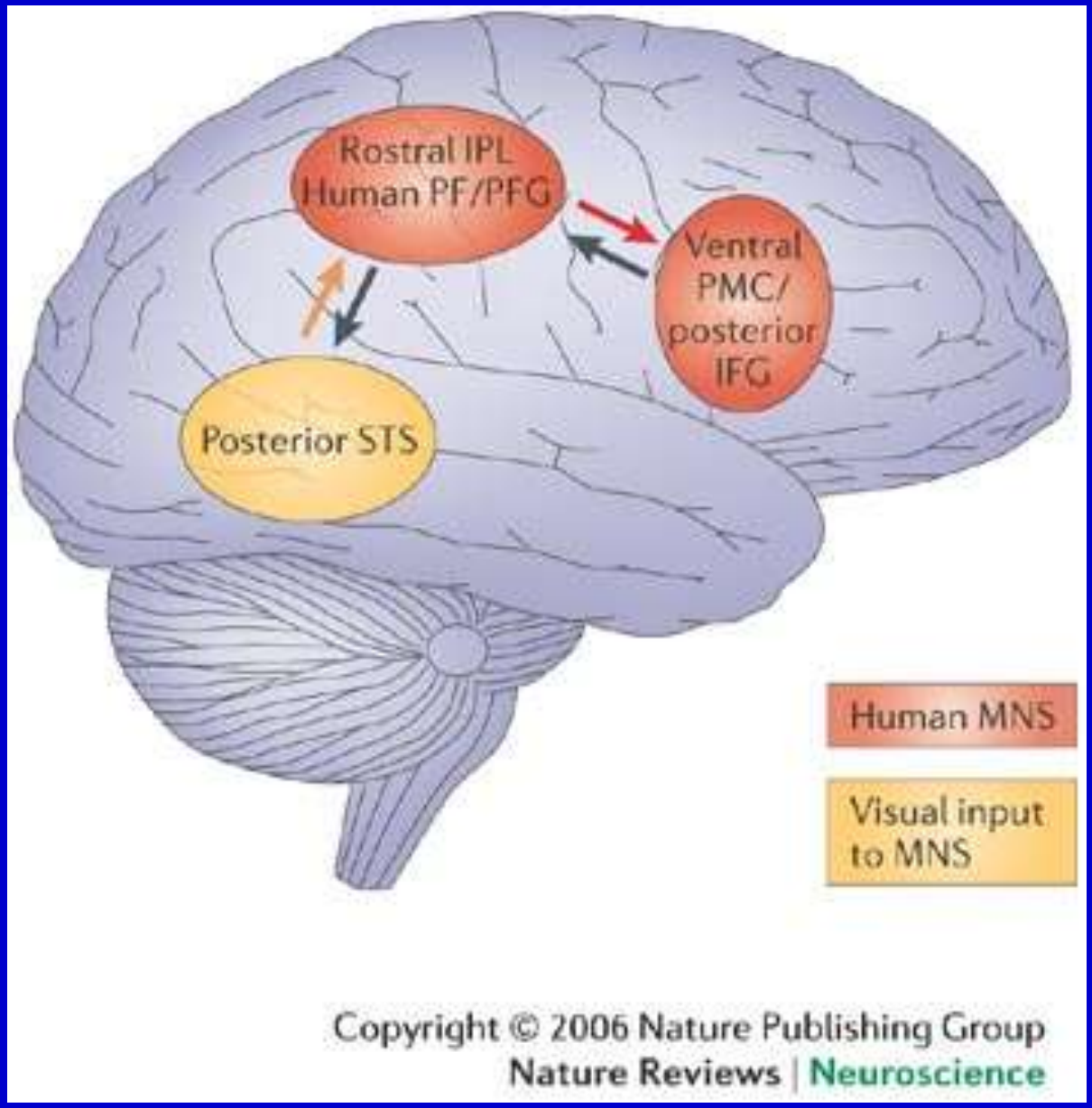
- There is a well defined brain system that becomes active with TOM functions
- There are some areas of the brain which seem to be highly dedicated to TOM functions



Vollm, B. A., A. N. Taylor, et al. (2006). "Neuronal correlates of theory of mind and empathy: a functional magnetic resonance imaging study in a nonverbal task." Neuroimage **29**(1): 90-8

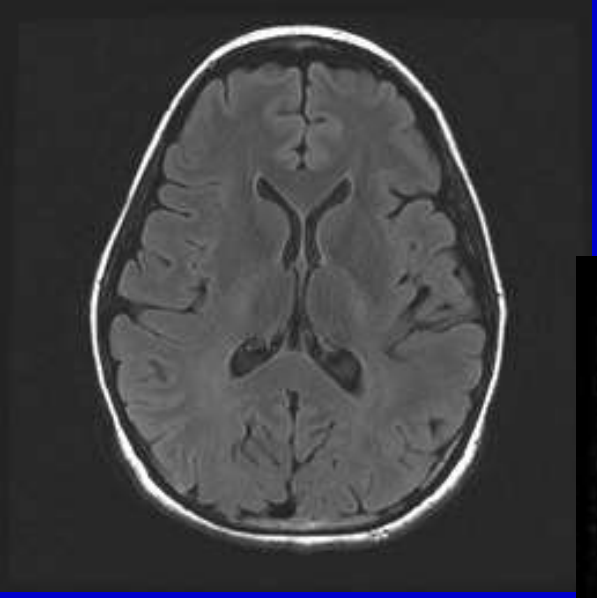
Mirror Neurons

- Neurons in the motor cortex that become active both when the individual observes and perform a specific action
- Presumably highly active in TOM functions.

