511-evo-devo

Rick Gilmore

2021-09-02 13:08:06

- Fun
- Evolution
    - Public acceptance of evolution
        - Types of evidence
        - Why Gilmore thinks the theory so controversial (in the U.S.)
    - Evolution and development
        - Ontogenesis and phylogenesis
            - Ontogeny does not recapitulate phylogeny (Haeckel), but…
        - Complex multicellular life emerged "recently"
        - Nervous system architectures
            - How nervous systems differ
        - The essentials of biological computation
            - Information processing universals
        - From nerve net to nerve ring, nerve cord, and brain
        - Vertebrate CNS organization
- Human brain development
    - Prenatal period
        - Insemination
        - Fertilization
        - Implantation
        - Early embryogenesis
        - Formation of *neural tube* (neurulation)
        - Neurogenesis and gliogenesis
        - Radial glia and cell migration
    - Differentiation
    - Infancy & Early Childhood
        - Synaptogenesis
        - Proliferation, pruning
        - Apoptosis

Fun

Evolution

Public acceptance of evolution

[[@miller2006public]](http://dx.doi.org/10.1126/science.1126746)

(Miller, Scott, & Okamoto, 2006) (http://dx.doi.org/10.1126/science.1126746)

Types of evidence

- Fossil
  - Fossil dating
- Geological
  - Where fossils are found relative to one another
  - How long it takes to form layers
- Genetic

    - Rates of mutation
- Anatomical
    - Homologous structures across species

> *“Seen in the light of evolution, biology is, perhaps, intellectually the most satisfying and inspiring science. Without that light, it becomes a pile of sundry facts some of them interesting or curious, but making no meaningful picture as a whole.”*

(Dobzhansky, 1973) (http://dx.doi.org/10.2307/4444260)

Why Gilmore thinks the theory so controversial (in the U.S.)

- Contradicts verbatim/non-metaphorical reading of some religious texts
- Makes humans seem less special
- Time scales involved beyond human experience
- Scientific method vs. other ways of knowing
- Found in nature ≠ good for human society
- Few negative consequences of ‘disbelief’
- U.S. culture individualistic, skeptical, anti-elitist, anti-intellectual
- Lower levels of religious belief among U.S. scientists (http://news.rice.edu/2015/12/03/first-worldwide-survey-of-religion-and-science-no-not-all-scientists-are-atheists/)
- Politics (http://www.people-press.org/2009/07/09/section-4-scientists-politics-and-religion/)
- A minority of citizens support teaching evolution-only (http://www.pbs.org/wgbh/nova/blogs/education/2015/12/evolutionschools/)
- Majority of classroom teachers aren’t strong advocates (https://www.sciencedaily.com/releases/2011/01/110127141657.htm)

Evolution and development

Ontogenesis and phylogenesis

- *Ontogenesis*
    - Development within lifetimes, history of individuals

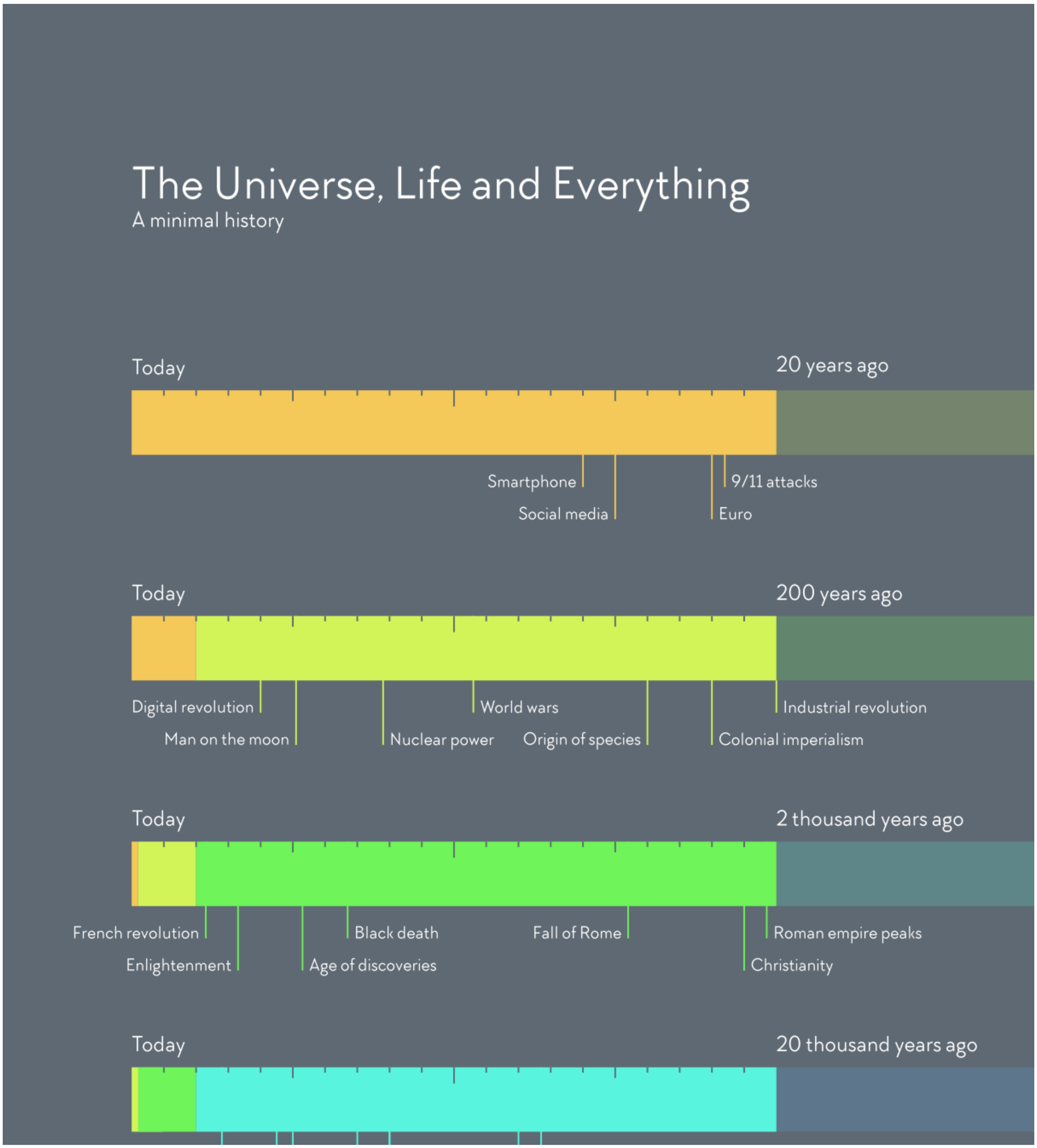
- *Phylogenesis*
    - Change across lifestimes, history of species

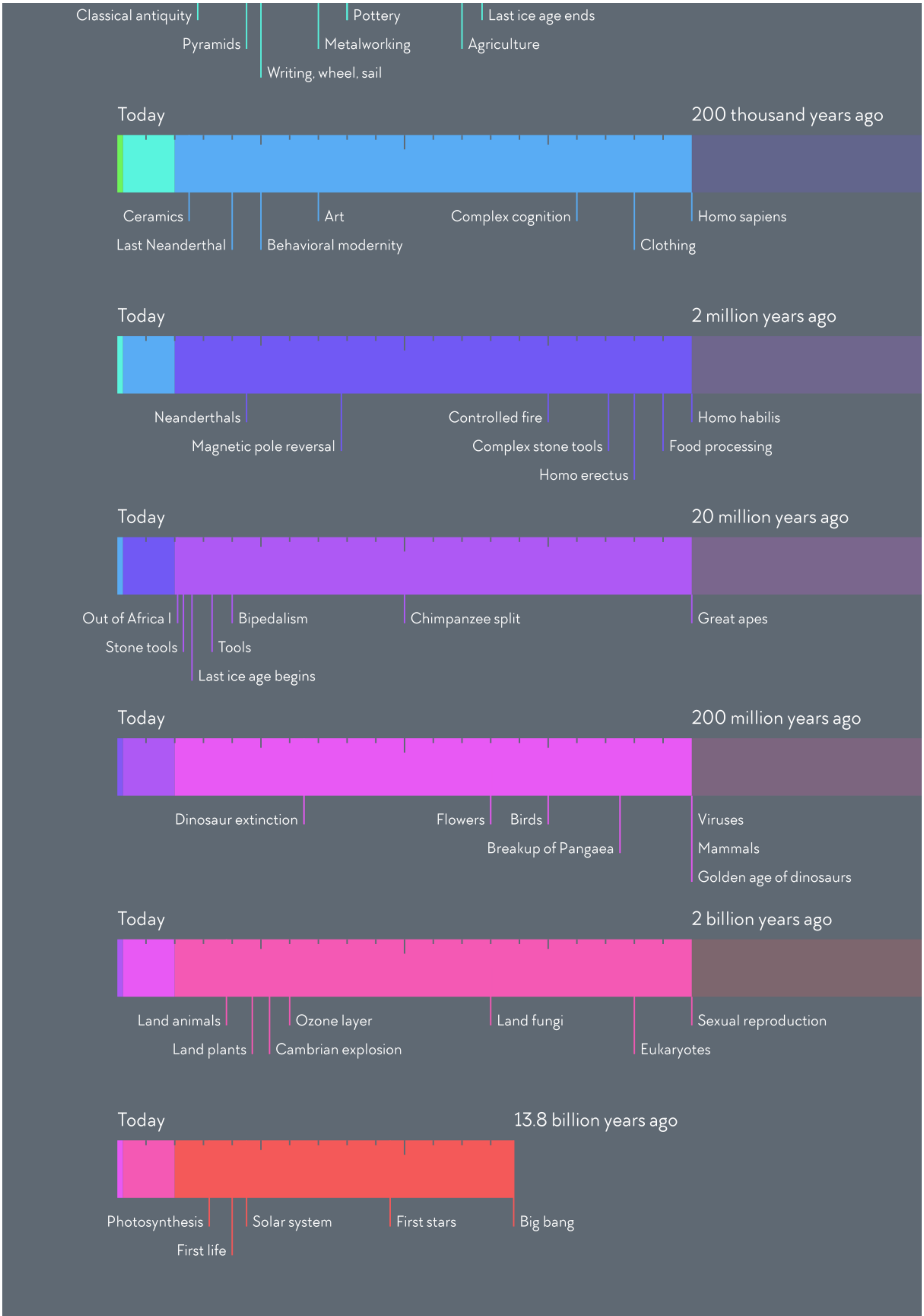
Ontogeny does not recapitulate phylogeny (Haeckel (https://en.wikipedia.org/wiki/Ernst_Haeckel)), but…

Source: Wikipedia

Source: Wikipedia

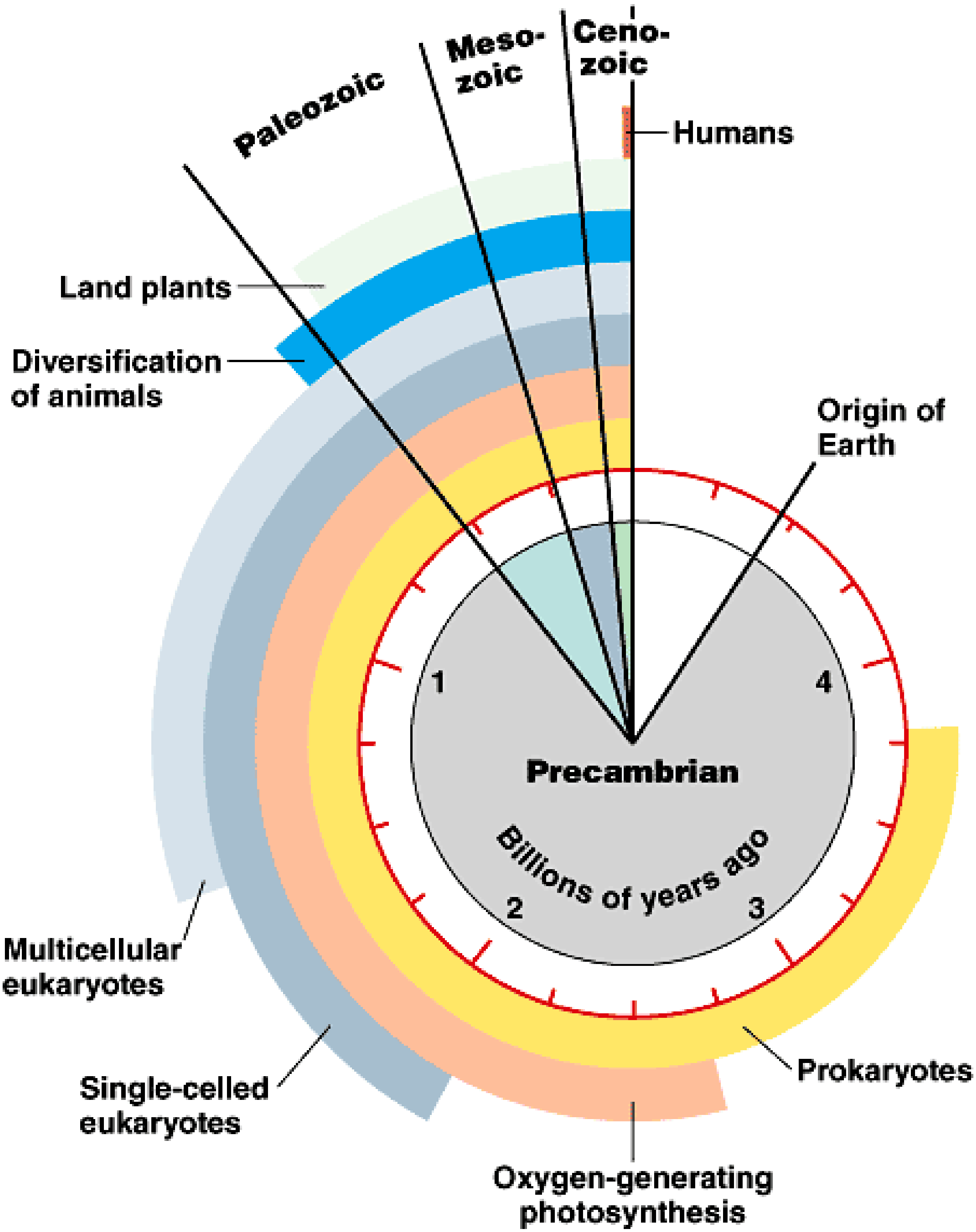
Complex multicellular life emerged “recently”





A minimal history of the Universe, Life and Everything. Compiled by Anthony Liekens in October 2019

http://anthony.liekens.net/pub/timeline.png
(http://anthony.liekens.net/pub/timeline.png)



Source: http://www.zo.utexas.edu/faculty/sjasper/images/26.2.gif (http://www.zo.utexas.edu/faculty/sjasper/images/26.2.gif)

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Nervous system architectures

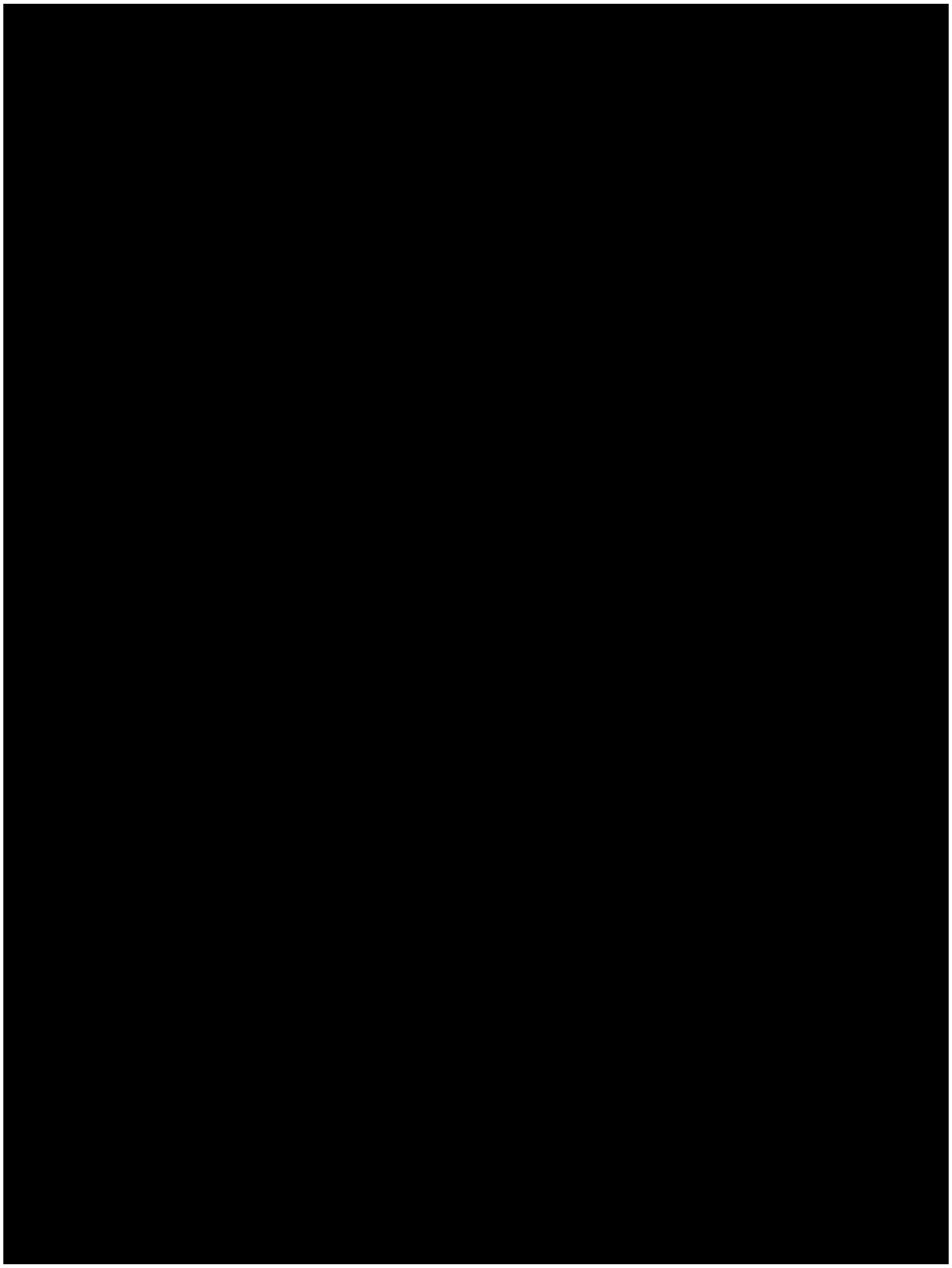
How nervous systems differ

- Body symmetry
  - radial
  - bilateral

Source: [[@arendt_nerve_2016]](https://doi.org/10.1038/nrn.2015.15)

Source: (Arendt, Tosches, & Marlow, 2016) (https://doi.org/10.1038/nrn.2015.15)

An animal with a nerve "net"

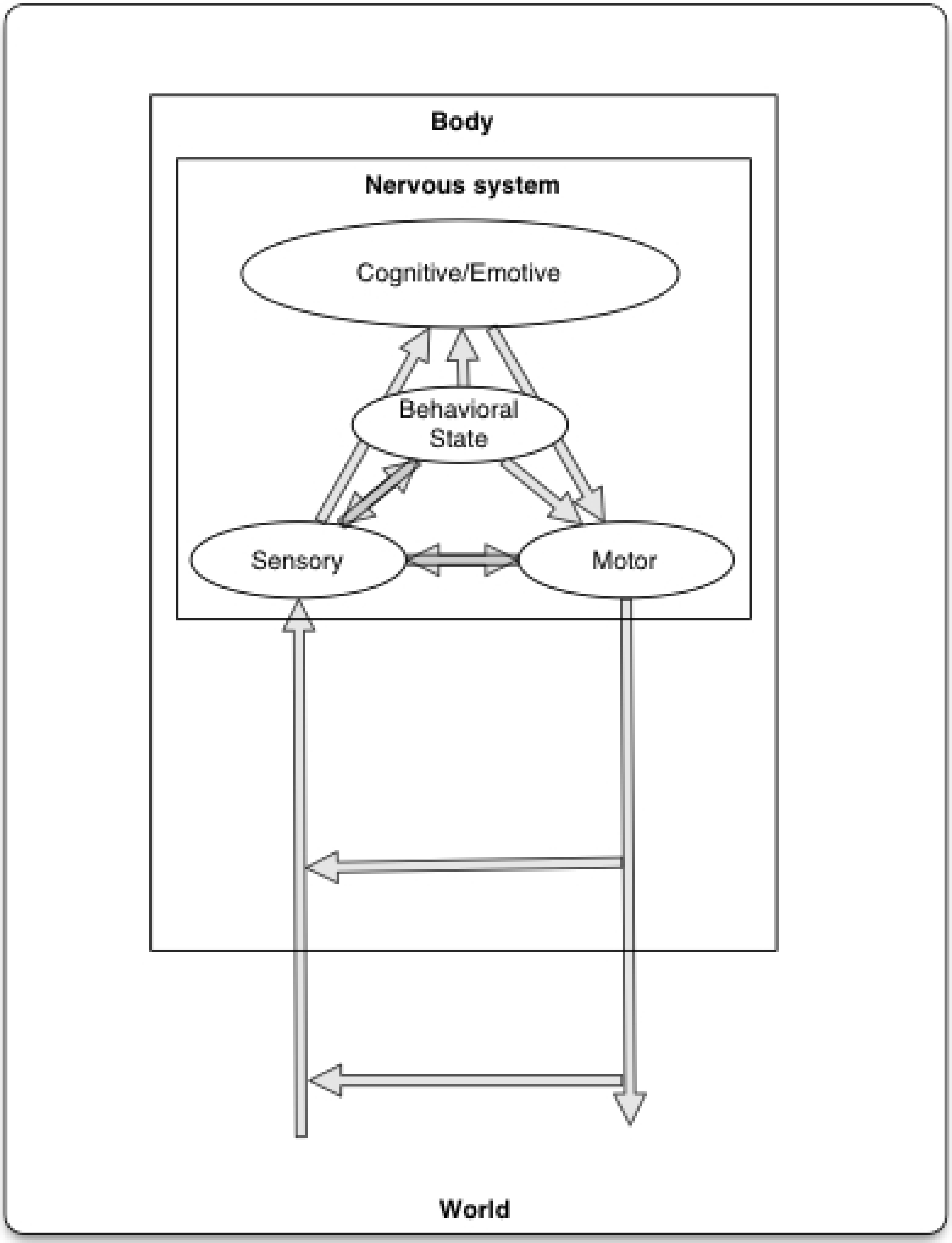


- Segmentation
- Cephalization (concentration of sensory & neural structures in anterior portion of body)
- Encasement in bone (vertebrates)
- Centralized vs. distributed function