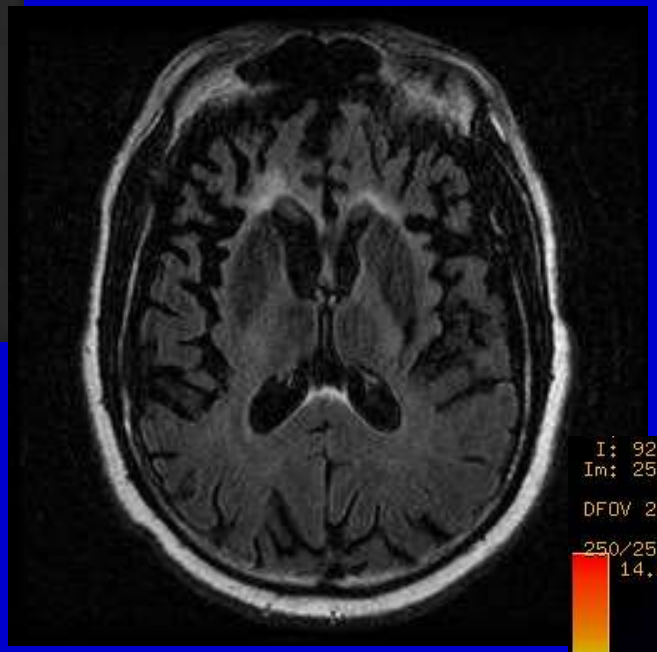


Alterations in Theory of Mind Function

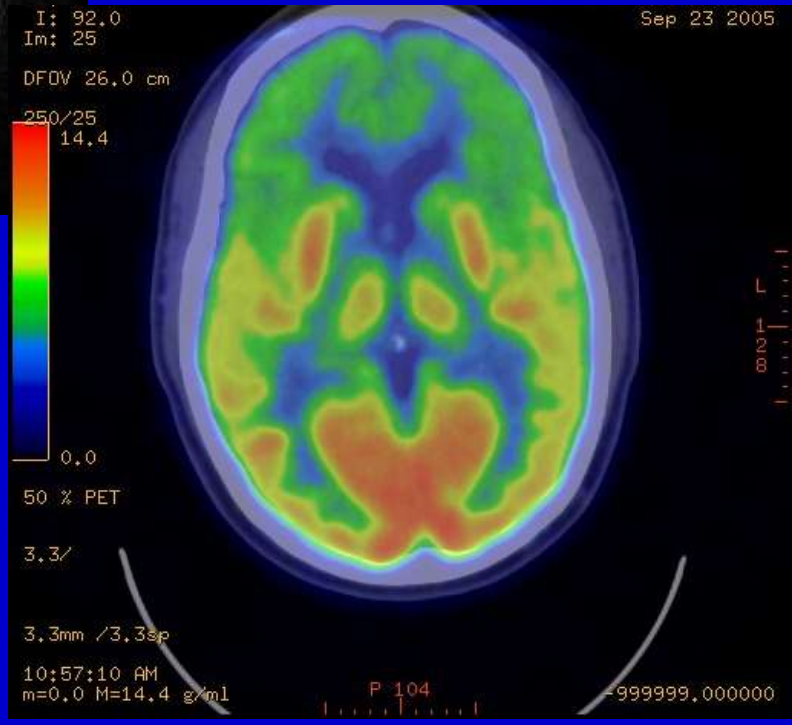
- Main cognitive deficit responsible for social dysfunction in patients with Autism
- Better functioning in theory of mind tests correlates with better social and vocational functioning
- Also affected in Psychiatric Disorders (Schizophrenia and Bipolar Disorders)
- Much interest in the association with alterations in TOM and dementia
- Sociopathic individuals do well in TOM tests but fail to feel empathy



Normal



Frontotemporal Dementia



Can TOM functions be enhanced?

- State of openness.
  - Temporary abandonment of one's owns patterns of thought and emotion
  - Acceptance that the other person may have different patterns of thoughts, emotions, and behaviors
- Knowledge
  - Person's history, cultural beliefs

Are there some individuals who are better at TOM functions?

- Joshua was a man “able to meet the spirit of every man” (could understand the feelings of all men). (Babylonian Talmud)
- “Wise in Secrets”, “Comprehensive Souls”
- God has “infinite awareness”, able to understand the thought process and feelings of every man