Cephalopods have "intelligent arms"

The essentials of biological computation

- Ingestion
- Defense
- Reproduction



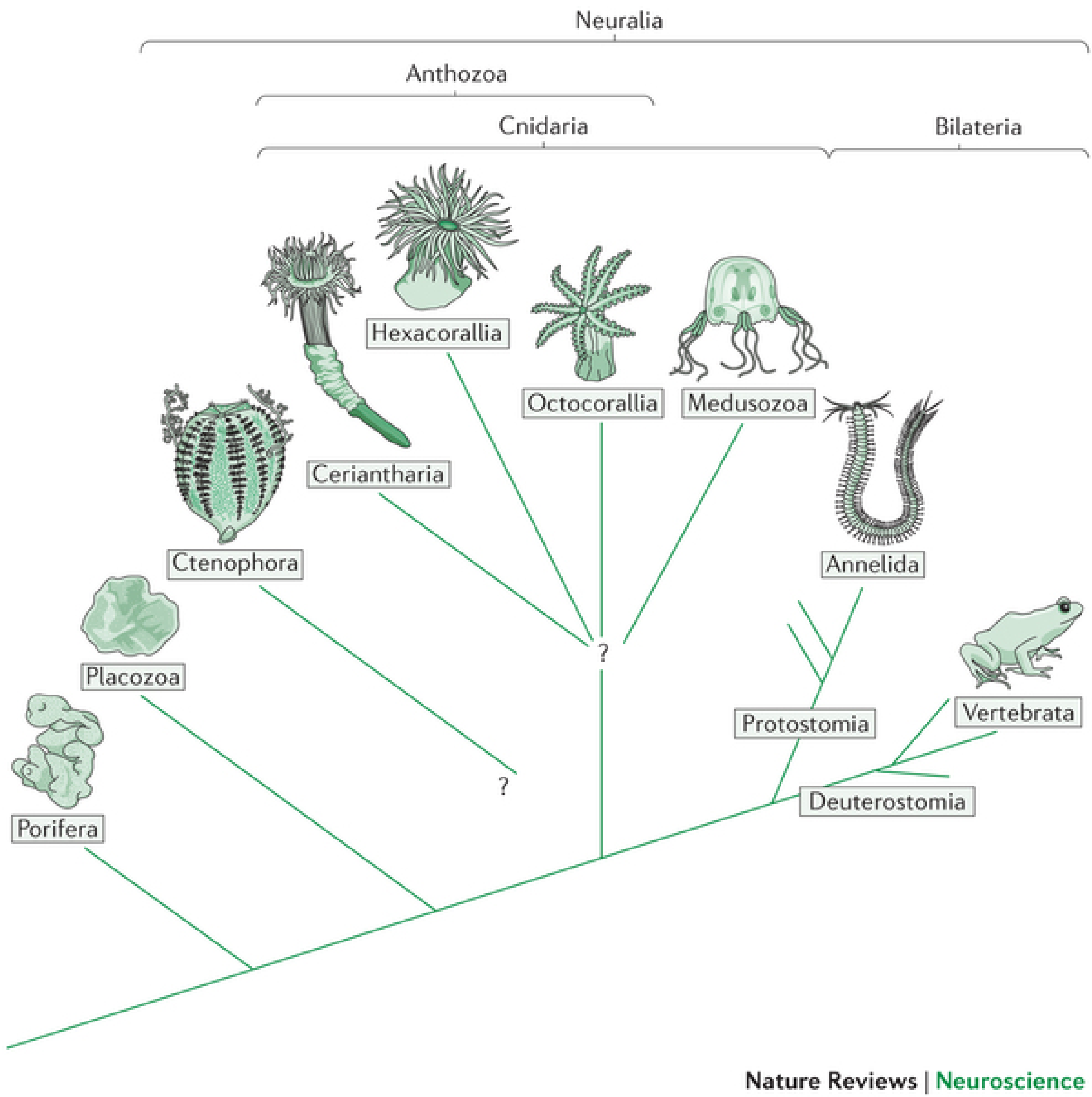
Information processing universals

- Sense/detect via sensors
  - Specialize by information source/type

    - Specialize by target location
        - Interoceptive
        - Exteroceptive
- Analyze, evaluate, decide
    - Current state
        - World
        - Organism
    - Current goals
    - Past state(s)
- Act
    - Move body
        - Approach/avoid
        - Manipulate
        - Ingest
        - Signal
    - Change physiological state

From nerve net to nerve ring, nerve cord, and brain

(Arendt, Tosches, & Marlow, 2016) (http://doi.org/10.1038/nrn.2015.15)



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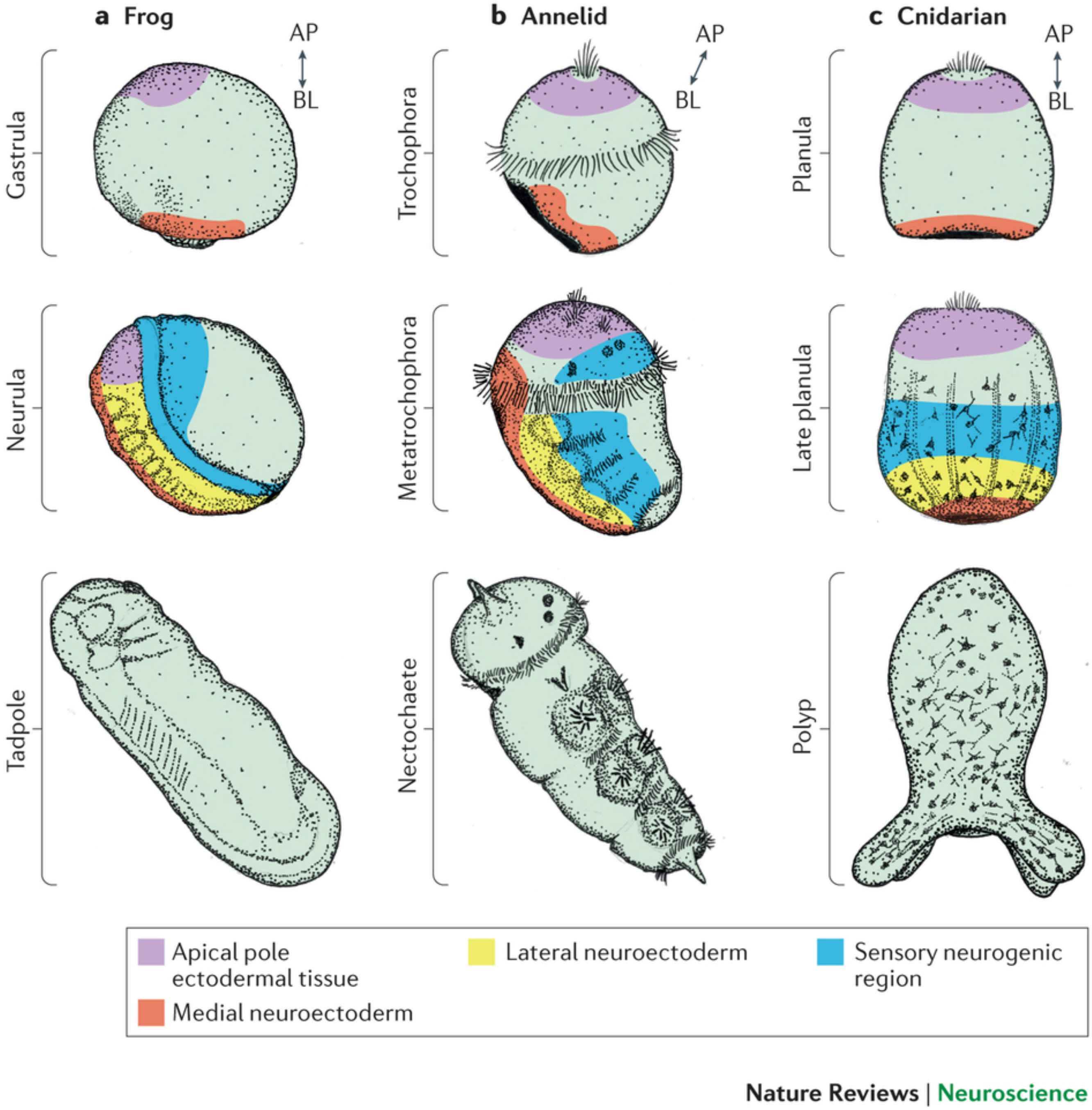
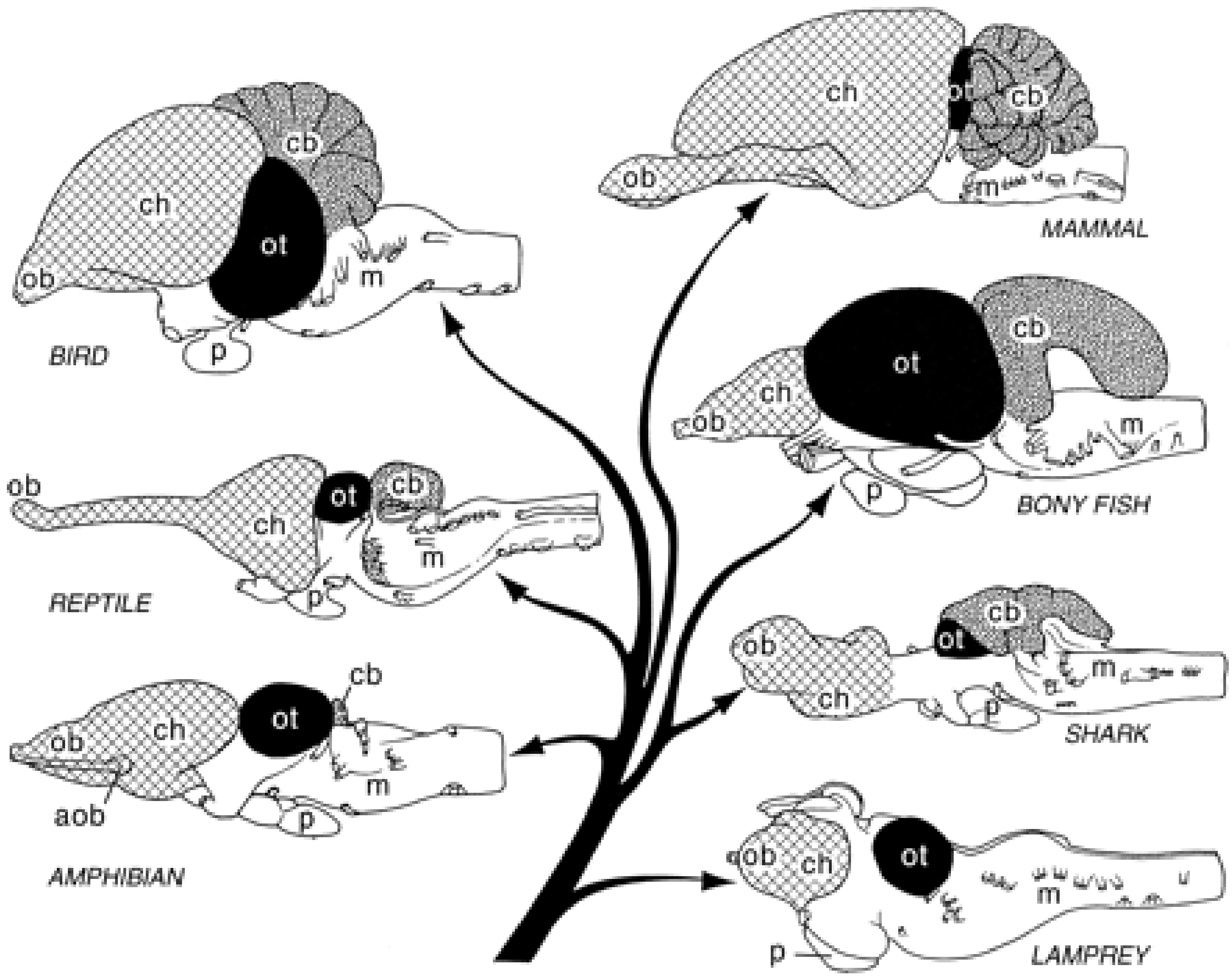


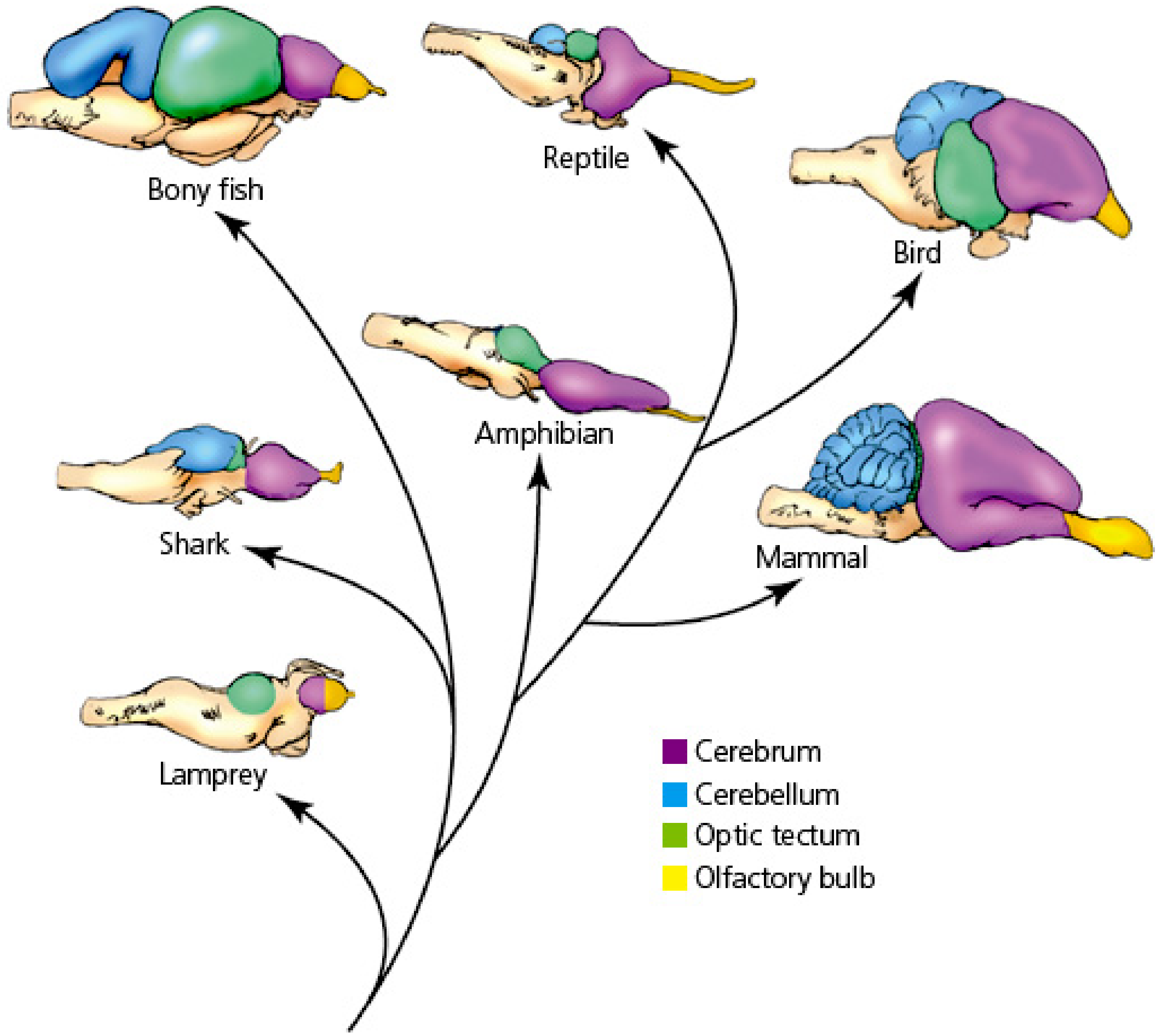
(Arendt, Tosches, & Marlow, 2016) (http://doi.org/10.1038/nrn.2015.15)

- Neurons and nervous systems 520-570 M years old
- Diverse nervous systems show developmental similarities at molecular level

Vertebrate CNS organization



(Northcutt, 2002) (http://doi.org/10.1093/icb/42.4.743)



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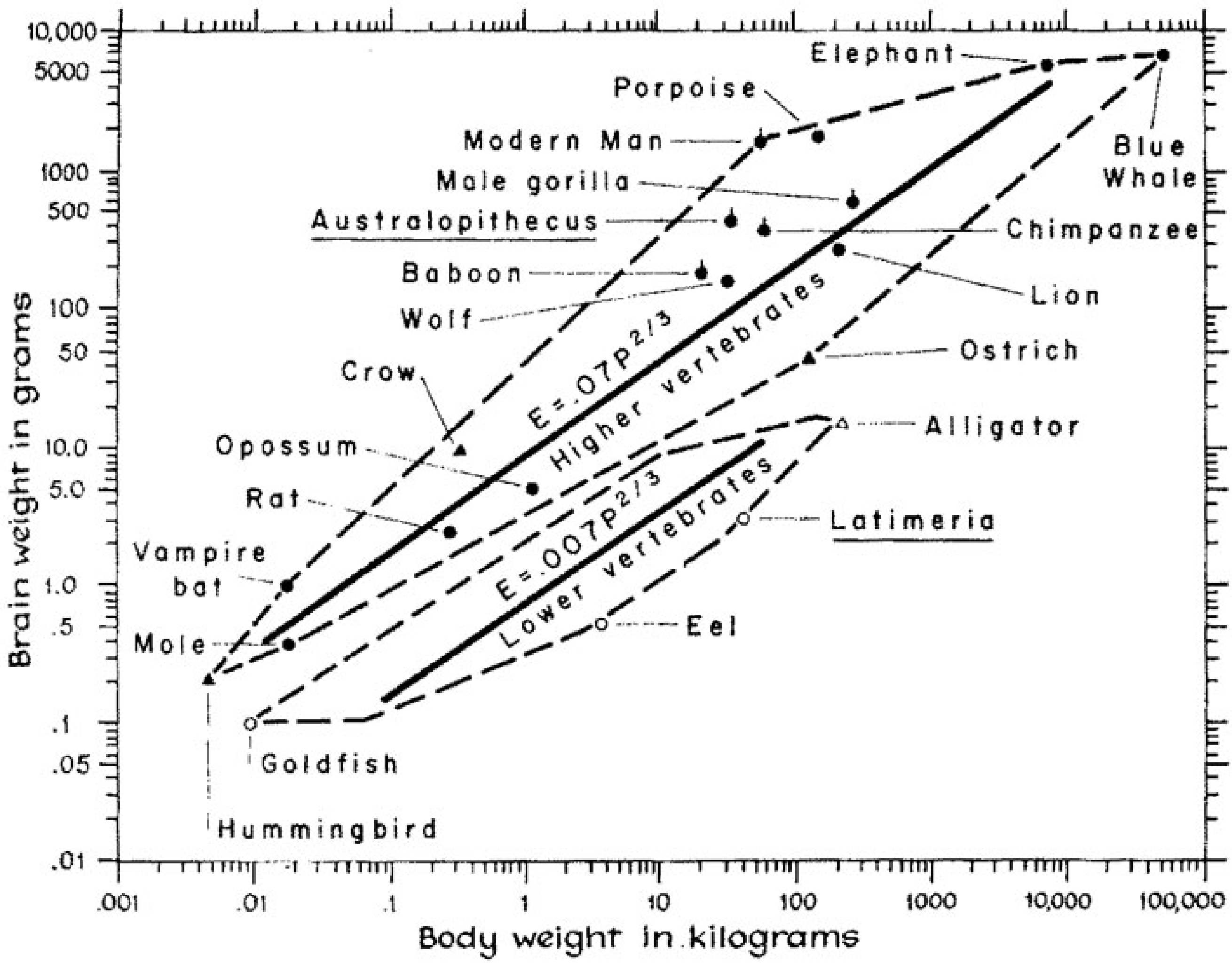

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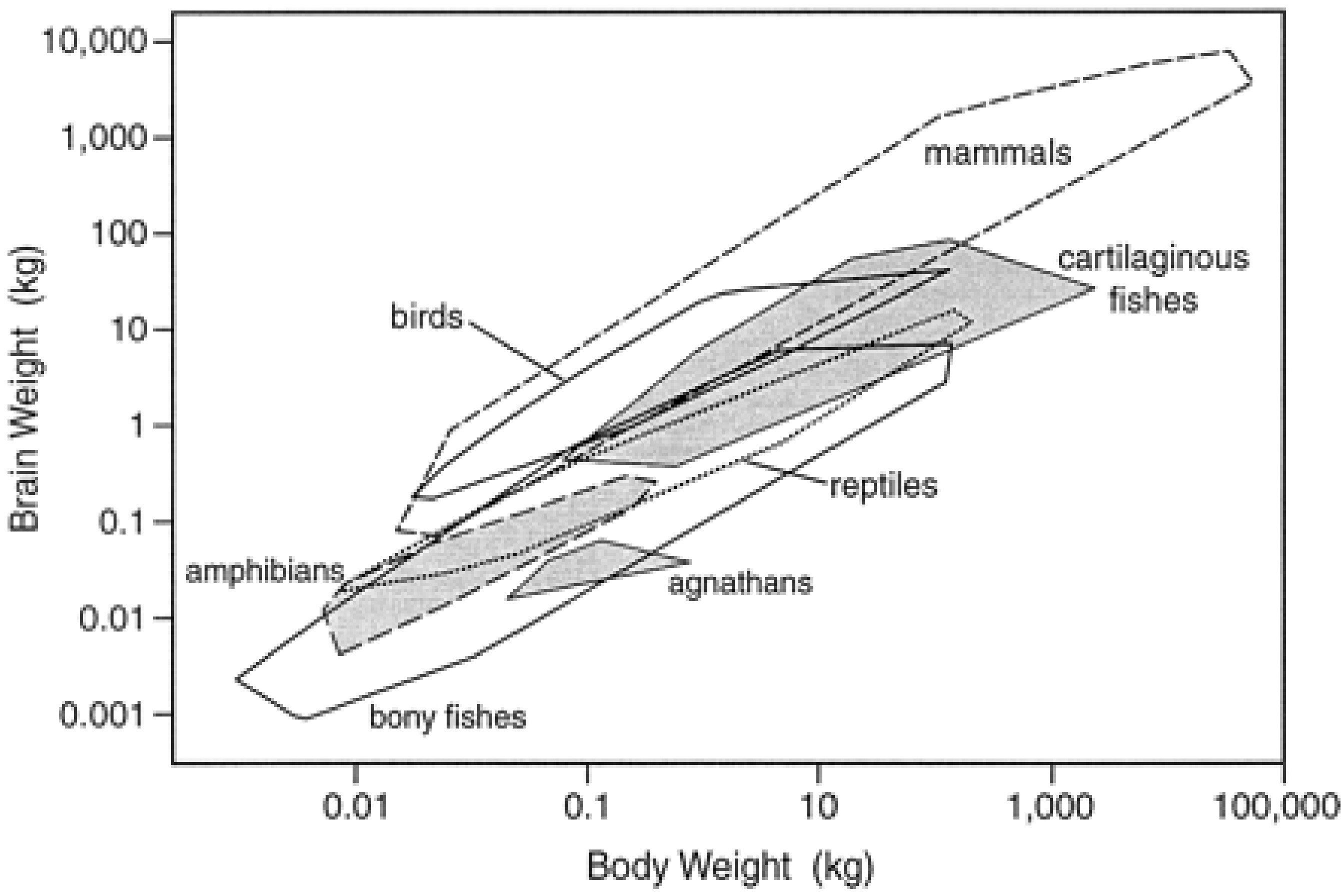
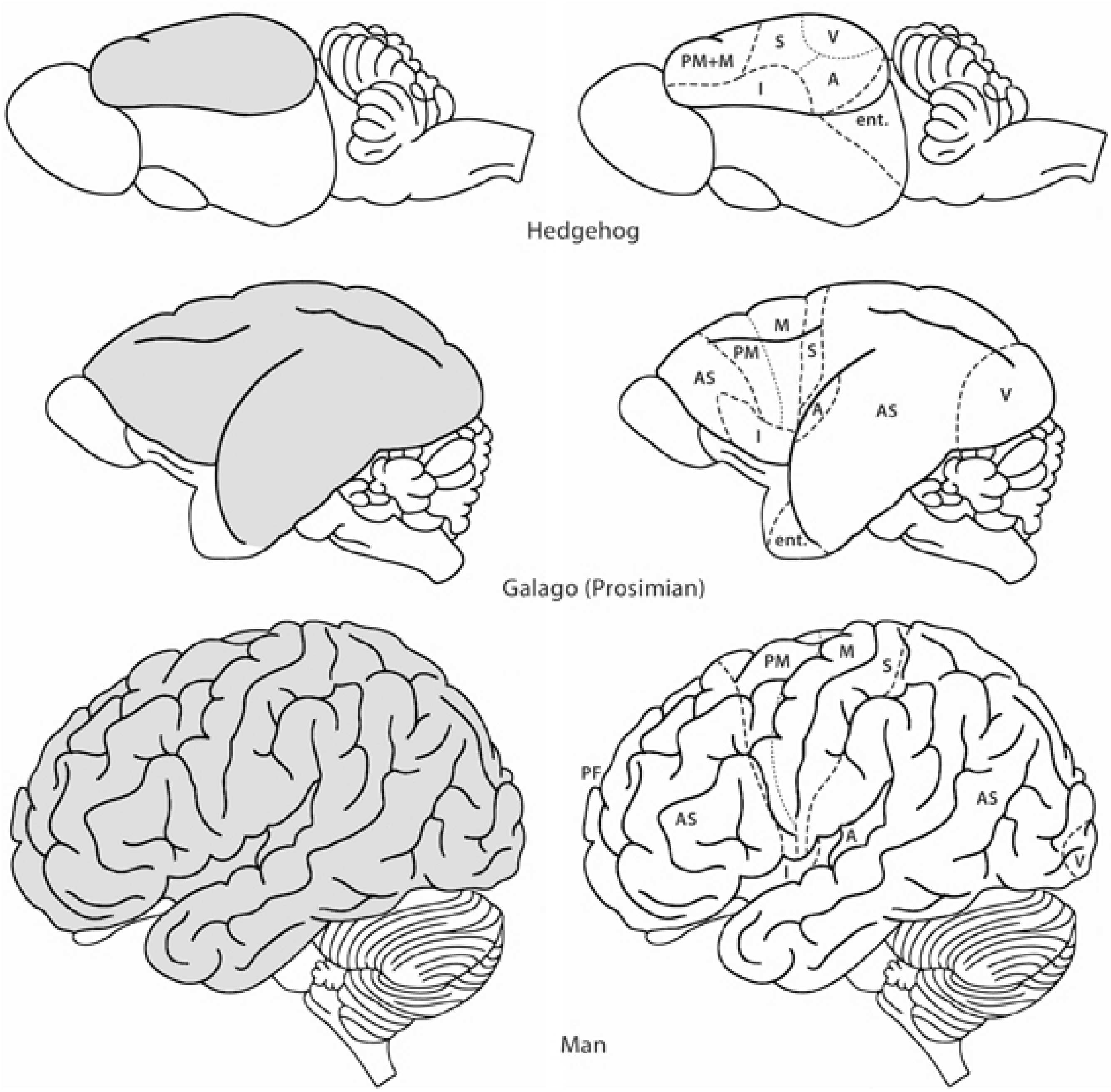


(Northcutt, 2002) (http://doi.org/10.1093/icb/42.4.743)

- Differences in size of the cerebral cortex



(Hofman, 2014) (https://doi.org/10.3389/fnana.2014.00015)

Figure 1. Lateral views of the brains of some mammals to show the evolutionary development of the neocortex (gray). In the hedgehog almost the entire neocortex is occupied by sensory and motor areas. In the prosimian Galago the sensory cortical areas are separated by an area occupied by association cortex (AS). A second area of association cortex is found in front of the motor cortex. In man these anterior and posterior association areas are strongly developed. A, primary auditory cortex; AS, association cortex; Ent, entorhinal cortex; I, insula;

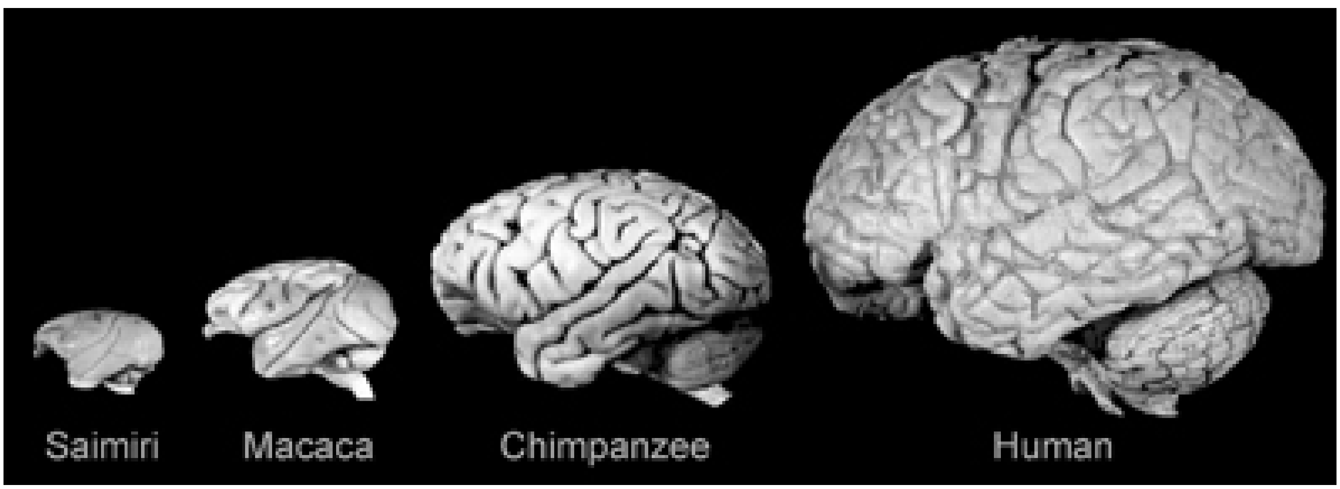
M, primary motor cortex; PF, prefrontal cortex; PM, premotor cortex; S, primary somatosensory cortex; V, primary visual cortex. Modified with permission from Nieuwenhuys (1994).

Structural measure	Non-human comparison	Human
Cortical gray matter %/tot brain vol	insectivores 25%	50%
Cortical gray + white	mice 40%	80%
Cerebellar mass	primates, mammals 10-15%	10-15%

- Evidence for greater gray and white matter (relative to total brain volume) in human cerebral cortex

[[@rakic2009evolution]](http://dx.doi.org/10.1038/nrn2719)

(Rakic, 2009) (http://dx.doi.org/10.1038/nrn2719)



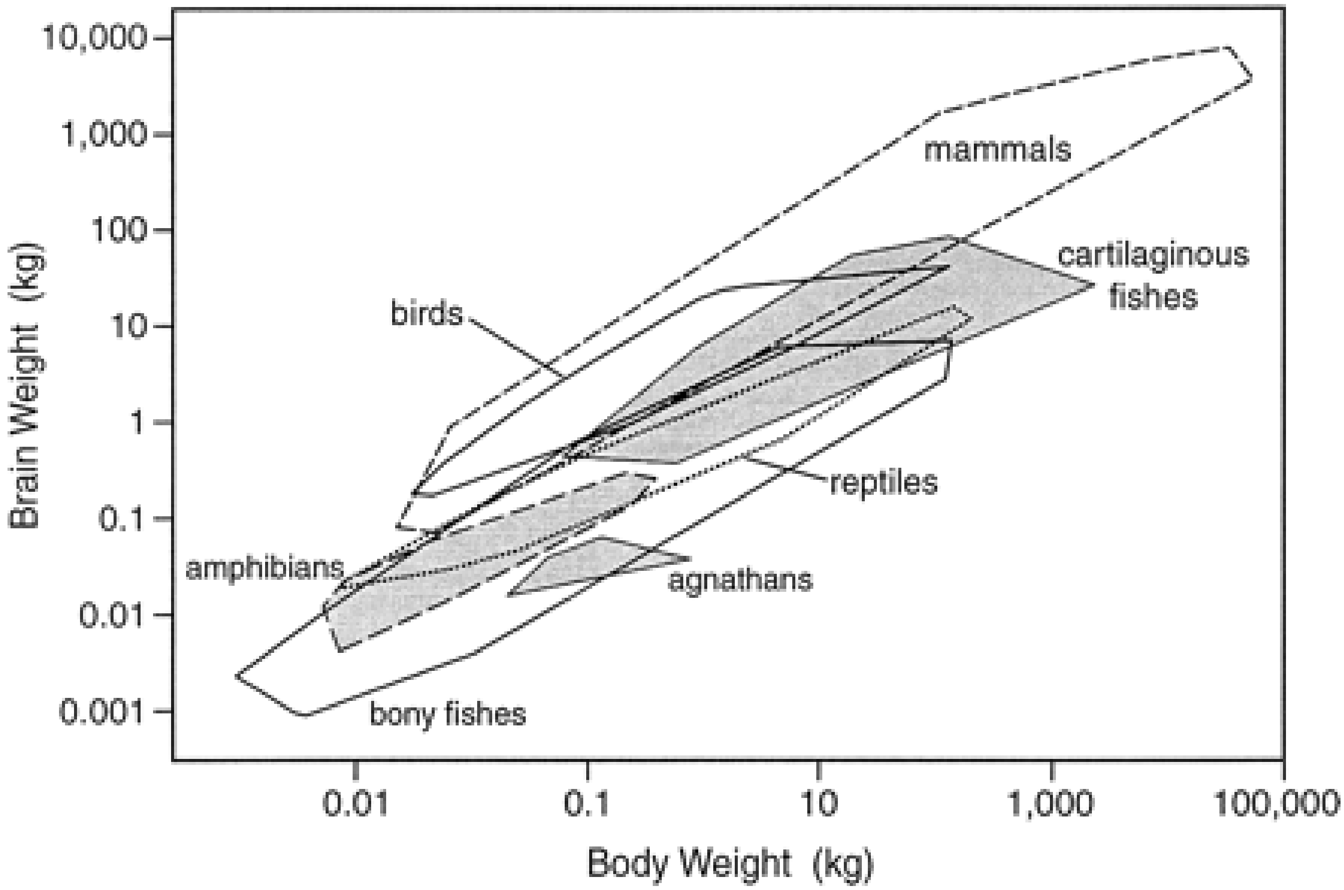
(Hofman, 2014) (https://doi.org/10.3389/fnana.2014.00015)

Take homes

- Brain sizes scale with body size
- Brain sizes (more or less) scale with animal class (more or less)

Old story

- Within mammals, human brains bigger than expected
    - Higher *encephalization quotient* – deviation from species-typical norm

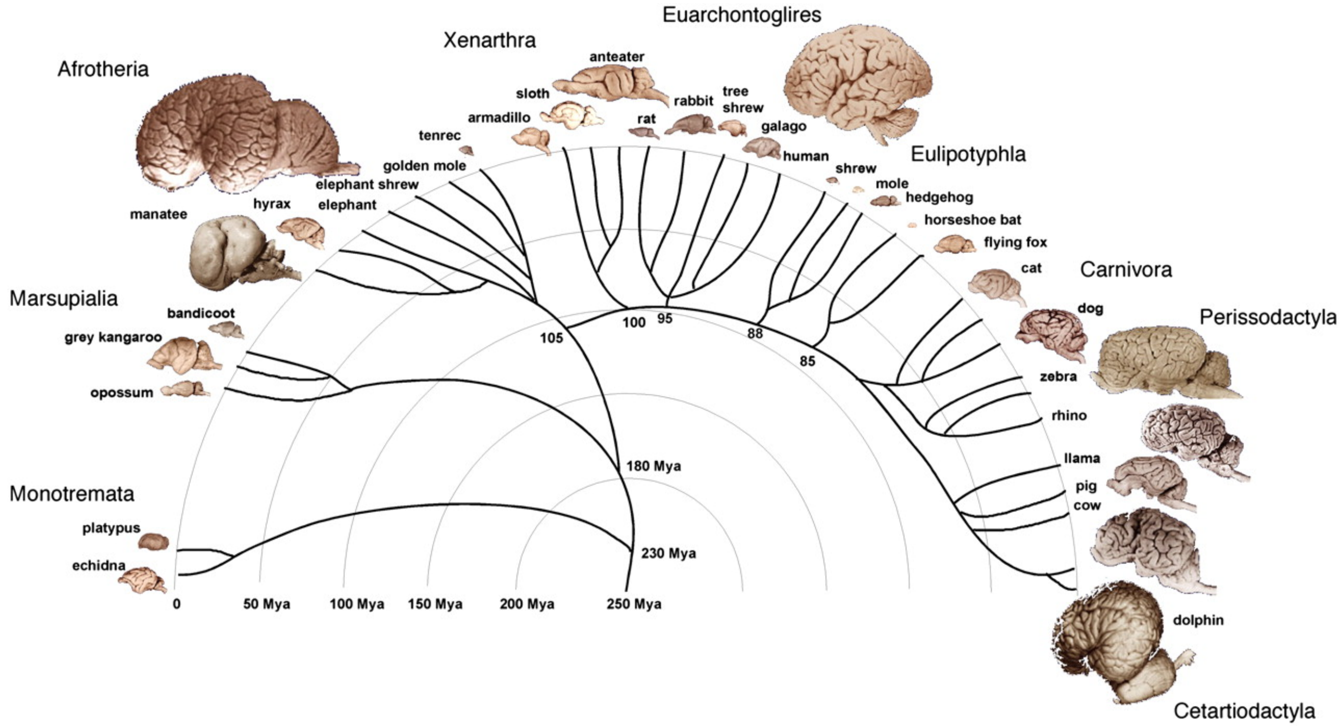


(Northcutt, 2002) (http://doi.org/10.1093/icb/42.4.743)

- Humans have larger cerebral cortical gray + white matter than comparable mammals

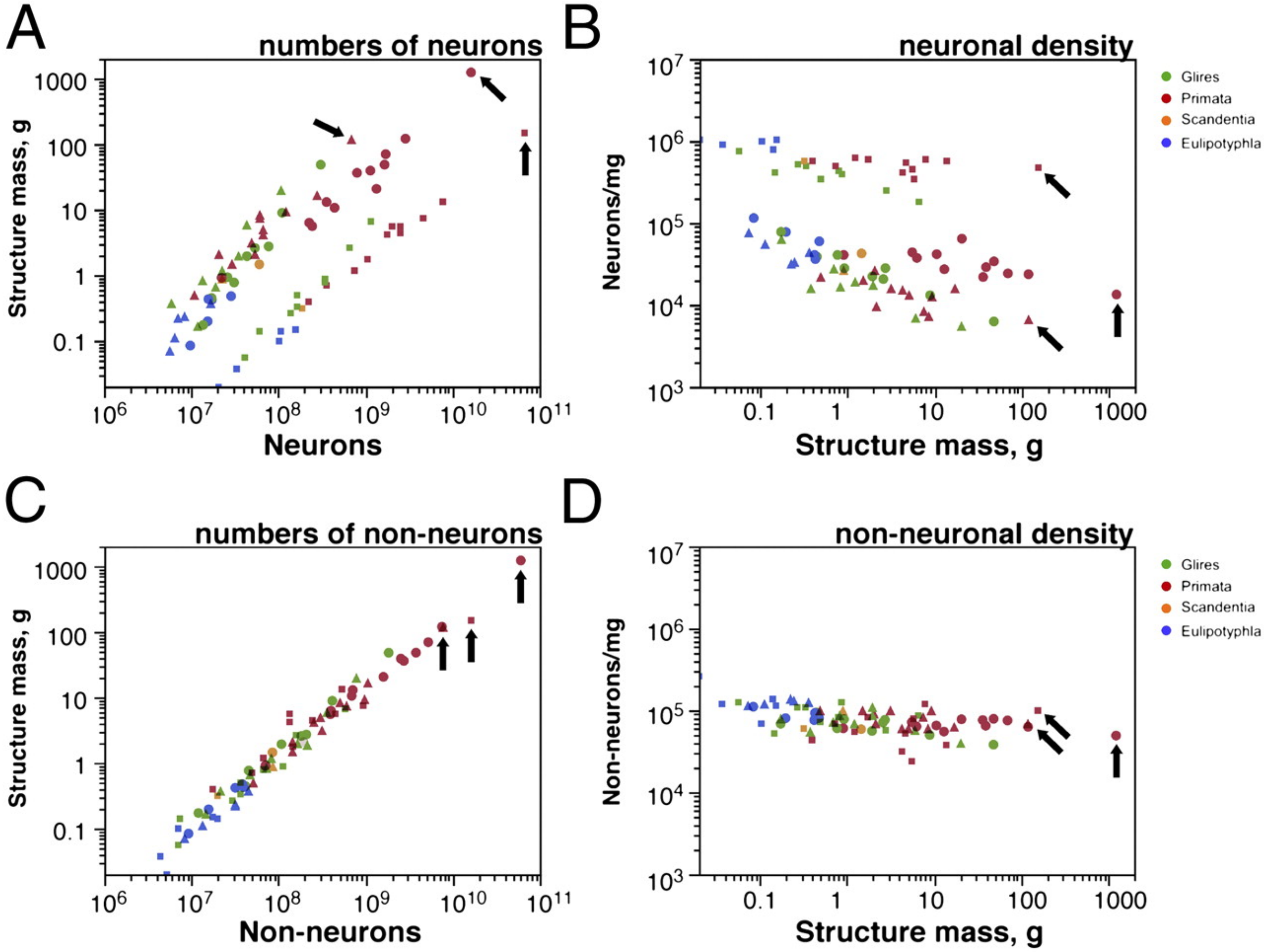
vs. New story

- Does brain size/mass matter (that much)?
- “Size matters” (brain mass) presumes similarity among brains at micro-level
- Big (large mass) brains arise in multiple mammalian lineages