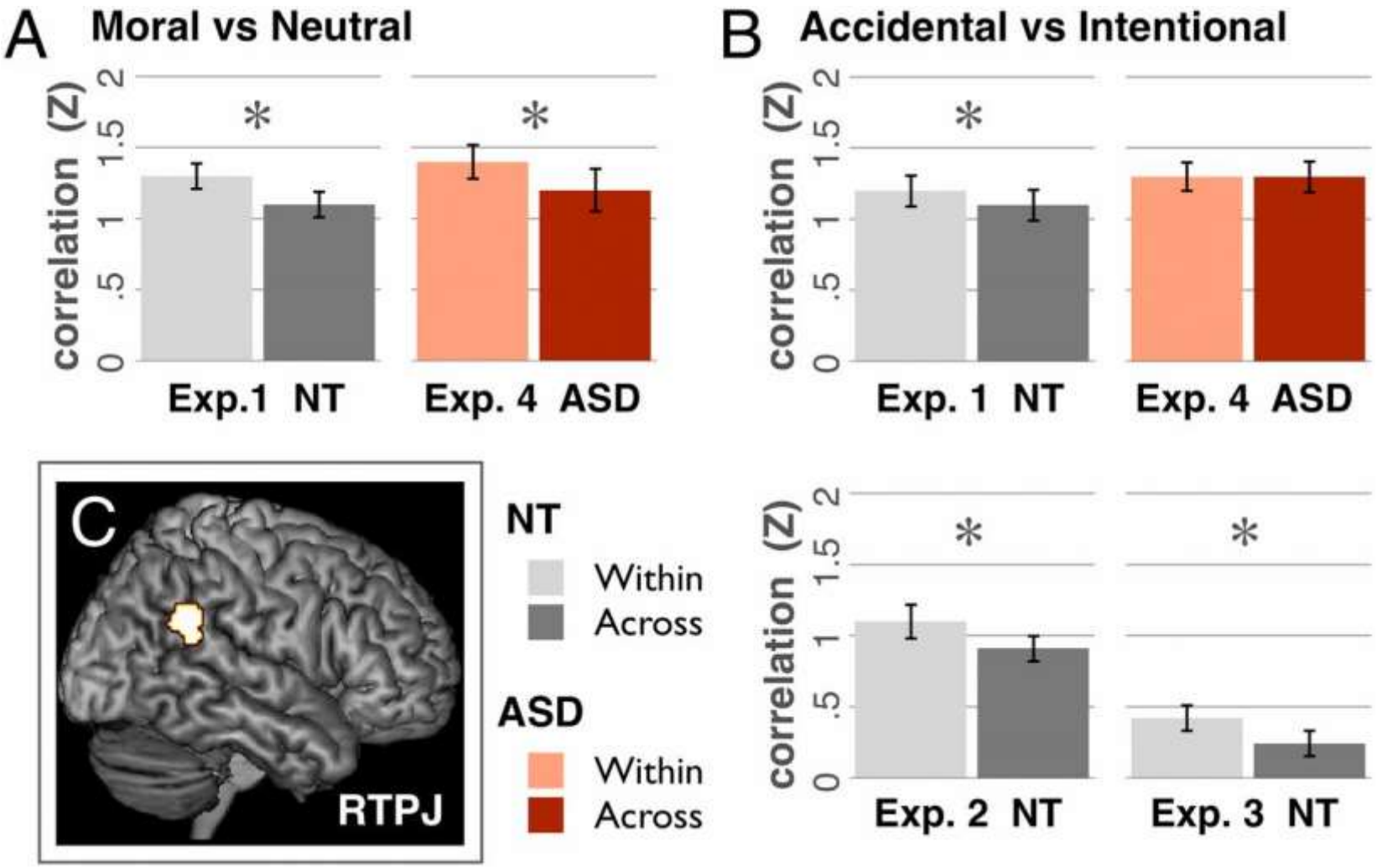
Disruption of the right temporoparietal junction with transcranial magnetic stimulation reduces the role of beliefs in moral judgments

Liane Young[a,1], Joan Albert Camprodon[b], Marc Hauser[c], Alvaro Pascual-Leone[b], and Rebecca Saxe[a]

[a]Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139; [b]Berenson–Allen Center for Noninvasive Brain Stimulation, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, MA 02215; and [c]Departments of Psychology and Human Evolutionary Biology, Harvard University, Cambridge, MA 02138

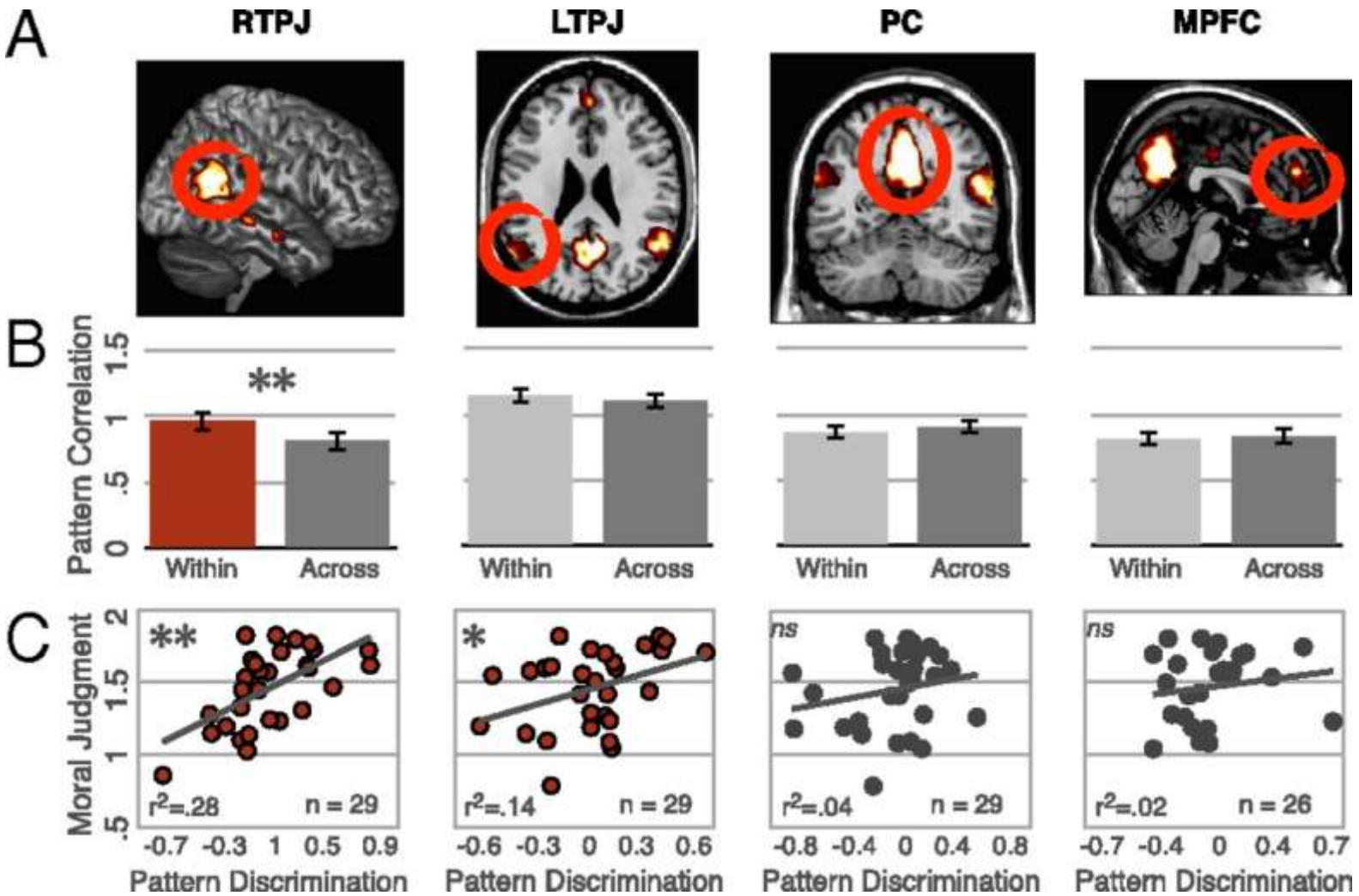
Edited* by Nancy G. Kanwisher, Massachusetts Institute of Technology, Cambridge, MA, and approved February 22, 2010 (received for review December 21, 2009)