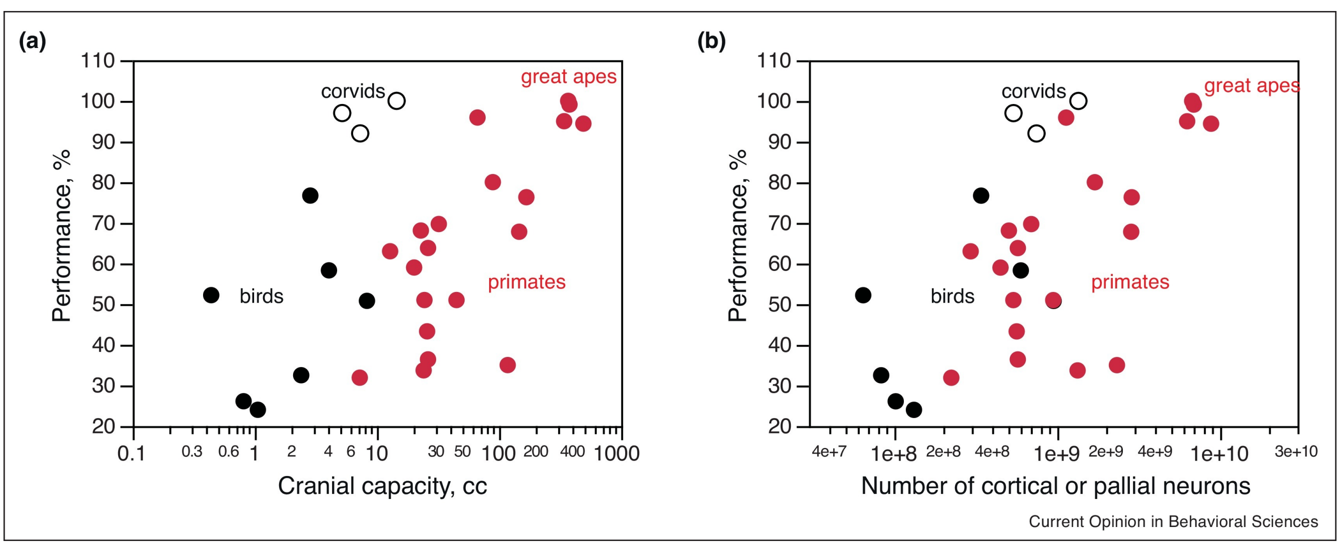
(Herculano-Houzel, 2012) (http://doi.org/10.1073/pnas.1201895109)

- *# of cortical neurons* more important difference than brain mass
- The primate advantage -> more cortical neurons, but not larger neurons & not more neurons in cerebellum
- Human brain just scaled up (non-ape) primate brain



(Herculano-Houzel, 2012) (http://doi.org/10.1073/pnas.1201895109)

# of cortical (or in birds, pallidum) neurons predicts "cognition?"

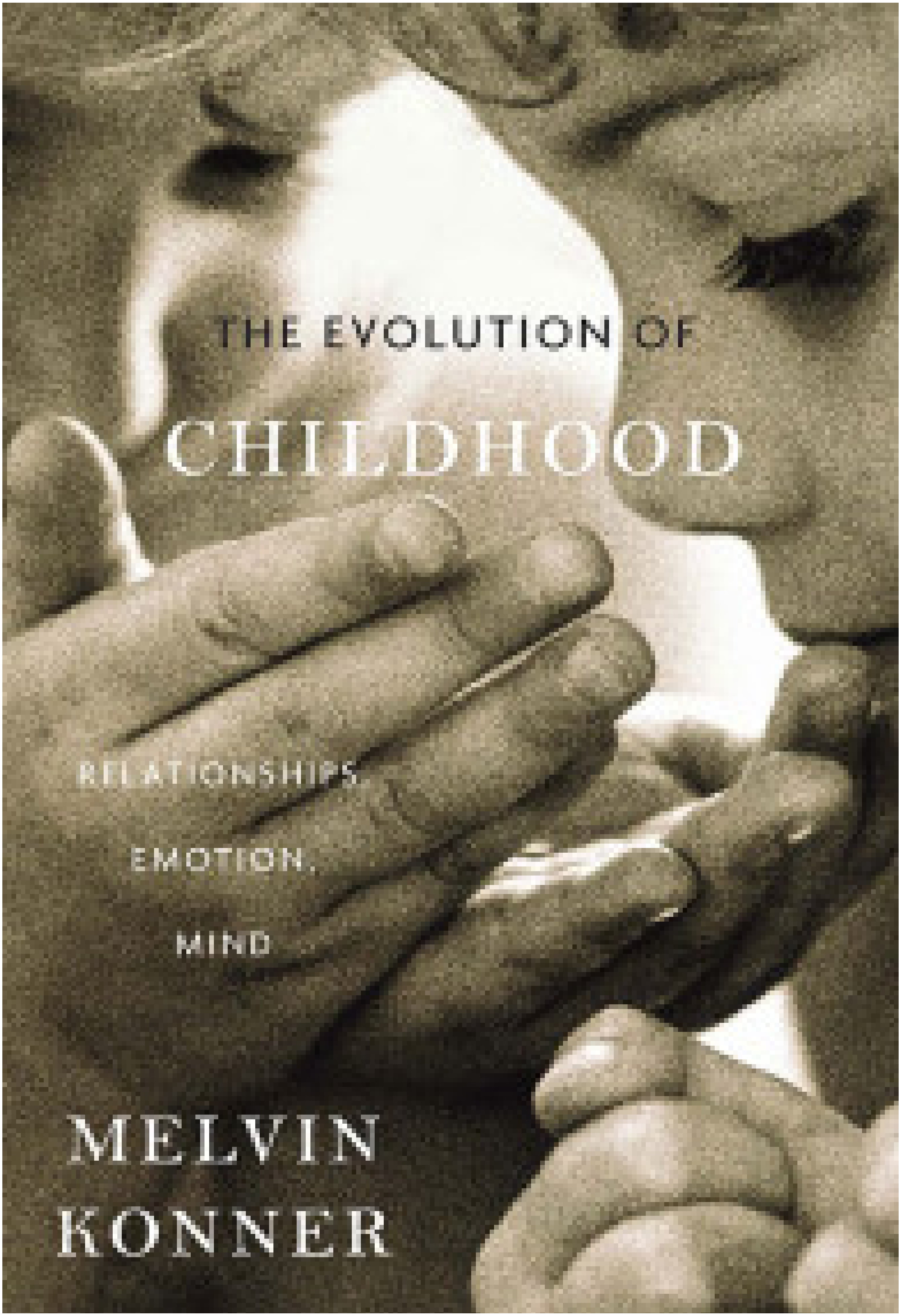


(Herculano-Houzel, 2017) (http://doi.org/10.1016/j.cobeha.2017.02.004)

The Human Advantage (Herculano-Houzel, 2016)

- Brain
    - More neurons in cerebral cortex than other mammals
- Behavior
    - Less time spent foraging
        - Higher quality/more energetically dense food
        - Higher food availability
    - Cultural factors (agriculture + cooking), see also (Wrangham, 2009)

A further human advantage


THE EVOLUTION OF
CHILDHOOD
RELATIONSHIPS,
EMOTION,
MIND
MELVIN
KONNER

Human brain development

Prenatal period

Insemination

- 3-4 days before or up to 1-2 days after…
    - Ovulation

Fertilization

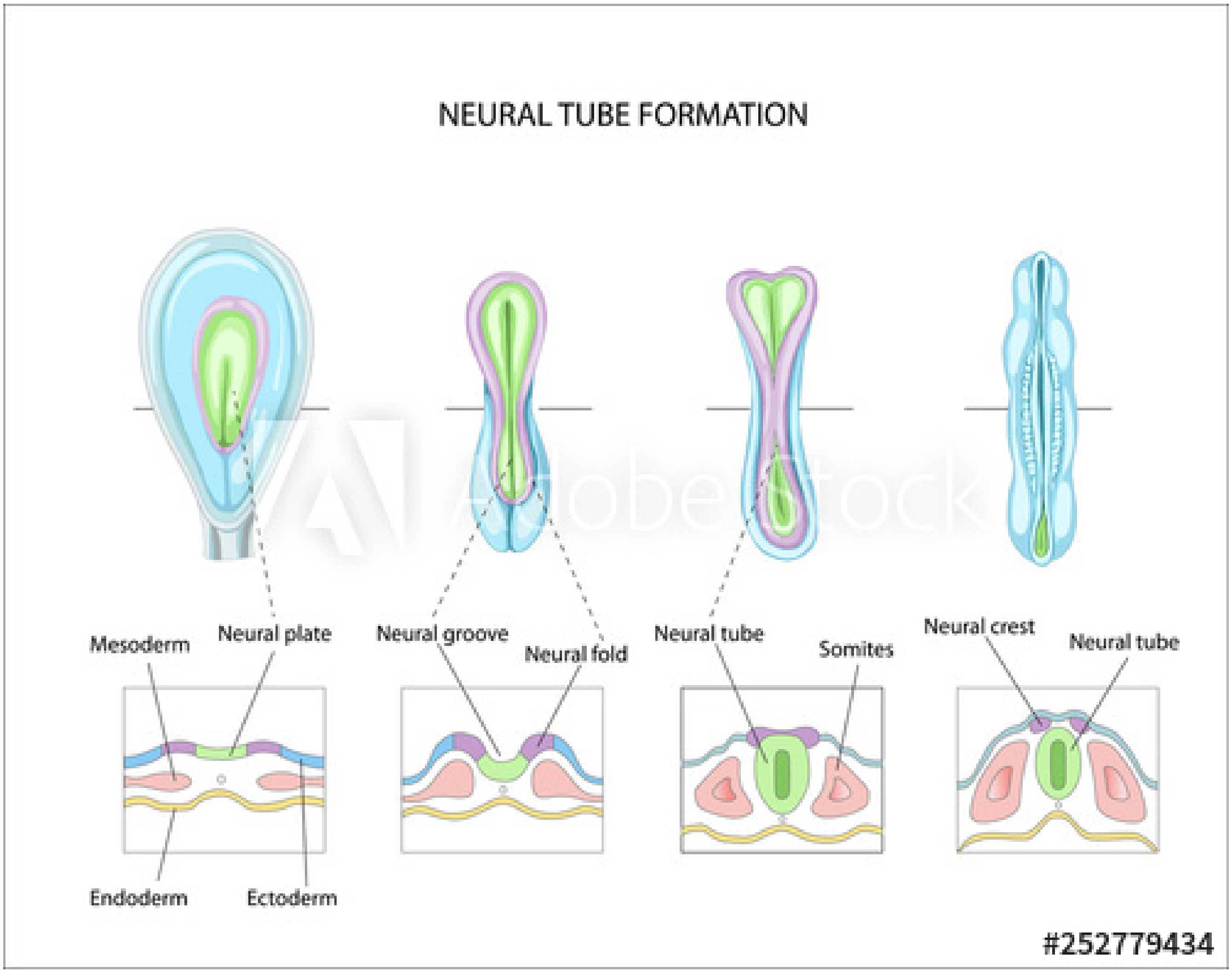
- Within ~ 24 hrs of ovulation

Implantation

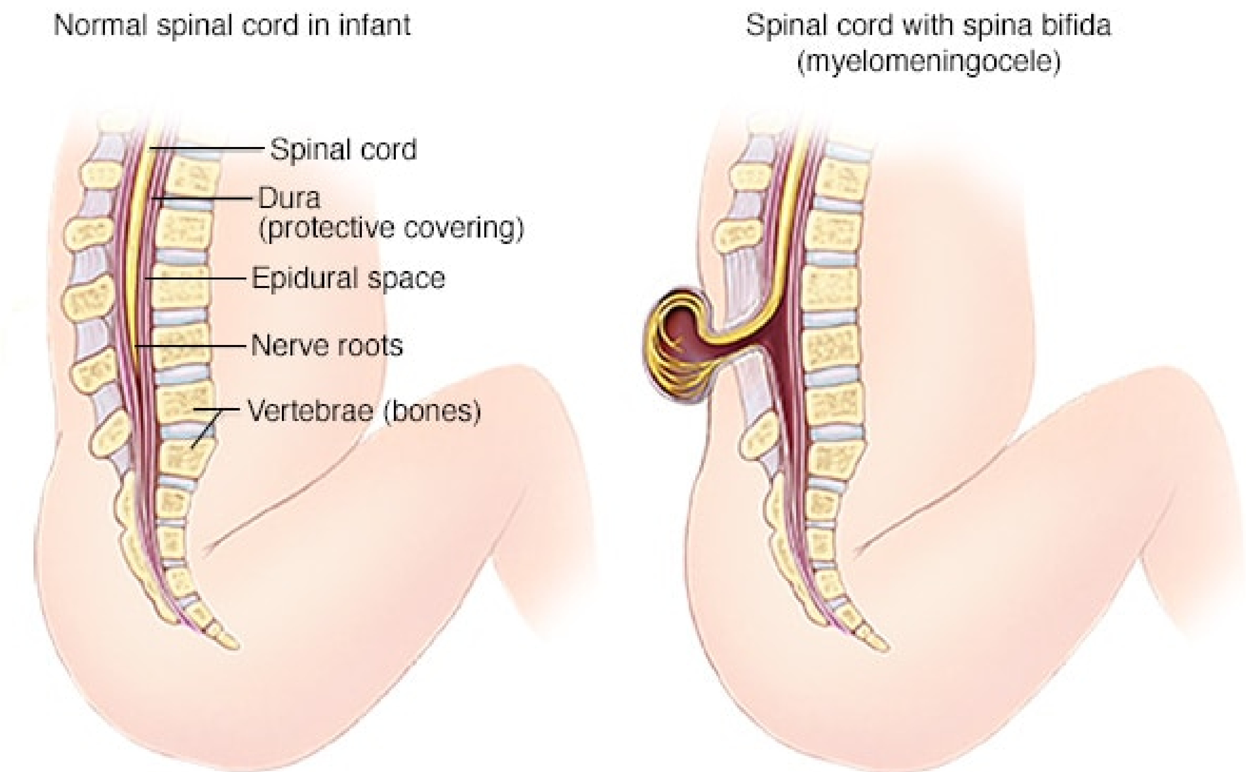
- ~ 6 days after fertilization

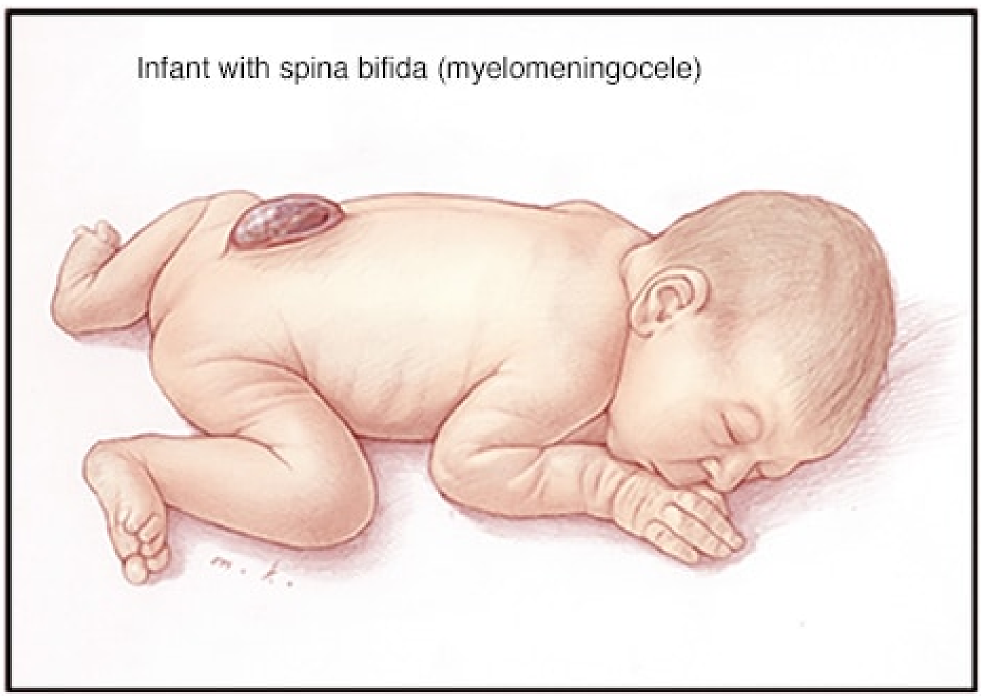
Early embryogenesis

Formation of *neural tube* (neurulation)



- Embryonic layers: ectoderm, mesoderm, endoderm
- ~18-26 days
- Failures of neural tube closure
  - Anencephaly (rostral neuraxis)
  - Spina bifida (caudal neuraxis)

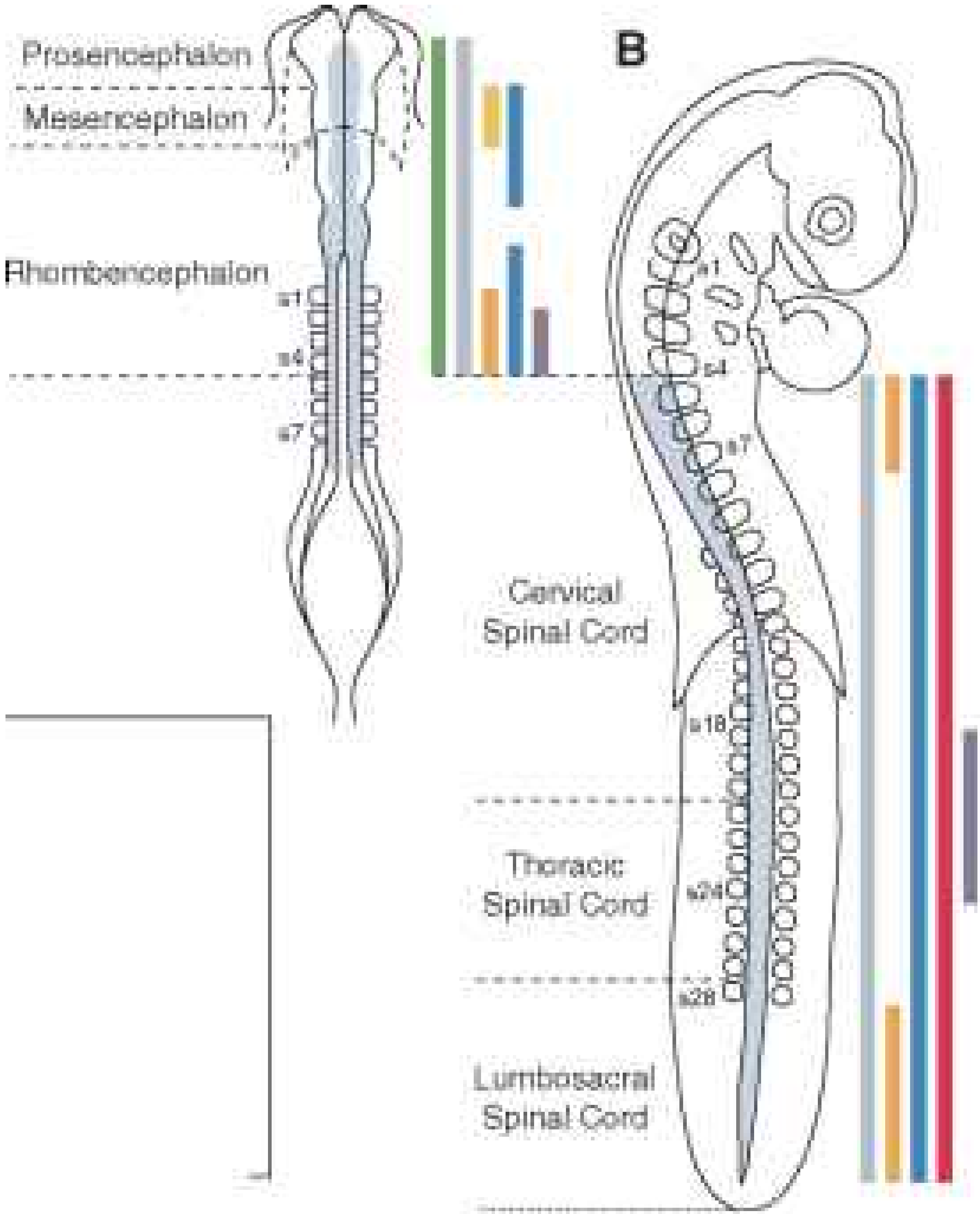




https://www.mayoclinic.org/diseases-conditions/spina-bifida/symptoms-causes/syc-20377860 (https://www.mayoclinic.org/diseases-conditions/spina-bifida/symptoms-causes/syc-20377860)

- Neural tube becomes
  - Ventricles & cerebral aqueduct

- Central canal of spinal cord



Neurogenesis and gliogenesis

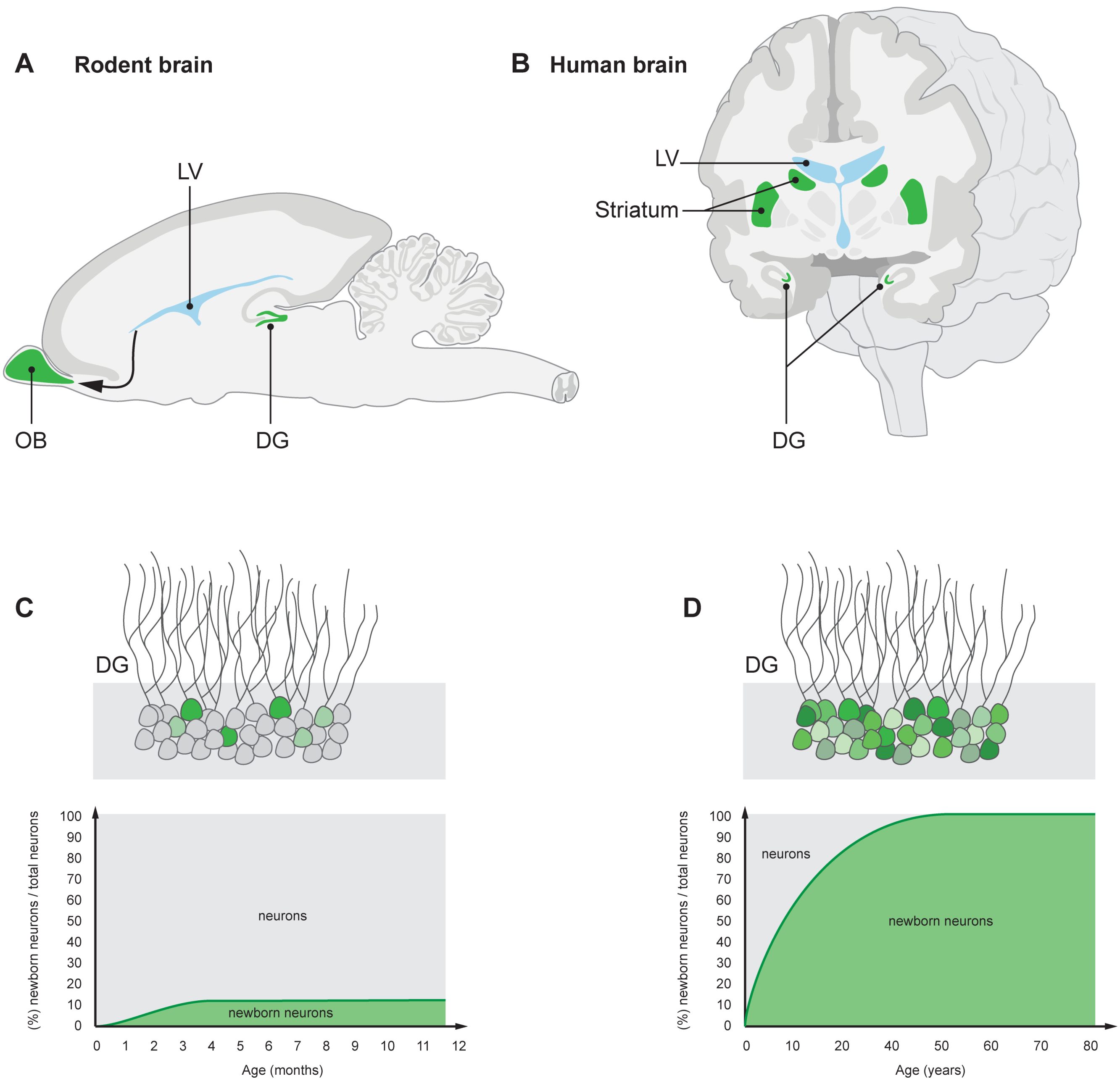
- Neuroepithelium cell layer lines neural tube

- Peri-ventricular regions remain home to cells that can produce new cells

[[@Gotz2005-yj]](https://doi.org/10.1038/nrm1739)

(Götz & Huttner, 2005) (https://doi.org/10.1038/nrm1739)

- Areas in adult human brain that generate new neurons
  - hippocampus
  - striatum
  - olfactory bulb (minimally)
  - weak evidence for neurogenesis in adult cerebral cortex

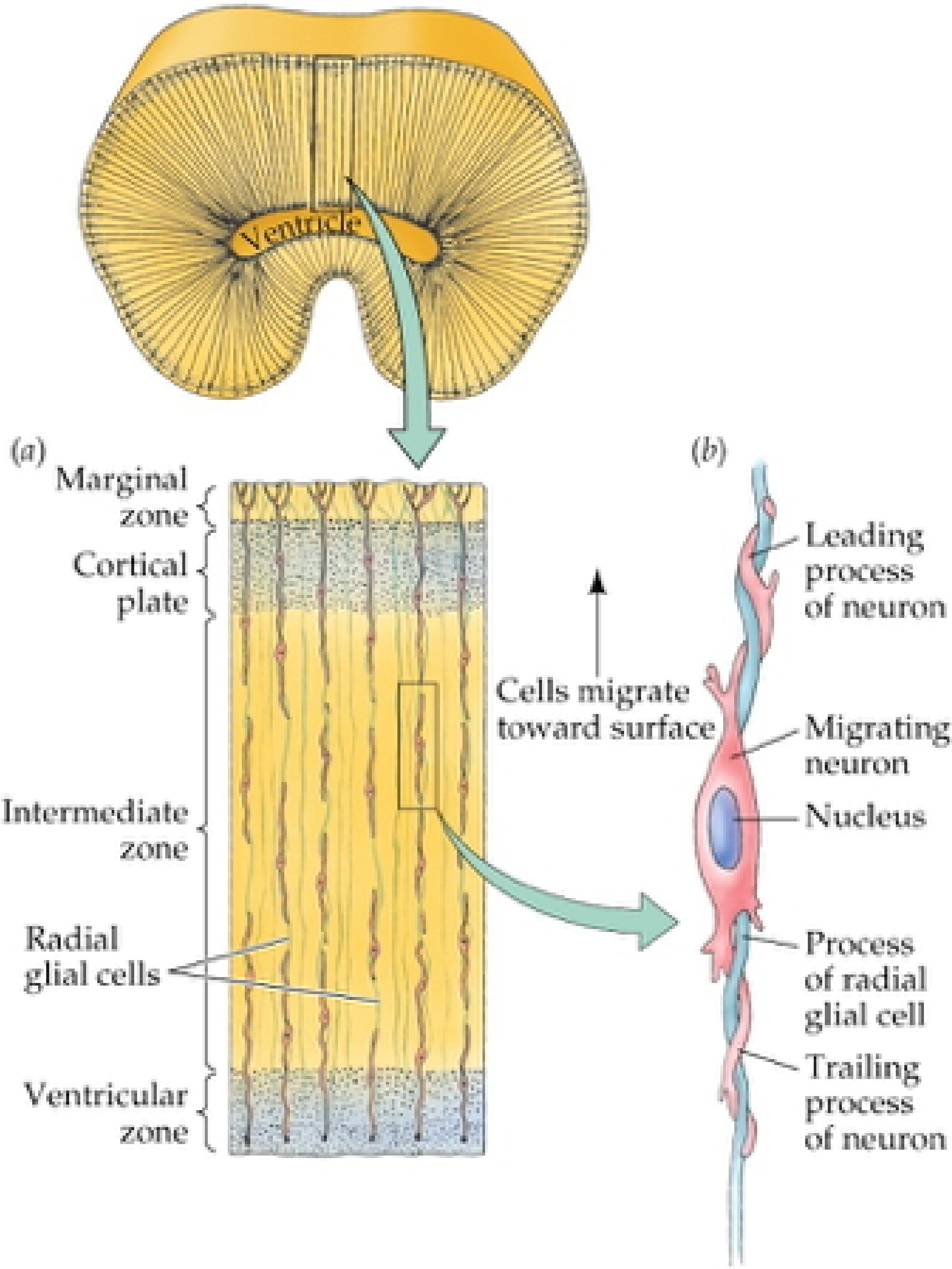


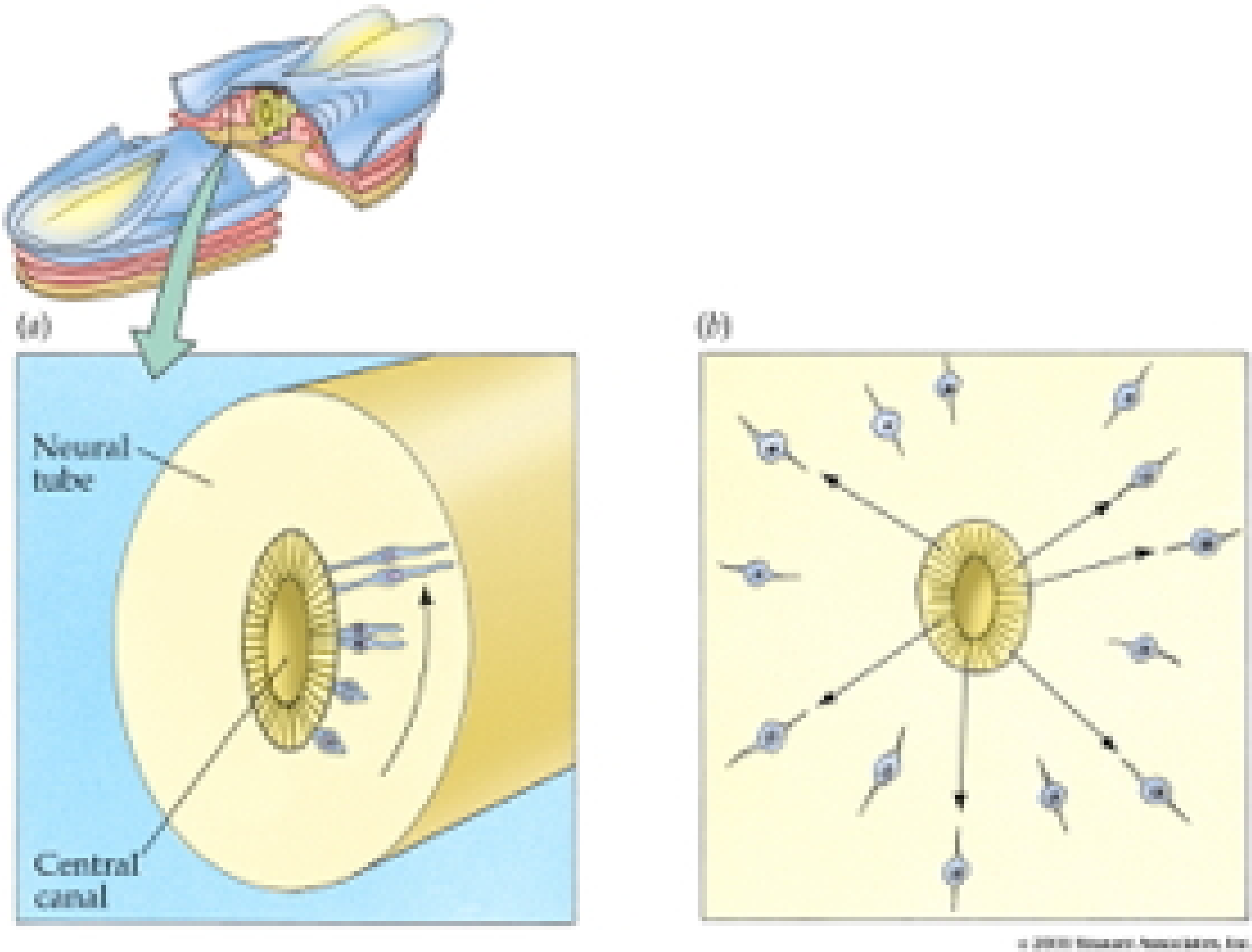
Ernst & Frisen 2015 (https://doi.org/10.1371/journal.pbio.1002045)

- Neural stem cells

    - Undergo *symmetric* & *asymmetric* cell division
    - Generate glia, neurons, and basal progenitor cells

Radial glia and cell migration


Ventricle
(a)
Marginal zone
Cortical plate
Intermediate zone
Radial glial cells
Ventricular zone
Cells migrate toward surface
(b)
Leading process of neuron
Migrating neuron
Nucleus
Process of radial glial cell
Trailing process of neuron



Radial unit hypothesis

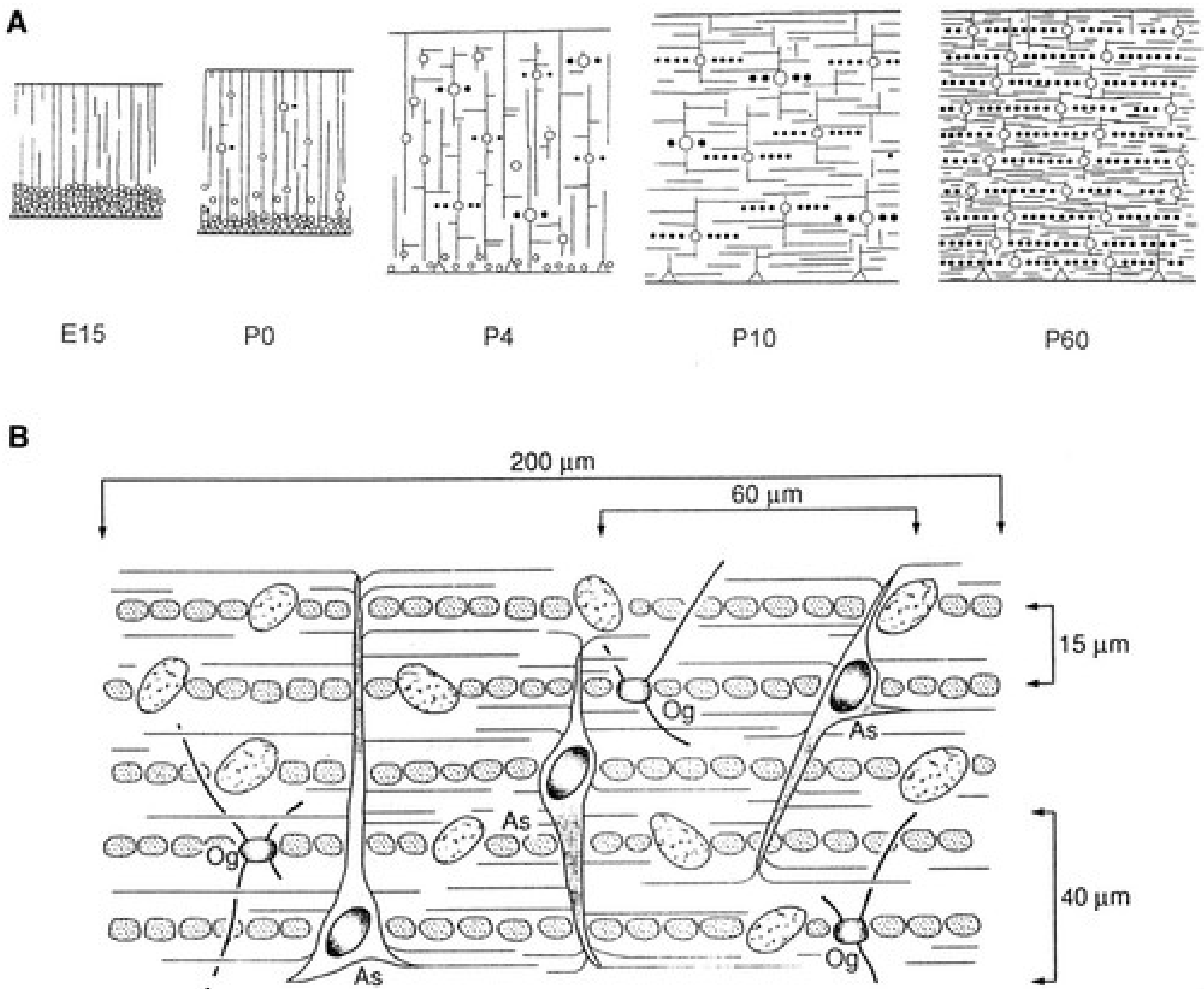
[[@rakic2009evolution]](http://dx.doi.org/10.1038/nrn2719)

(Rakic, 2009) (http://dx.doi.org/10.1038/nrn2719)

Axon growth cone

- Chemoattractants
  - e.g., Nerve Growth Factor (NGF)
- Chemorepellents
- Receptors in growth cone detect chemical gradients

Glia migrate, too



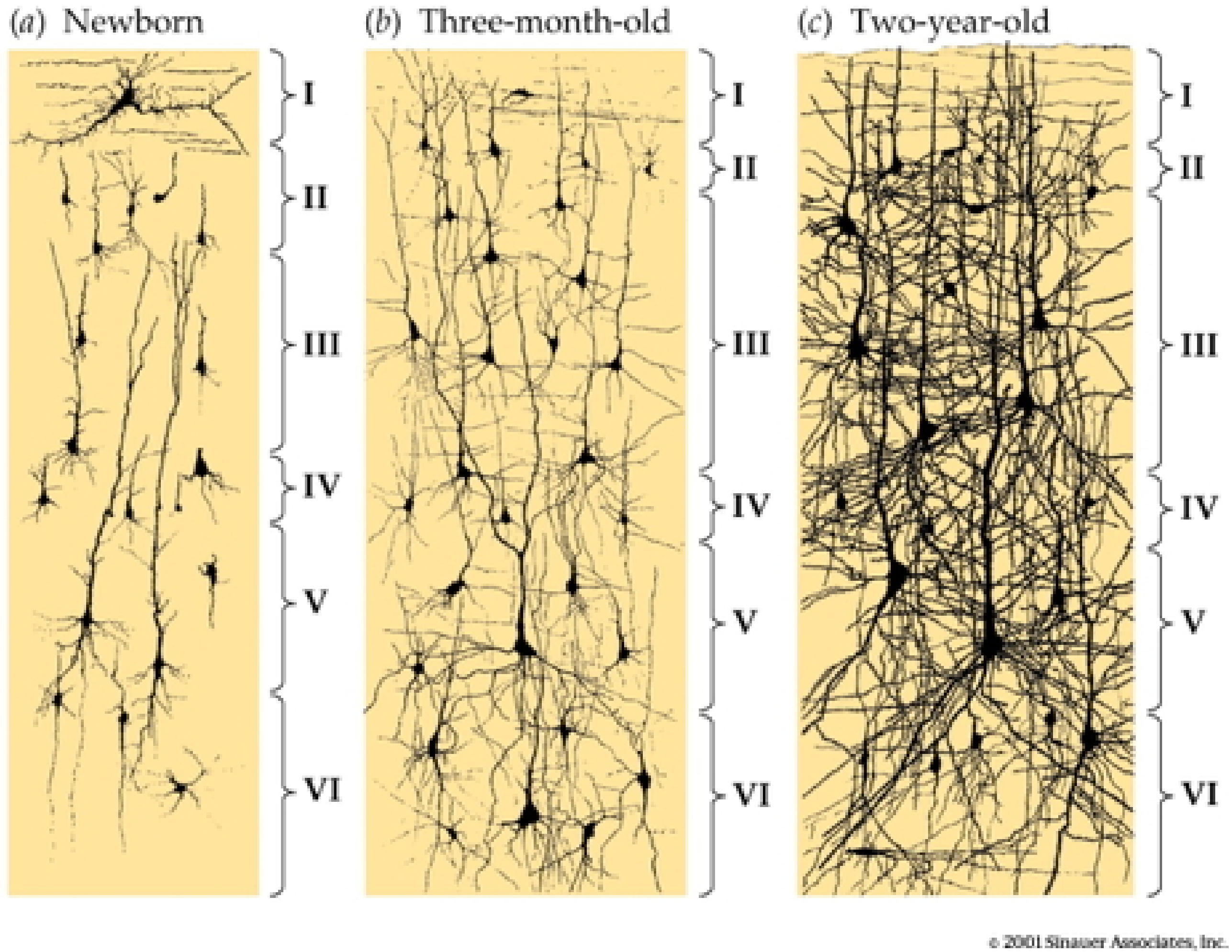
(Baumann & Pham-Dinh, 2001) (http://dx.doi.org/10.1152/physrev.2001.81.2.871)

Differentiation

- Neuron vs. glial cell
- Cell type
  - myelin-producing vs. astrocyte vs. microglia
  - pyramidal cell vs. stellate vs. Purkinje vs. …
- NTs released
- Where to connect