MVPA results from experiments 1–4.



Koster-Hale J et al. PNAS 2013;110:5648-5653

MVPA results from experiments 1–3.



Koster-Hale J et al. PNAS 2013;110:5648-5653

Has the Brain Changed

Universal Human Functions

- Present in the vast majority of human beings with normal neurological development
- These functions have great similarities and minor differences
- Brain is “preconfigured” for that function but further definition closely associated with cultural factors
- Acquisition of function is highly related to relatively rigid time windows (acquisition versus learning)

Verbal Language

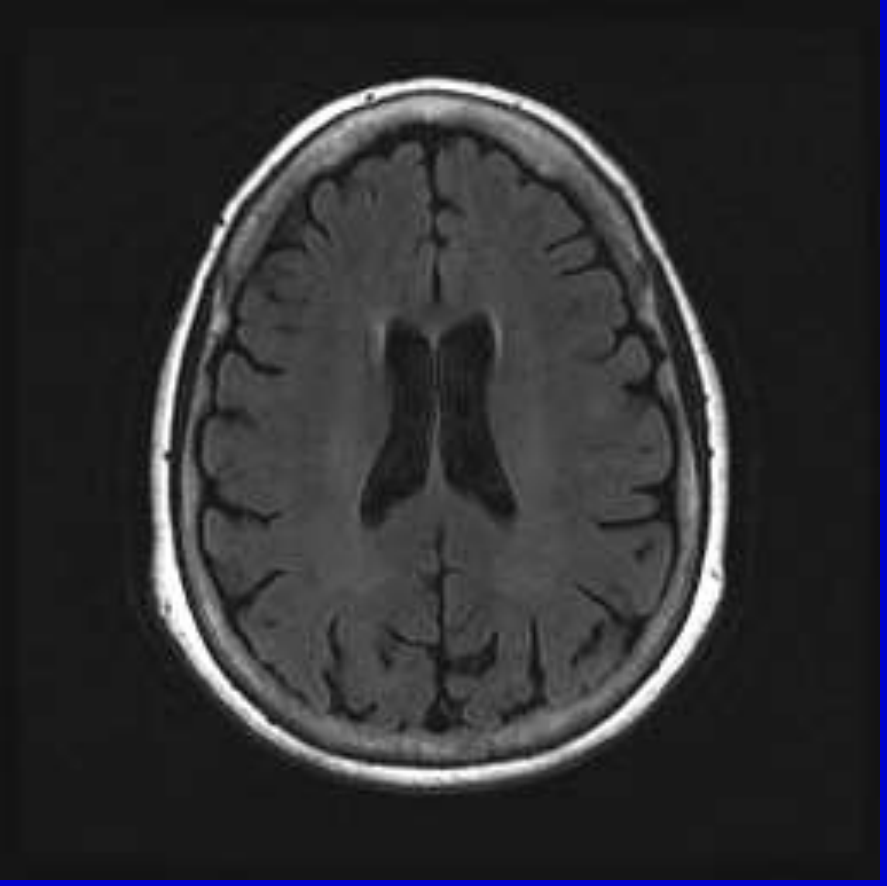
- "Universal" human function
- The neural substrate for "verbal" language (not for a specific language) exists in all humans
- All languages have similar structures (specific symbols differ)
- Language is "acquired" (not learned) during a highly specific window of time (highly efficient process)
- Outside of that window, language is "learned"
- During the language acquisition time window, the functional system is not entirely bound to specific brain geography