Infancy & Early Childhood

Synaptogenesis

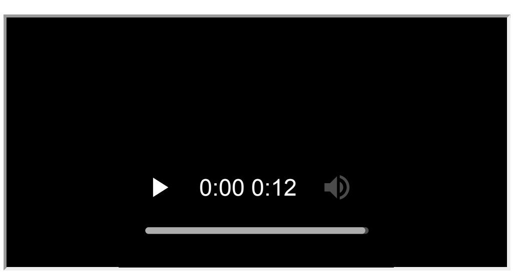


Proliferation, pruning

- Early proliferation
- Later pruning
- Rates, peaks differ by area

Apoptosis

- Programmed cell death

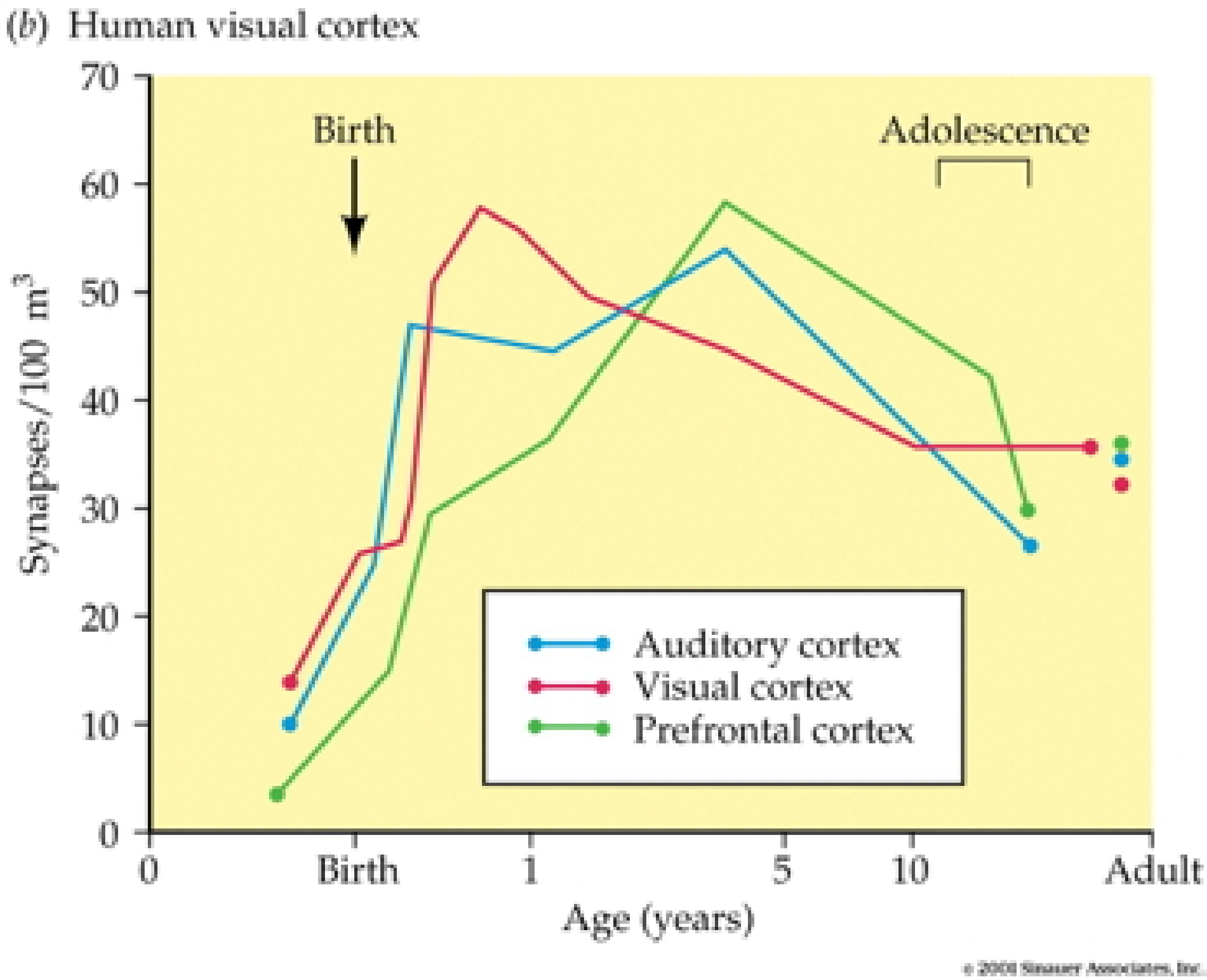


- 20-80%, varies by area
- Spinal cord >> cortex
- Quantity of nerve growth factors (NGF) influences

[[@rakic2009evolution]](http://dx.doi.org/10.1038/nrn2719)

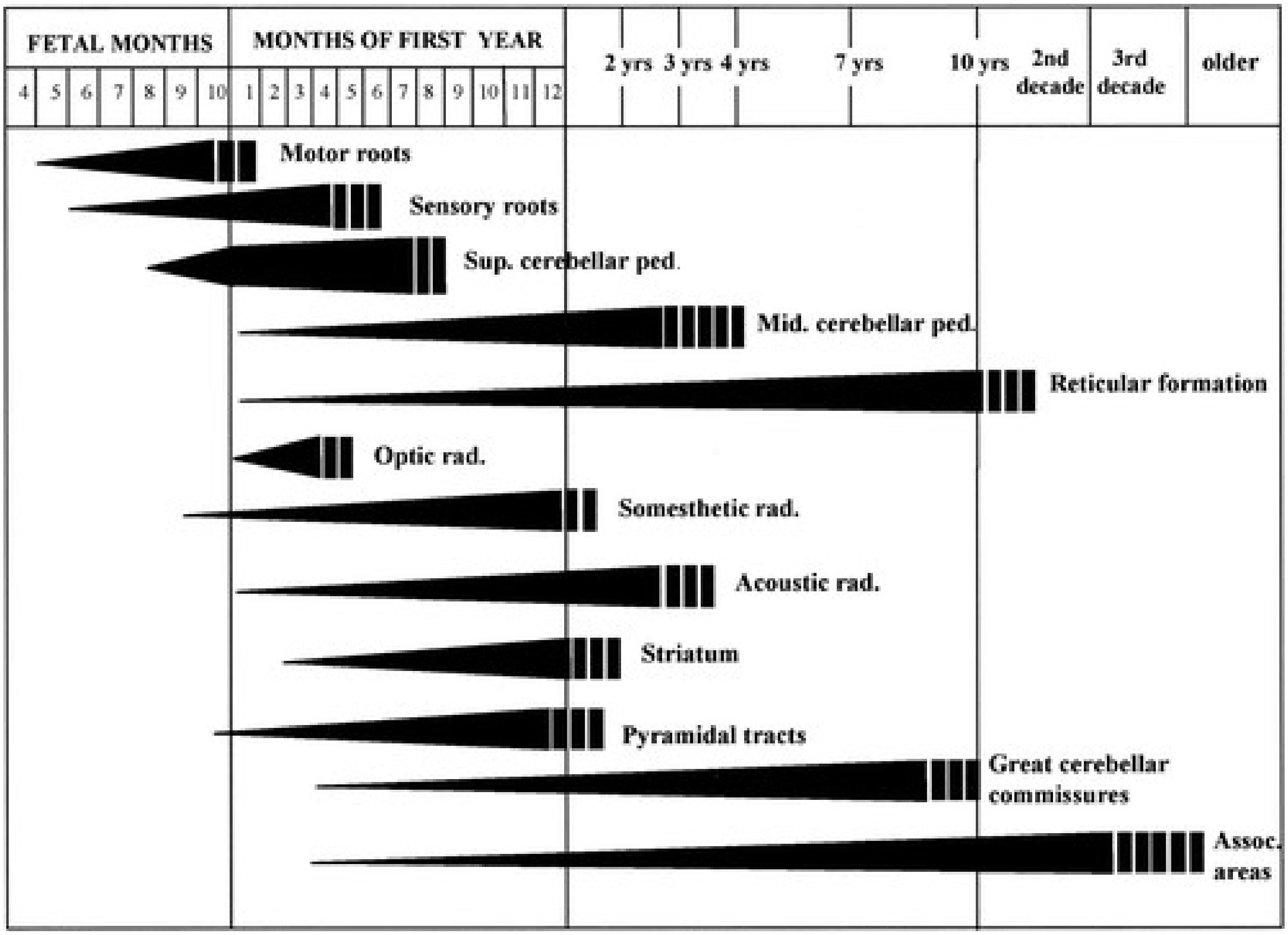
(Rakic, 2009) (http://dx.doi.org/10.1038/nrn2719)

Synaptic rearrangement



- Progressive phase: growth rate >> loss rate
- Regressive phase: growth rate << loss rate

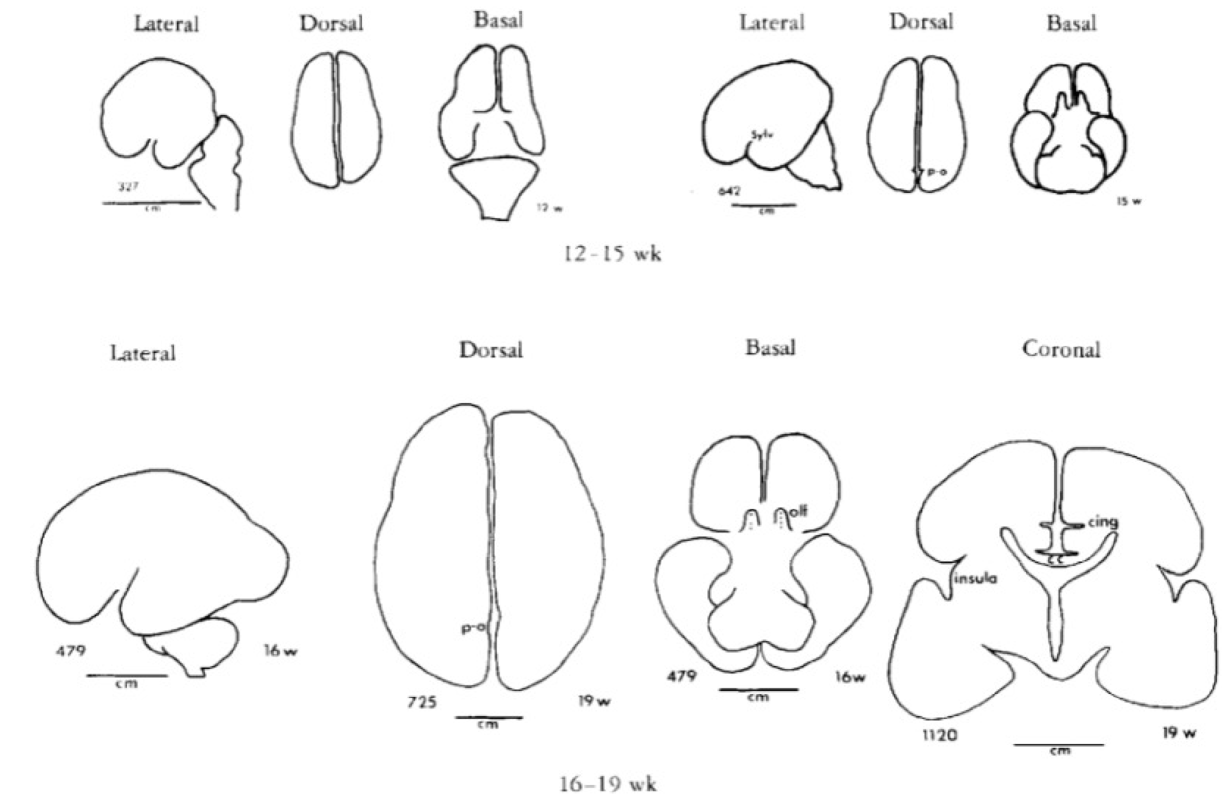
Myelination



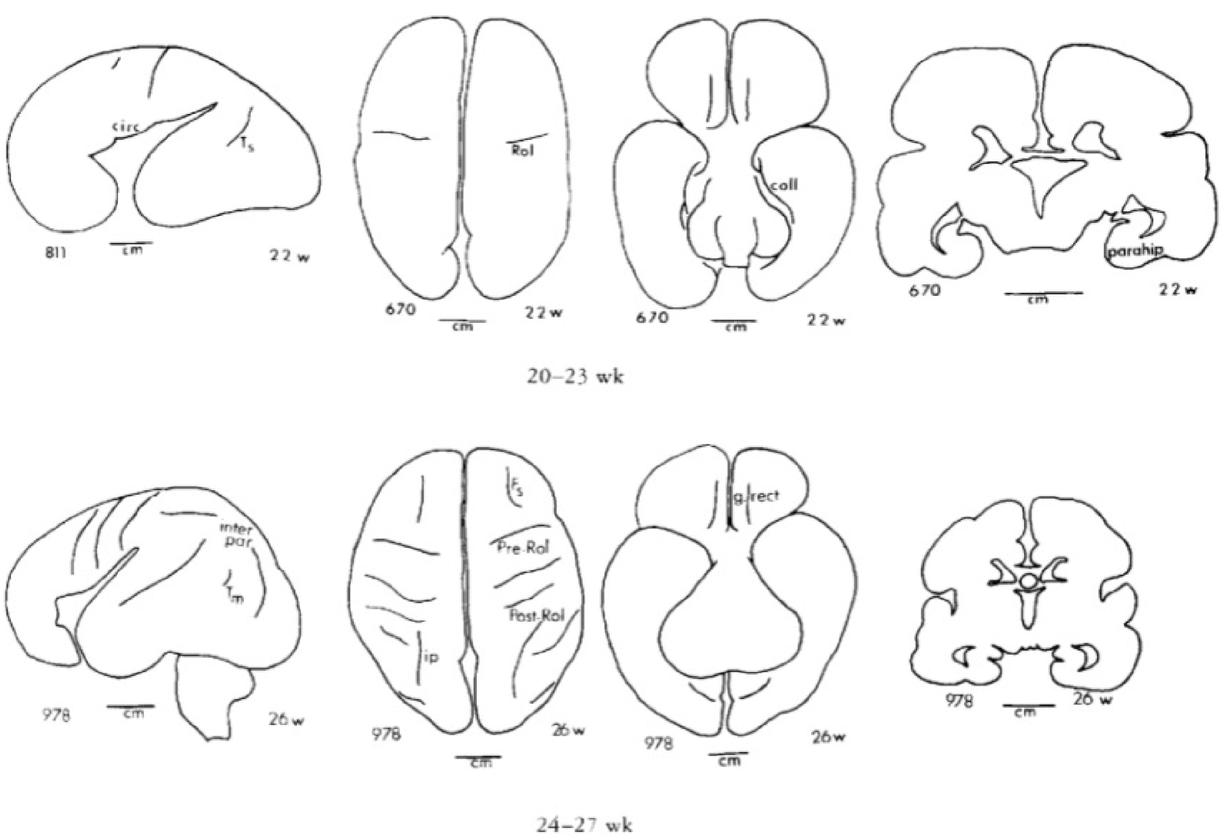
(Baumann & Pham-Dinh, 2001) (http://dx.doi.org/10.1152/physrev.2001.81.2.871)

- Neonatal brain largely unmyelinated
- Gradual myelination, peaks in mid-20s
- Non-uniform pattern
    - Spinal cord before brain
    - Sensory before motor

Gyral development



(Chi, Dooling, & Gilles, 1977) (http://doi.org/10.1002/ana.410010109)



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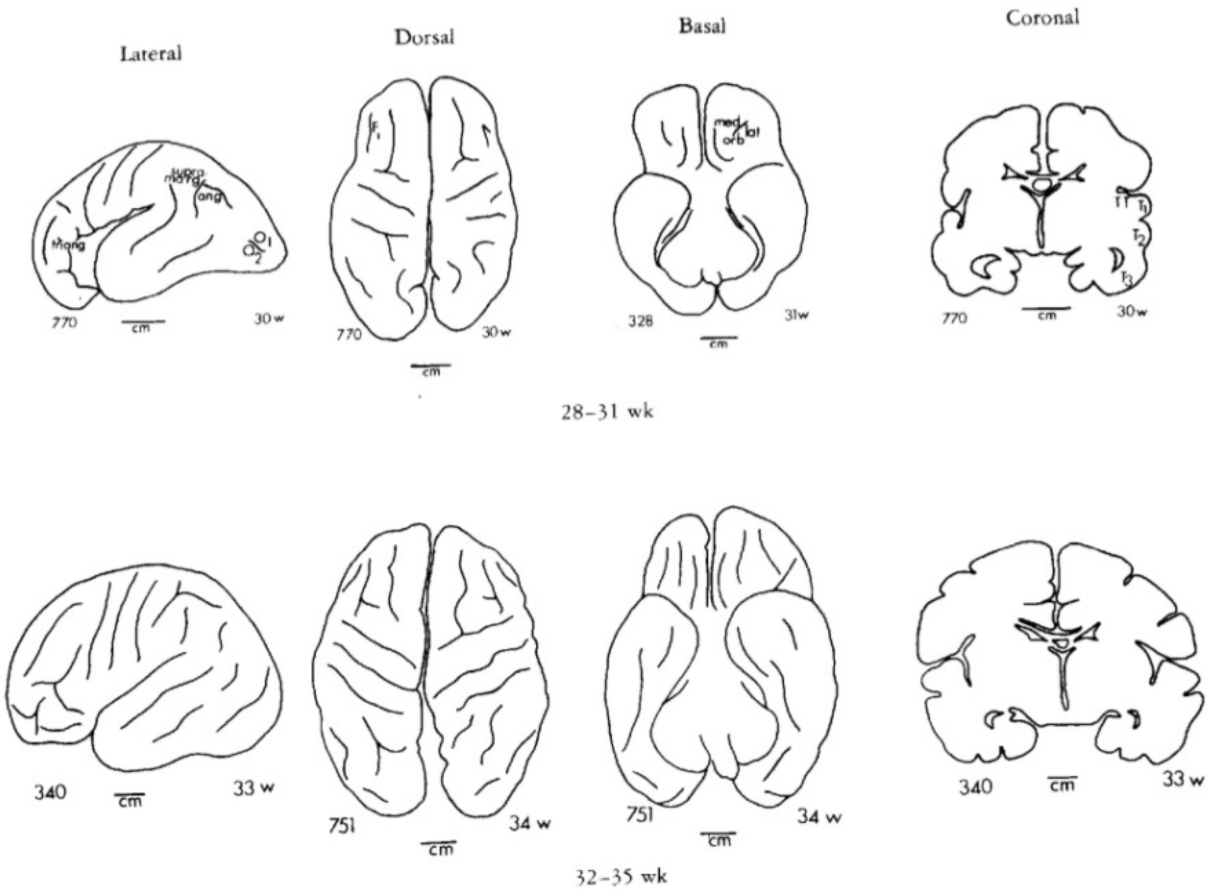

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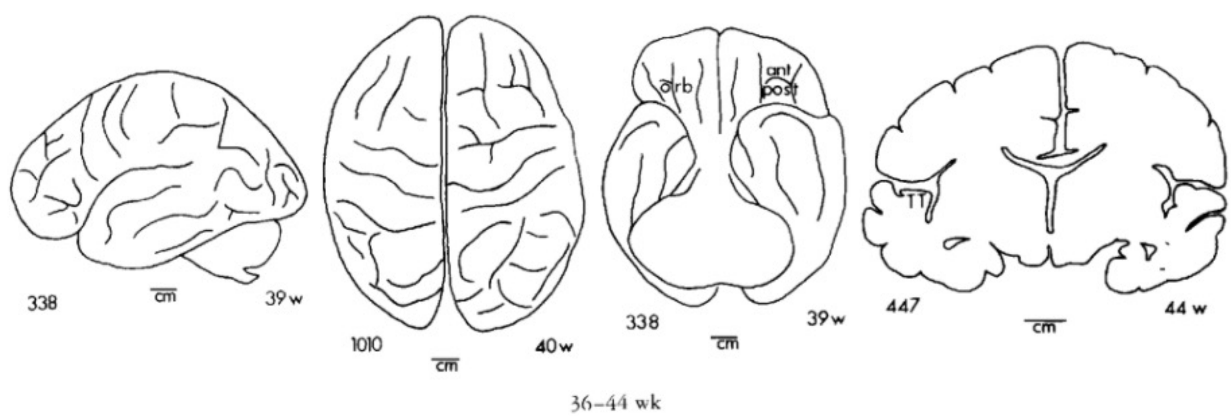
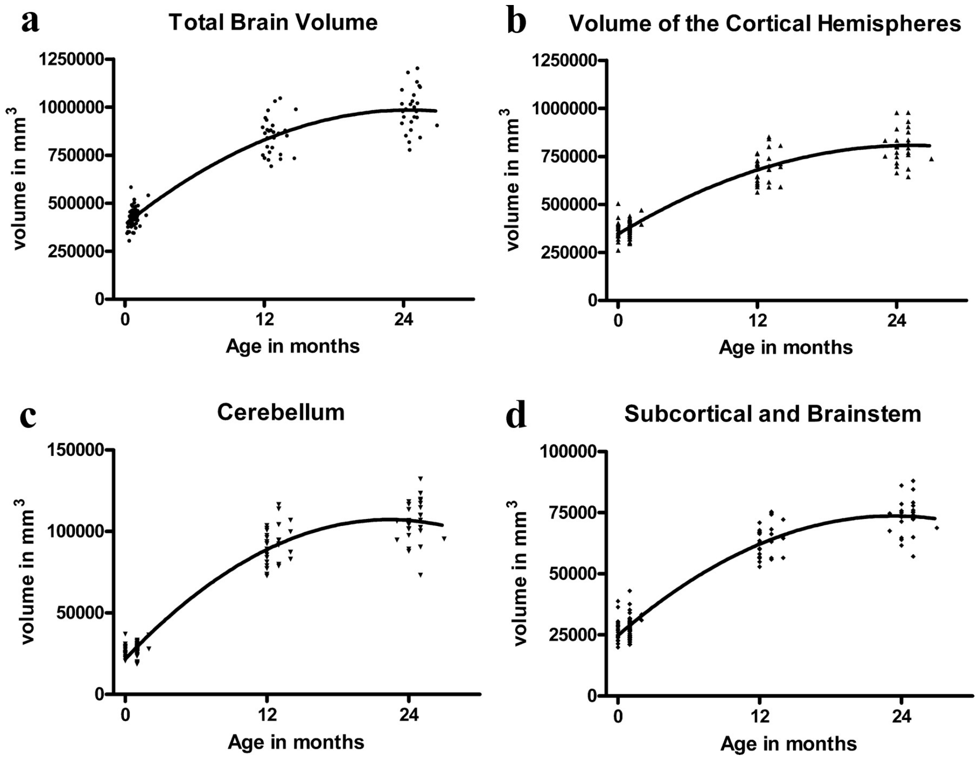


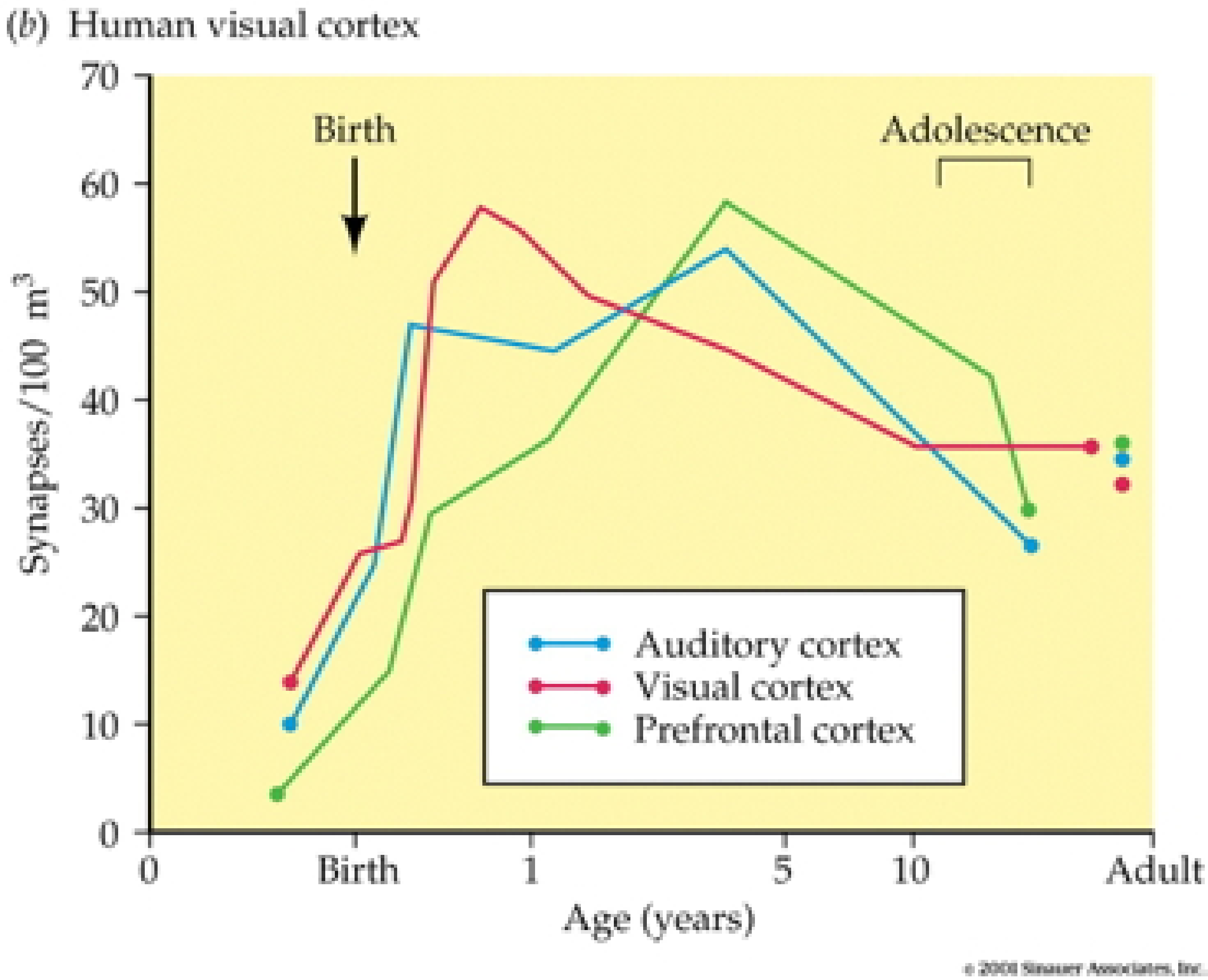
(Chi, Dooling, & Gilles, 1977) (http://doi.org/10.1002/ana.410010109)

Structural/morphometric development

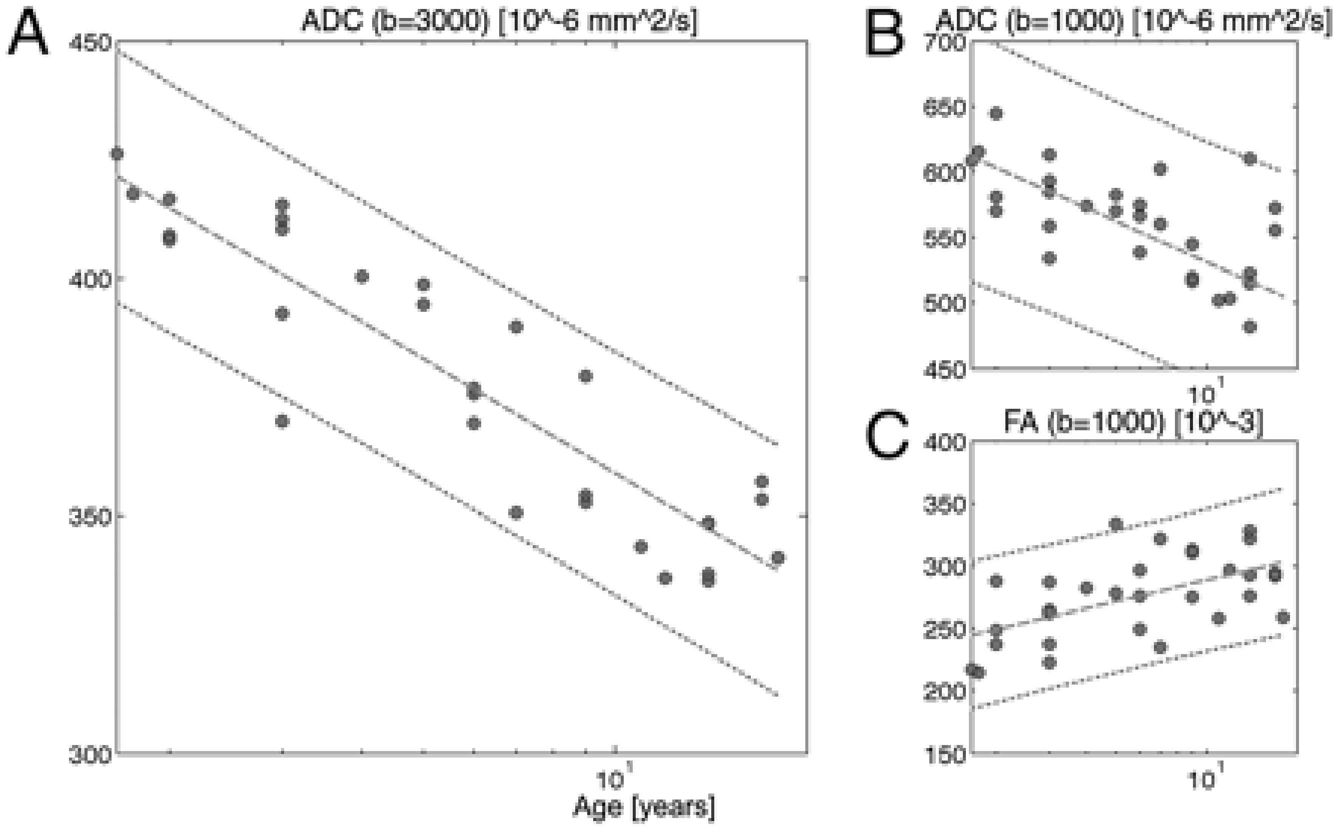


(Knickmeyer et al., 2008) (http://doi.org/10.1523/JNEUROSCI.3479-08.2008)

Synaptogenesis

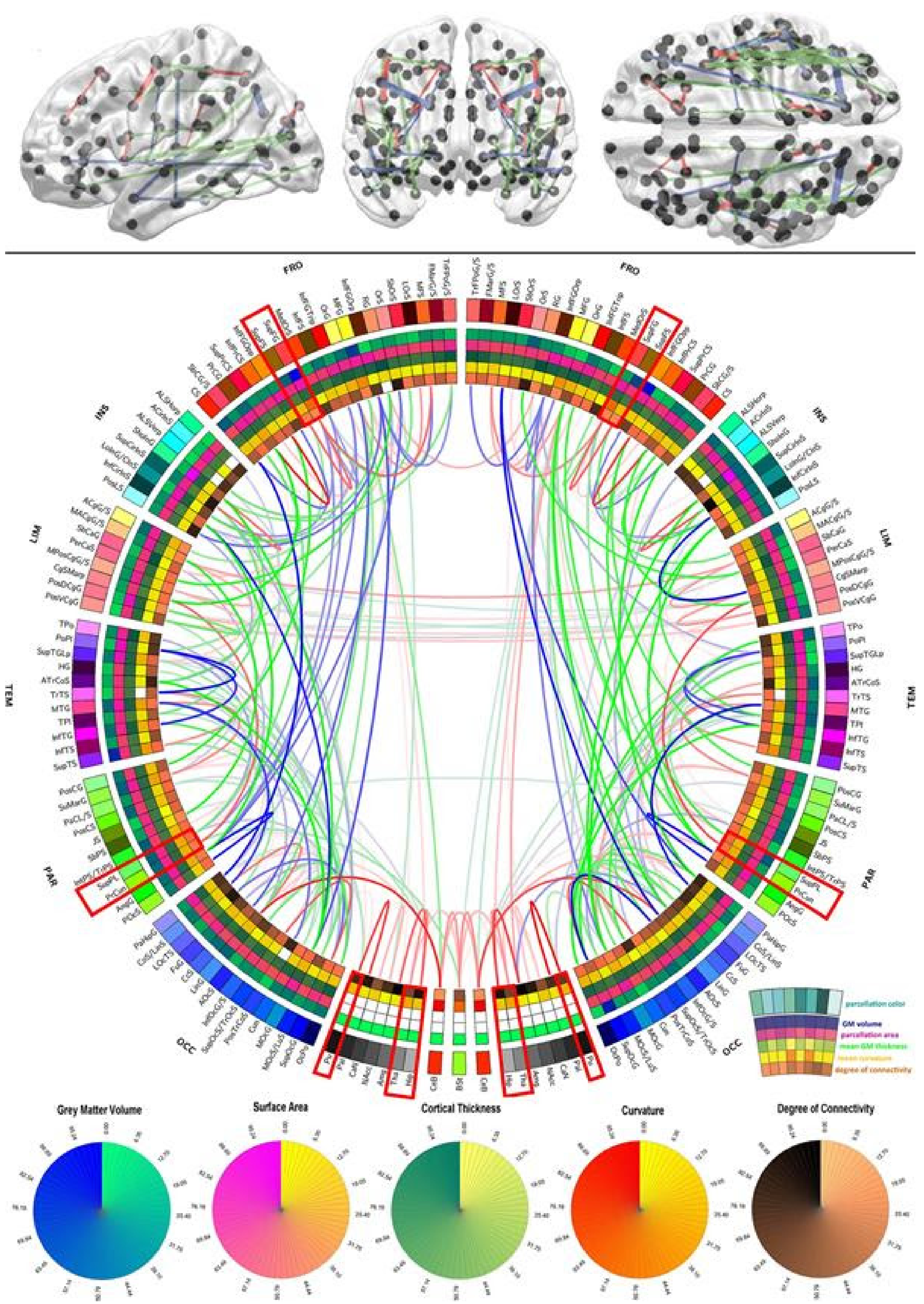


Myelination across human development



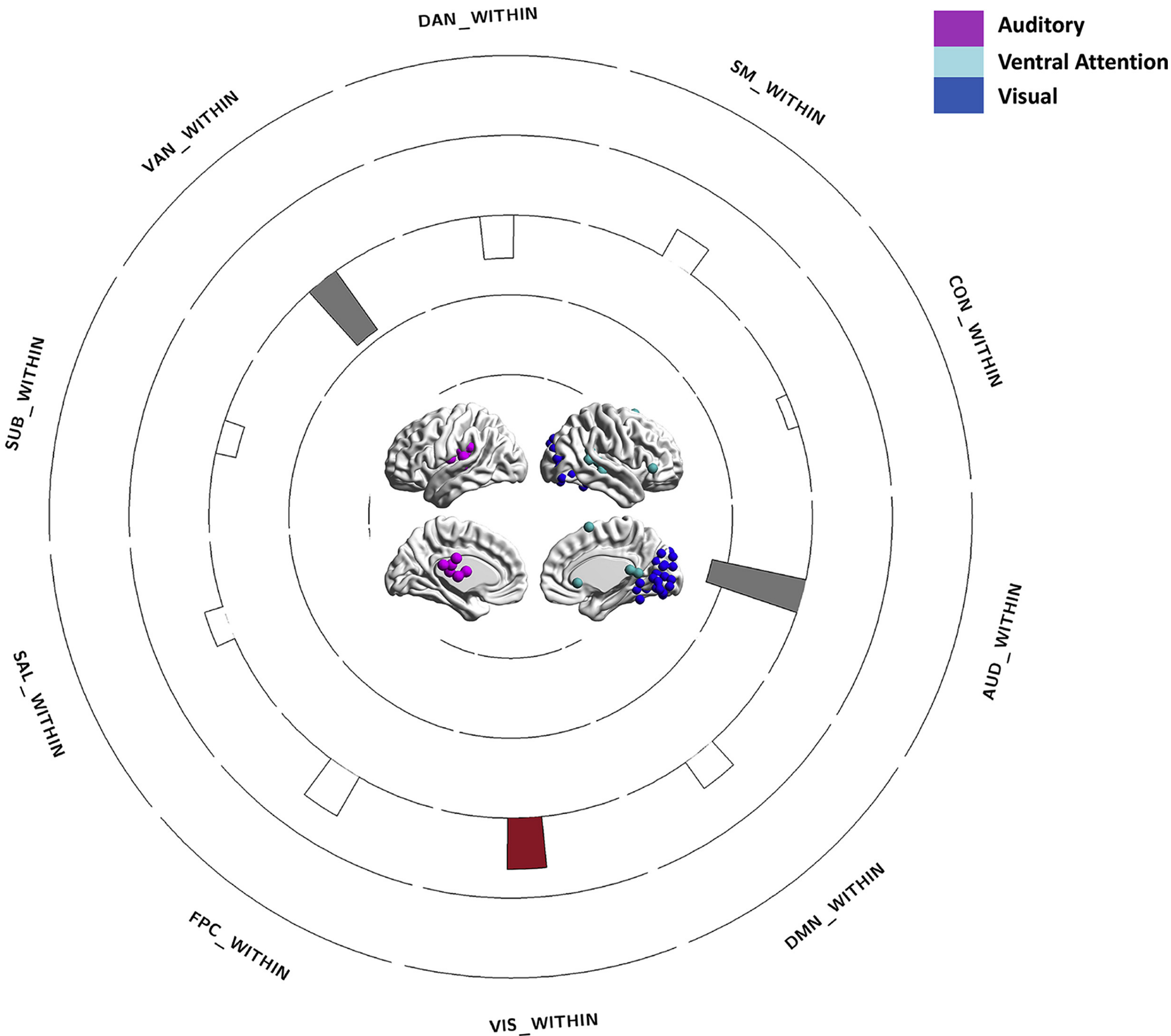
(Hagmann et al., 2010) (http://doi.org/10.1073/pnas.1009073107)

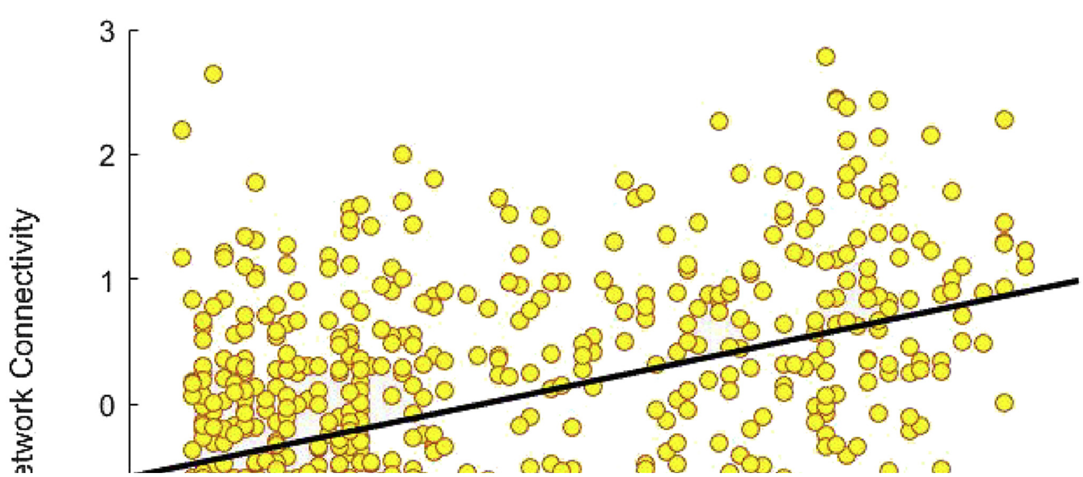
Networks in the brain

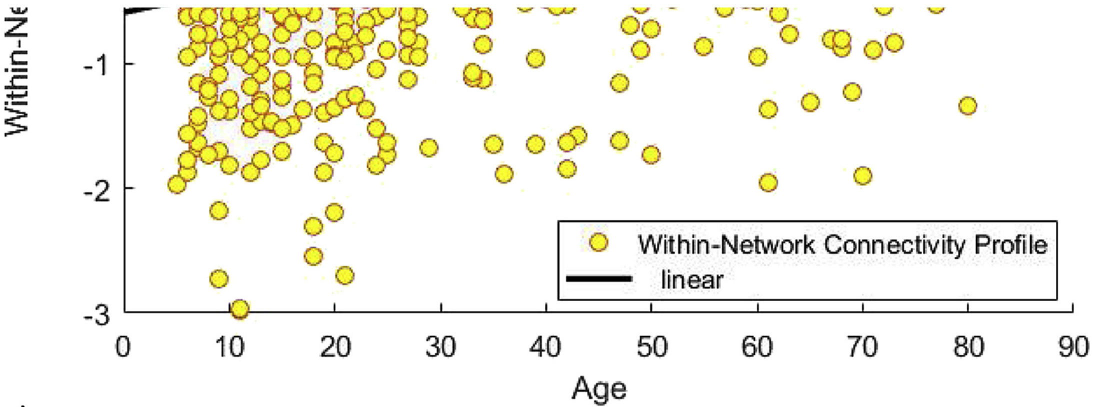


(Irimia & Van Horn, 2014) (http://doi.org/10.3389/fnhum.2014.00051)

- Age-related functional connectivity increases within visual-related areas (Petrican, Taylor, & Grady, 2017) (http://doi.org/10.1016/j.neuroimage.2017.09.025)