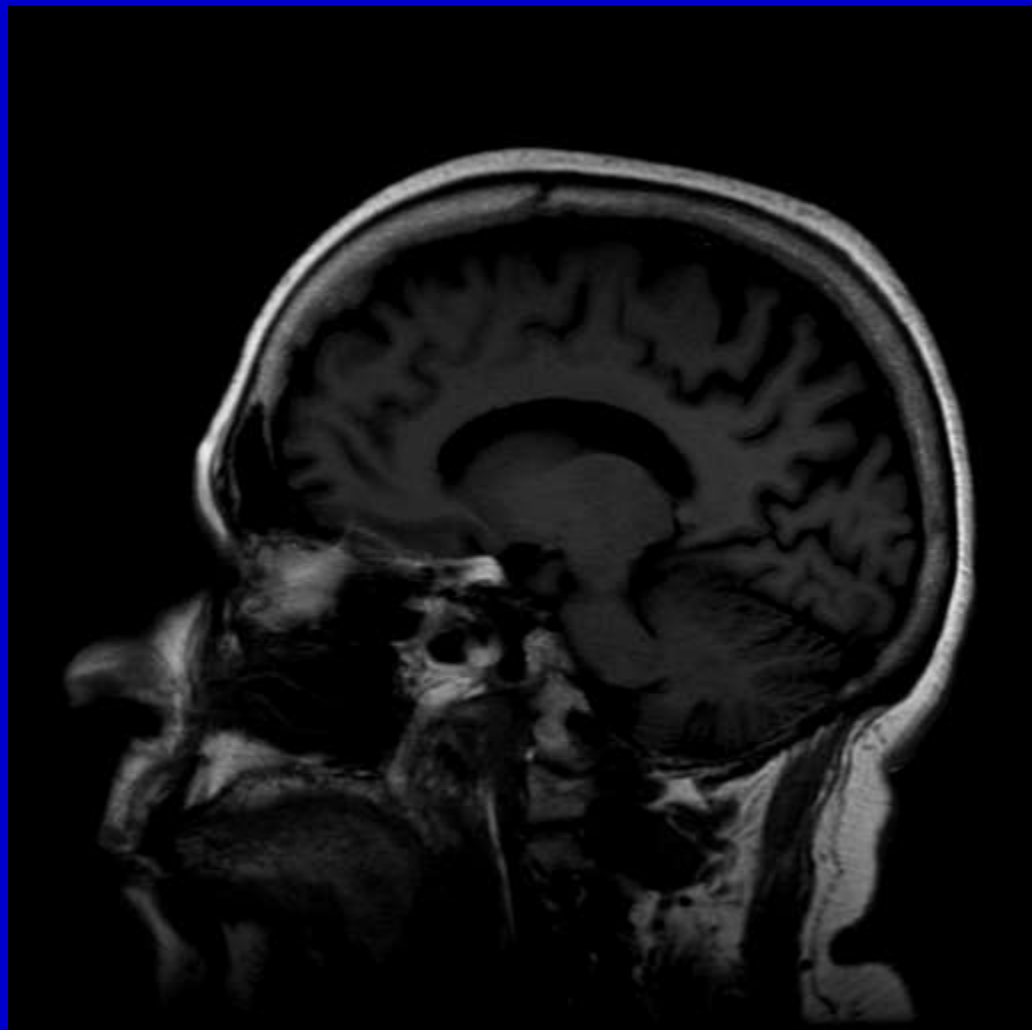
- Universal human functional systems are “fine tuned” with environmental interaction (culture driven plasticity) (language, music appreciation, religion??, etc).
- The system is “fine tuned” by environmental exposure during “critical time periods”.

Music as a Universal Human Function

- Musical Instruments date back 30000 years.
- All cultures studied have some type of “oral” music (not written)
- Infants have “innate” musical abilities regardless of environment
- There appear to be areas of the brain dedicated to musical perception.
- Certain characteristics of music are very similar in all cultures (Discrete pitch levels, Octave equivalences. Five to seven tones between octaves. Tonal hierarchy)

- **With an increase in literacy, would reading become a universal human function?**





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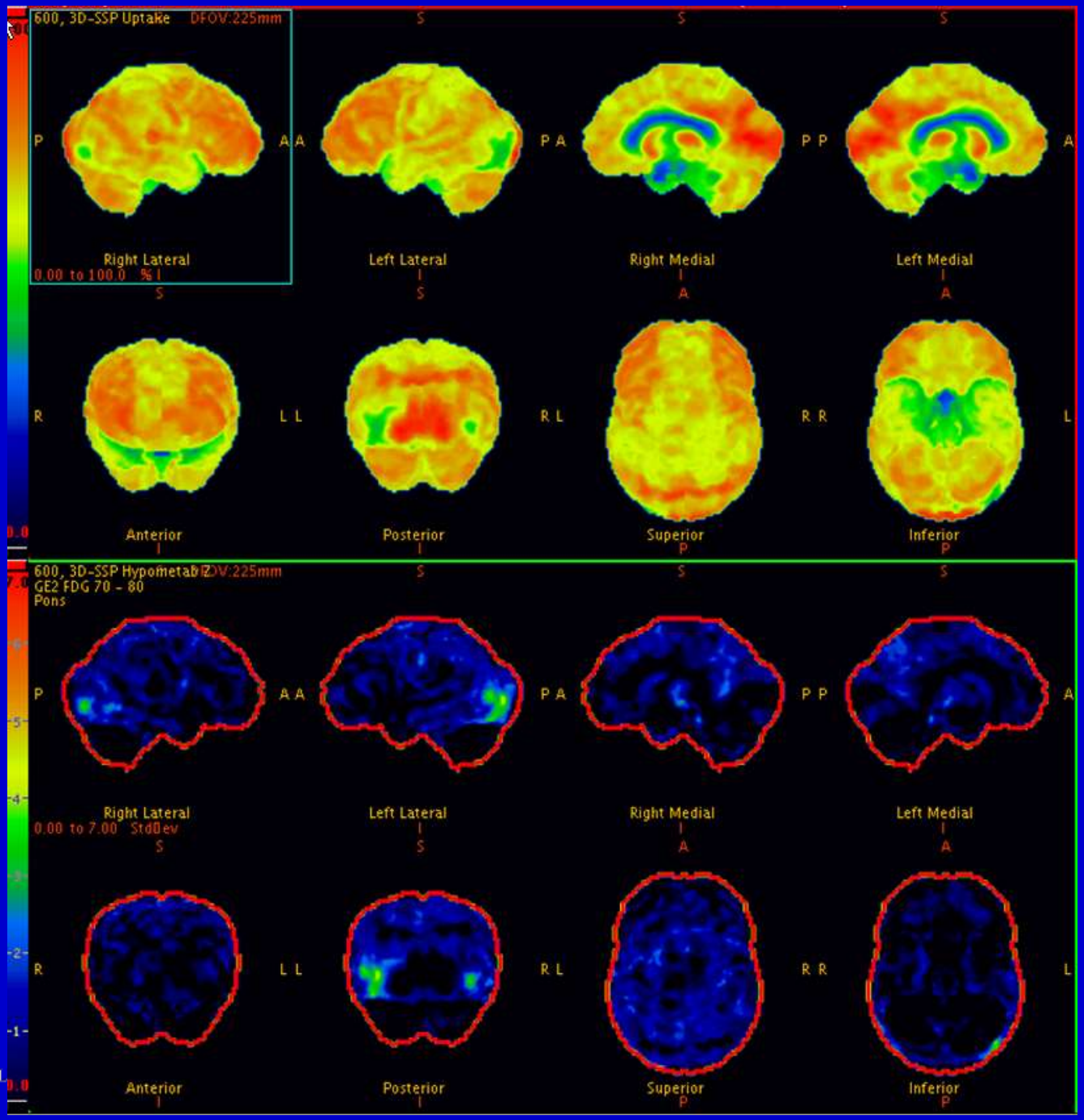
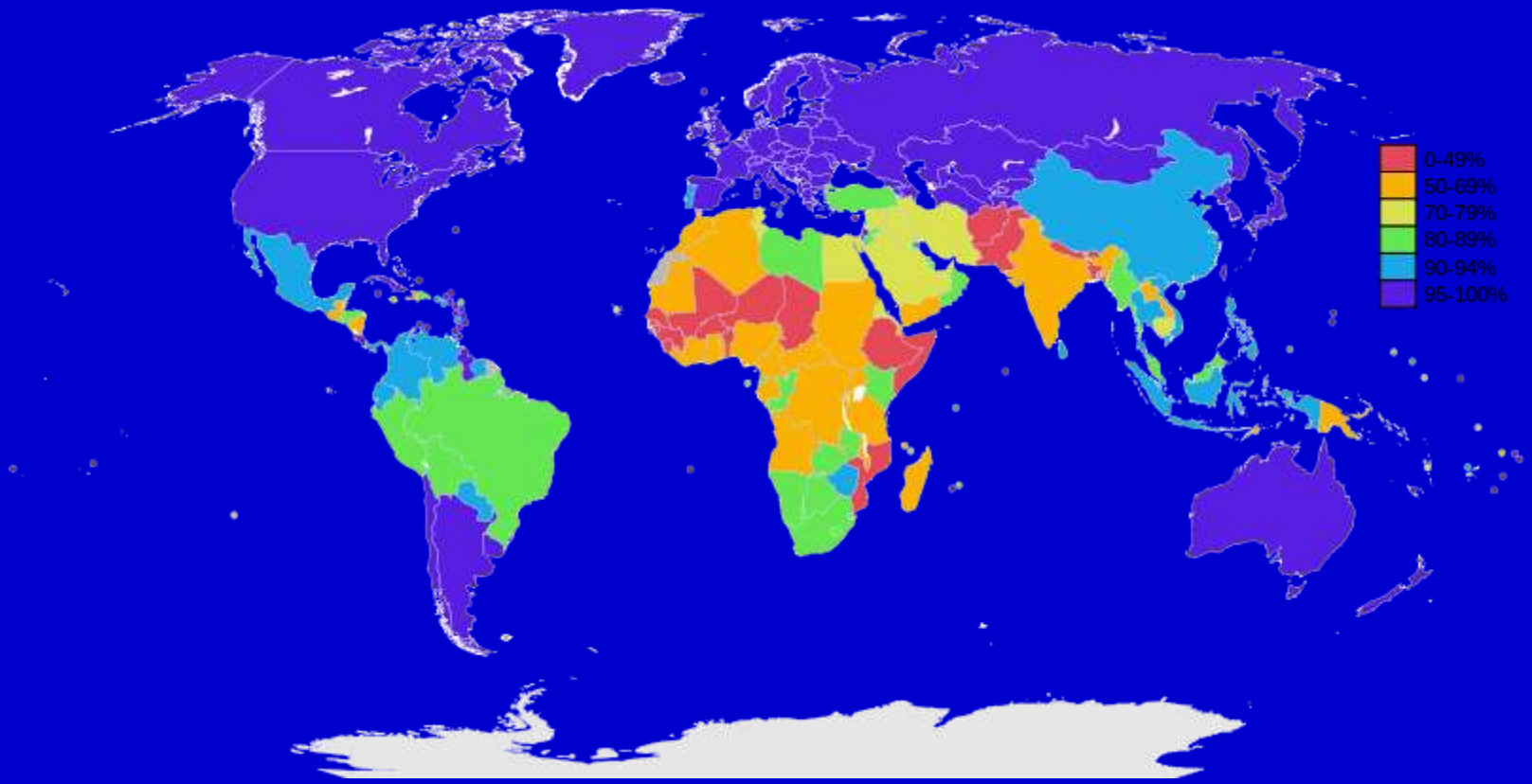

600, 3D-SSP Uptake DFOV:225mm
0.00 to 100.0 %I
Right Lateral
Left Lateral
Right Medial
Left Medial
Anterior
Posterior
Superior
Inferior
600, 3D-SSP Hypometab DFOV:225mm
GE2 FDG 70 - 80
Pons
0.00 to 7.00 StdDev
Right Lateral
Left Lateral
Right Medial
Left Medial
Anterior
Posterior
Superior
Inferior

According to UNESCO, in the world today there are about 1 billion non-literate adults.

- This 1 billion is approximately 26 percent of the world's adult population.
- Women make up two-thirds of all non-literates.
- 98 percent of all non-literates live in developing countries.
- In the least developed countries, the overall illiteracy rate is 49 percent.
- 52 percent of all non-literates live in India and China.
- Africa as a continent has a literacy rate of less than 60 percent.
- In Sub-Saharan Africa since 1980, primary school enrollment has declined, going from 58 percent to 50 percent.
- In all developing countries, the percentage of children aged 6-11 not attending school is 15 percent. In the least developed countries, it is 45 percent.(UNESCO 1998)

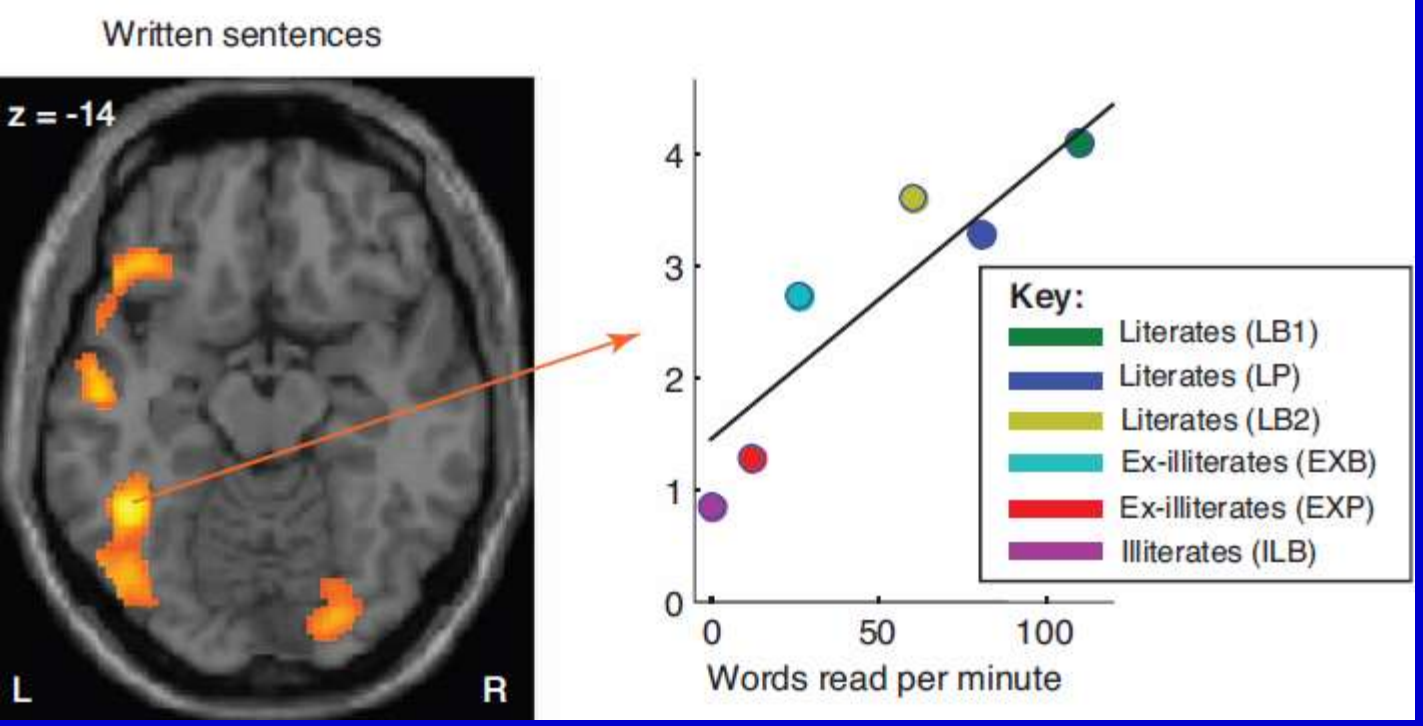

0-49%
50-69%
70-79%
80-89%
90-94%
95-100%

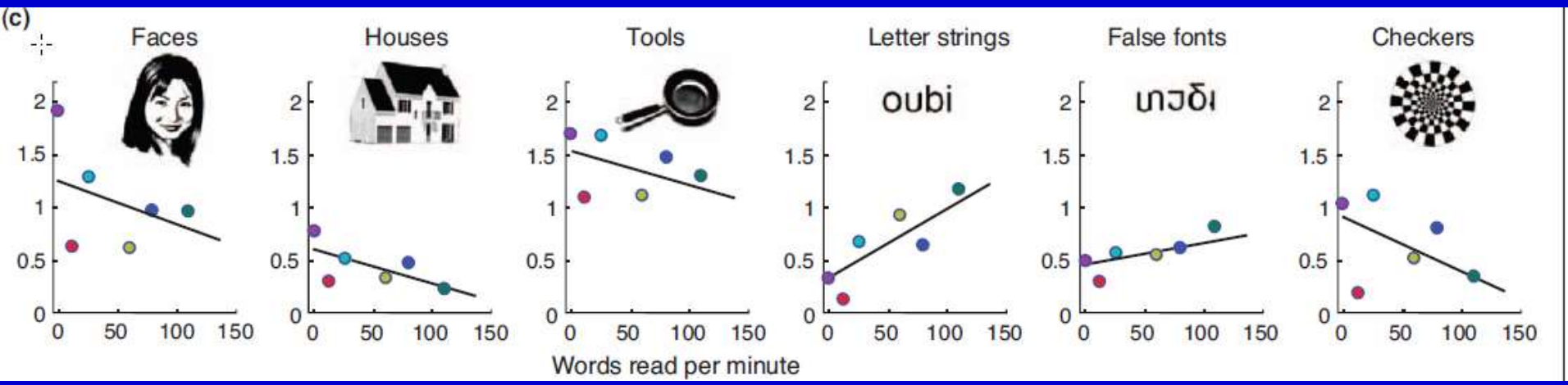
Reading is not a human universal function

- Writing and Reading probably go back approximately 4000 years
- Until the 19th century, reading was limited to a very selected and small percentage of the population
- Many current cultures with very rich heritages do not read or write and rely on verbal transmission of information

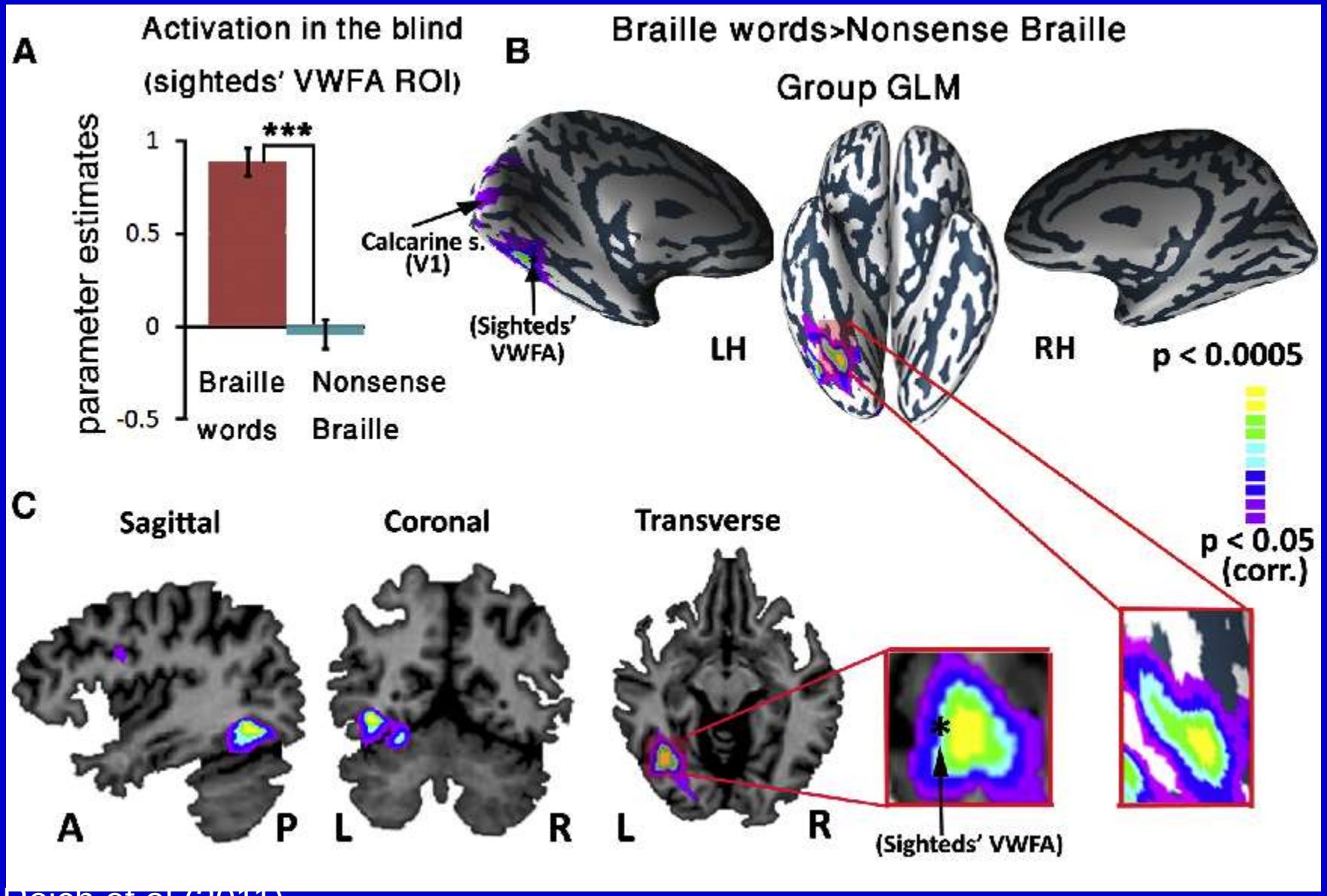
Reading is not a universal human function

- Knowledge of verbal language is a prerequisite (know what a word means)
- Highly dependent on declarative learning with application of rules inherent to that language
- Probably not subject to developmental plasticity time windows
- Unclear as to whether age affects acquisition





Dehaene (2011)



Reich et al (2011)

Conclusions

- Reading is probably not a universal human function
  - Not bound by developmental plasticity windows
  - Acquired through a non declarative process
  - The VWFA has a fundamental role in reading
  - With acquisition of literacy, plastic changes occur in the VFWA which make it almost exclusively dedicated to reading

Thank You

The Brain 10 Years Later

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The End