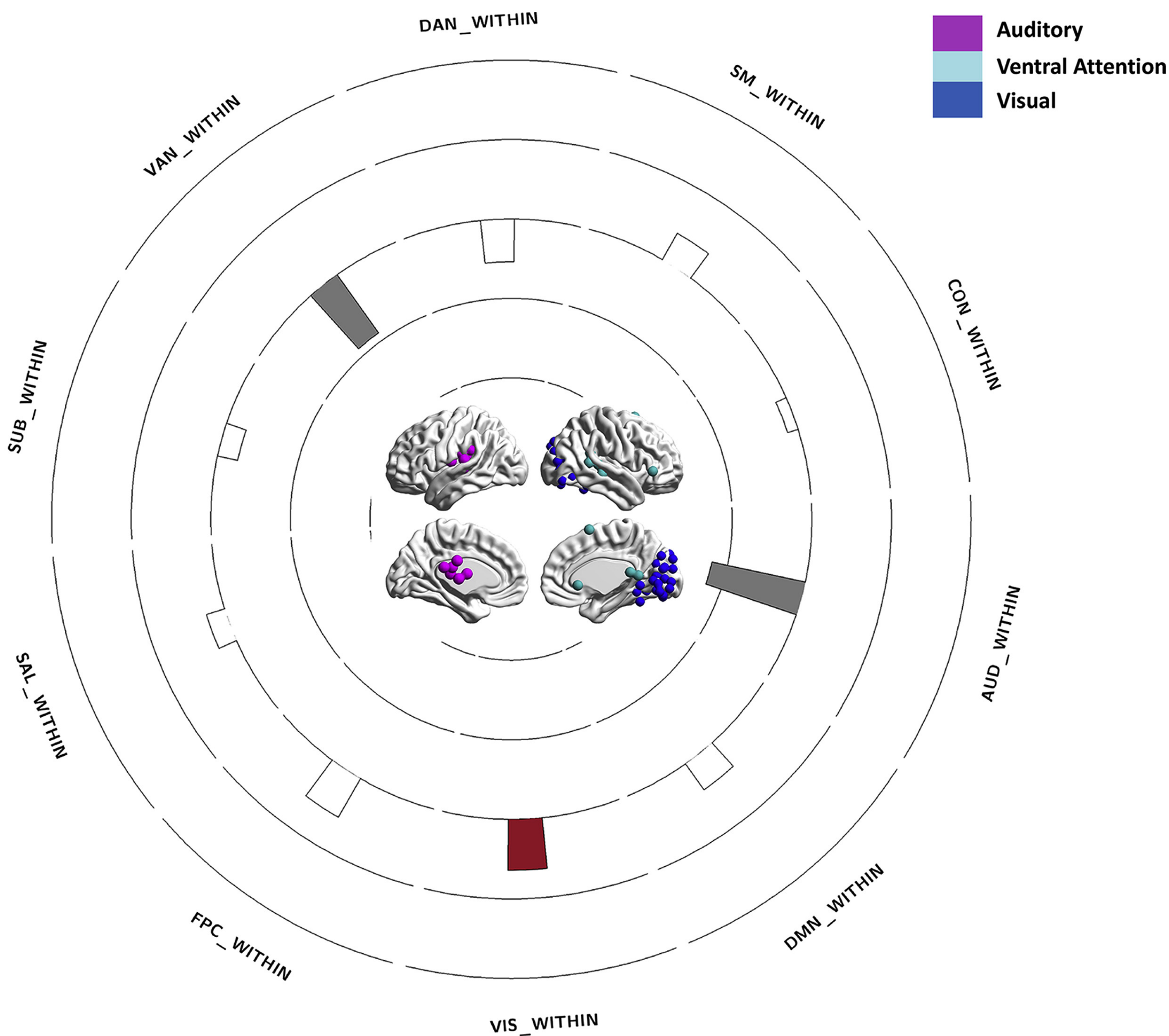


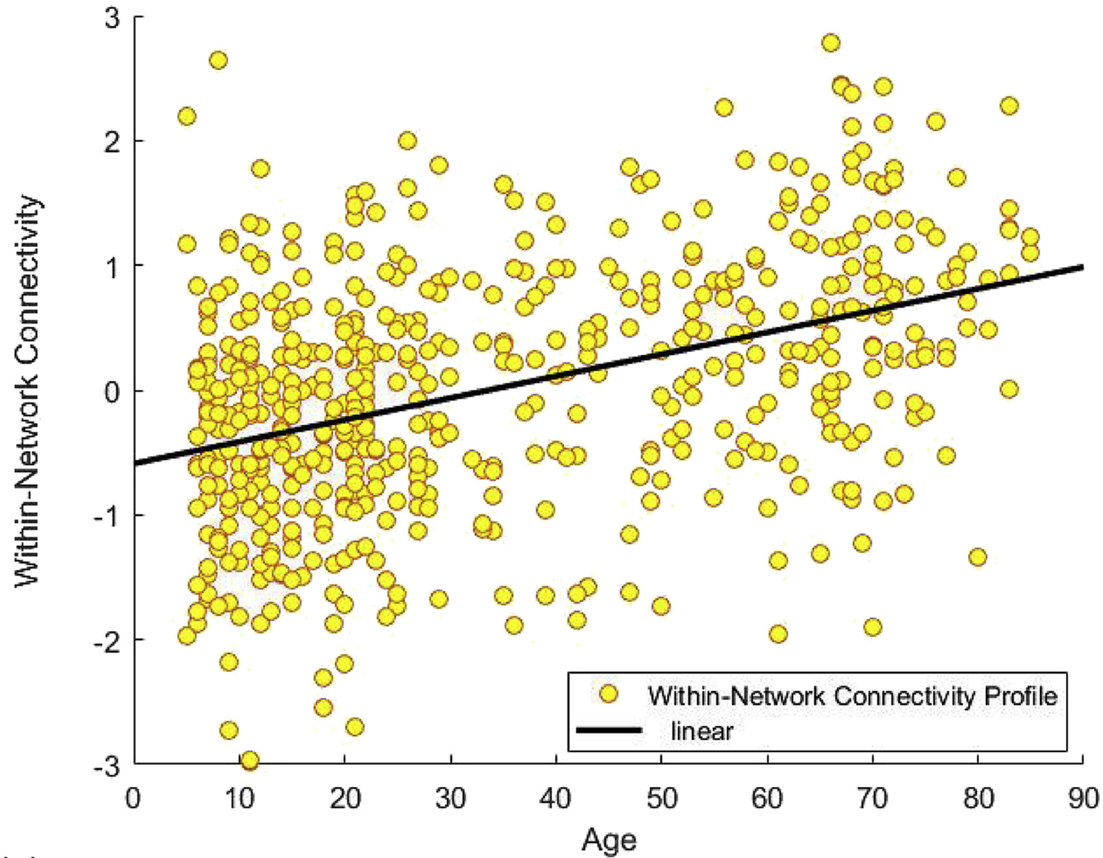


(a)

(Petrican, Taylor, & Grady, 2017)
(http://doi.org/10.1016/j.neuroimage.2017.09.025)

“Control” networks

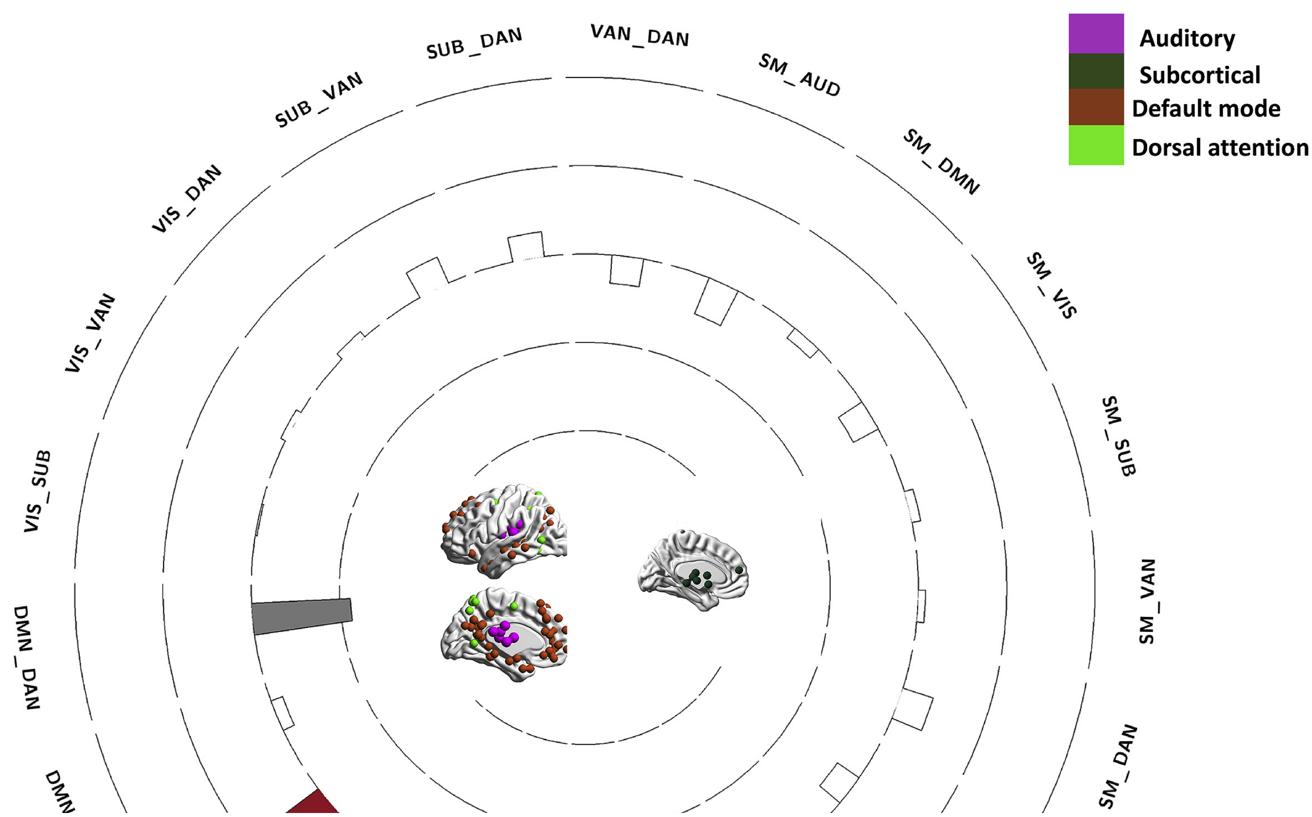


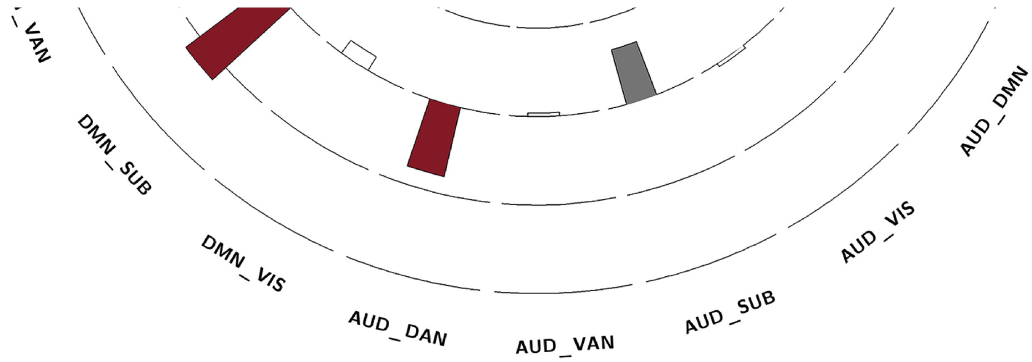


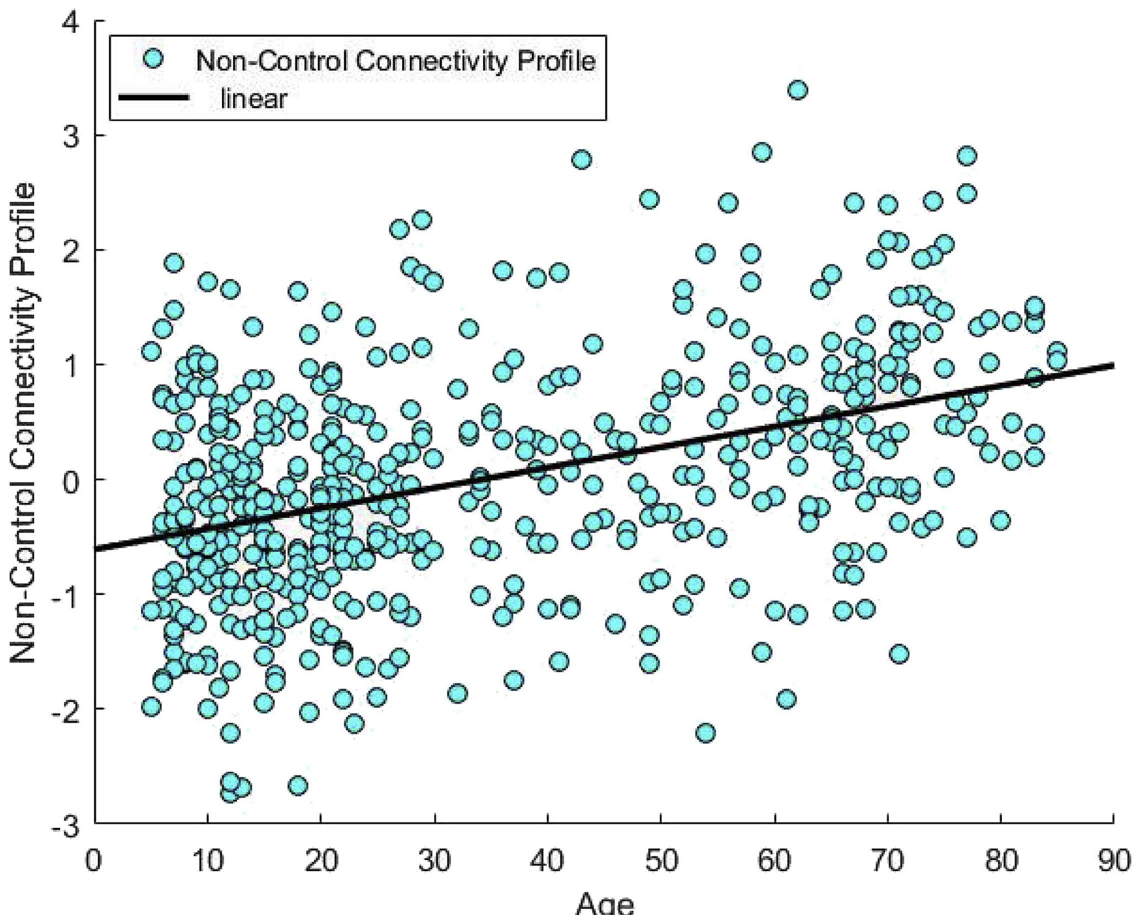
(a)

(Petrican, Taylor, & Grady, 2017)
(http://doi.org/10.1016/j.neuroimage.2017.09.025)

non-“control” networks



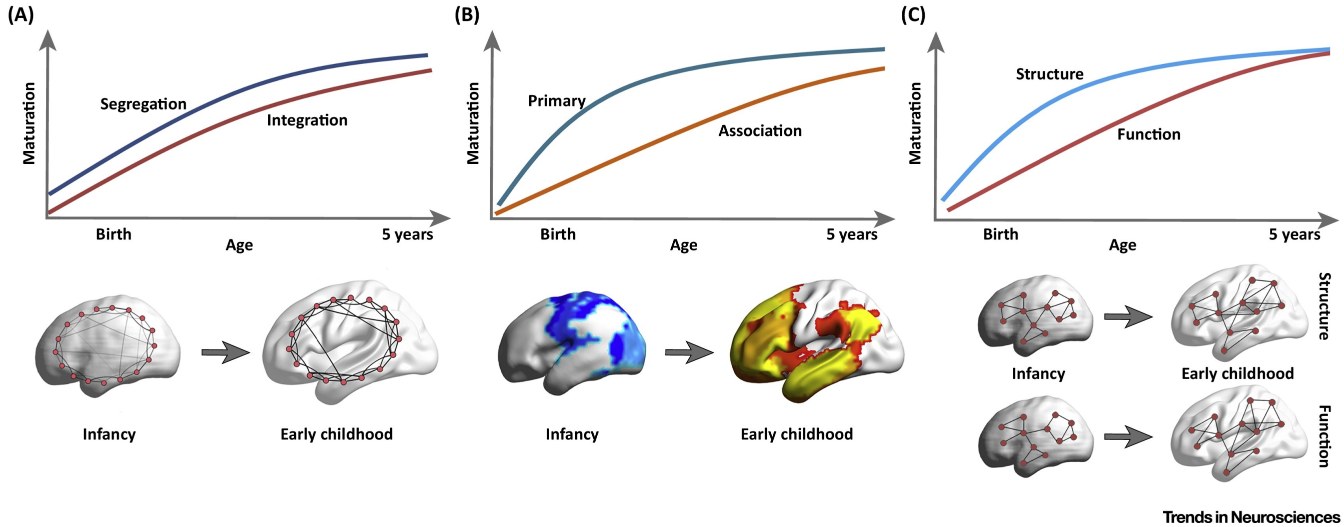




(c)

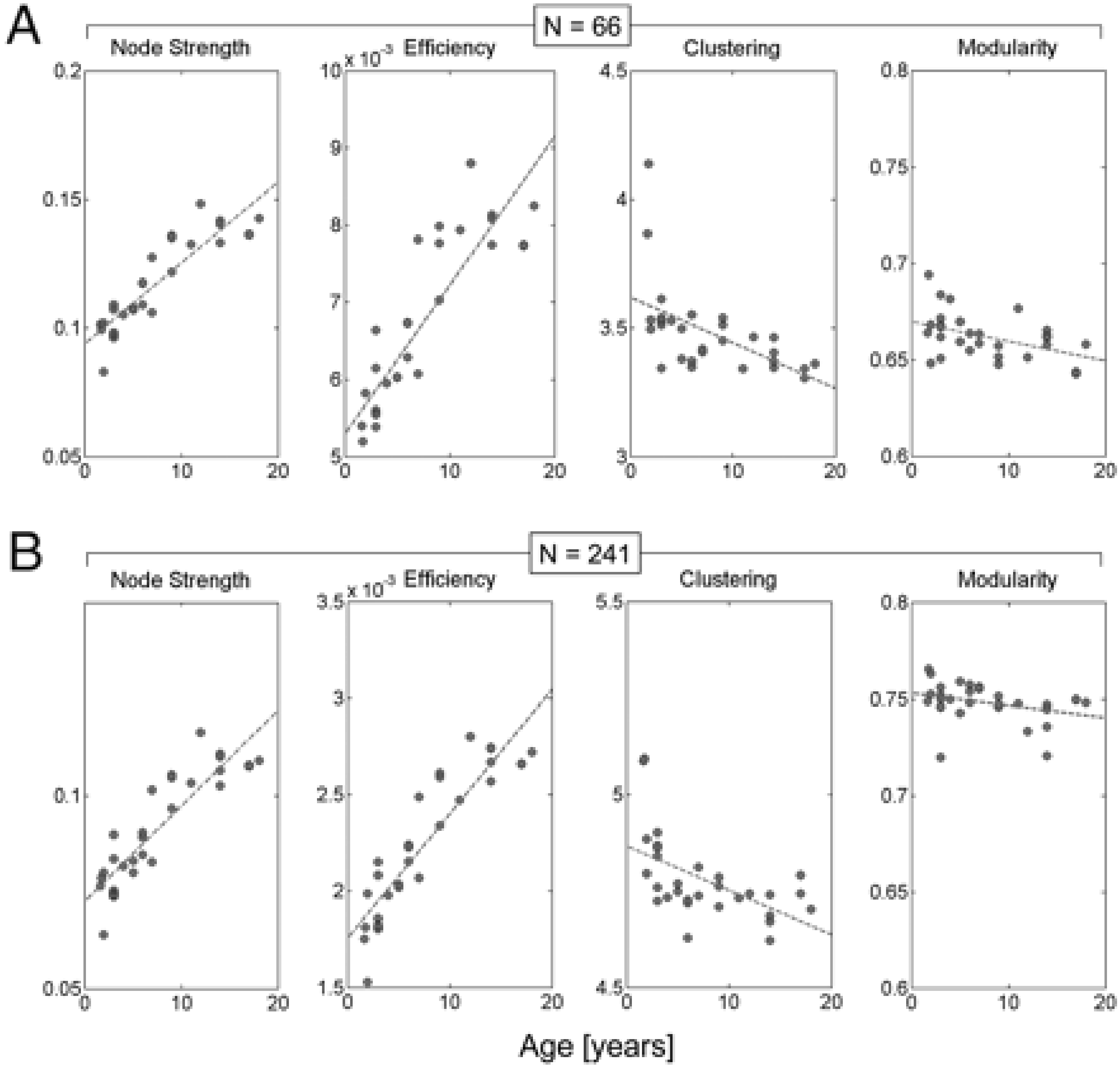
(Petrican, Taylor, & Grady, 2017)
(http://doi.org/10.1016/j.neuroimage.2017.09.025)

The “development” of developmental connectomics



(Cao, Huang, & He, 2017) (http://doi.org/10.1016/j.tins.2017.06.003)

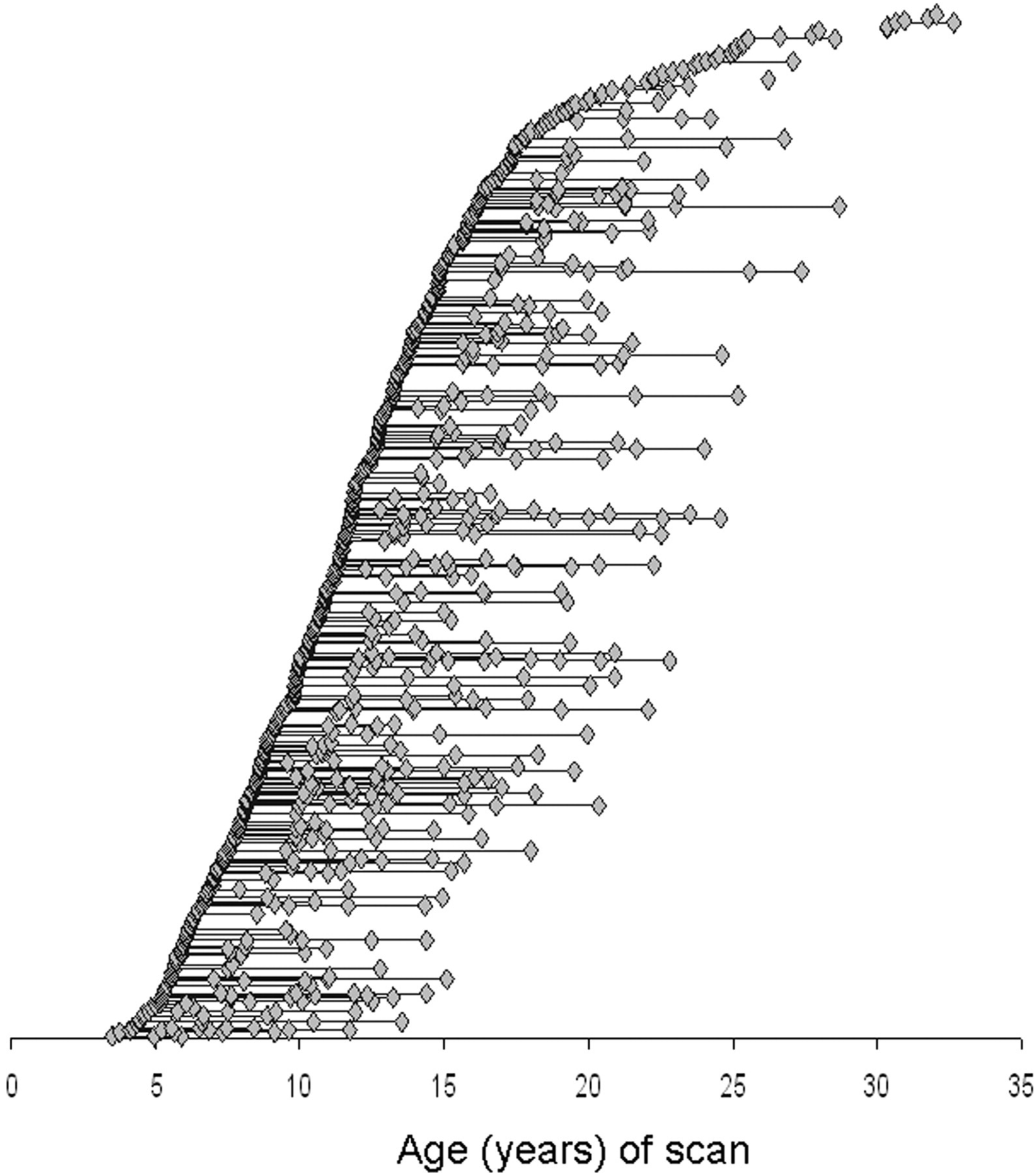
Myelination changes "network" properties



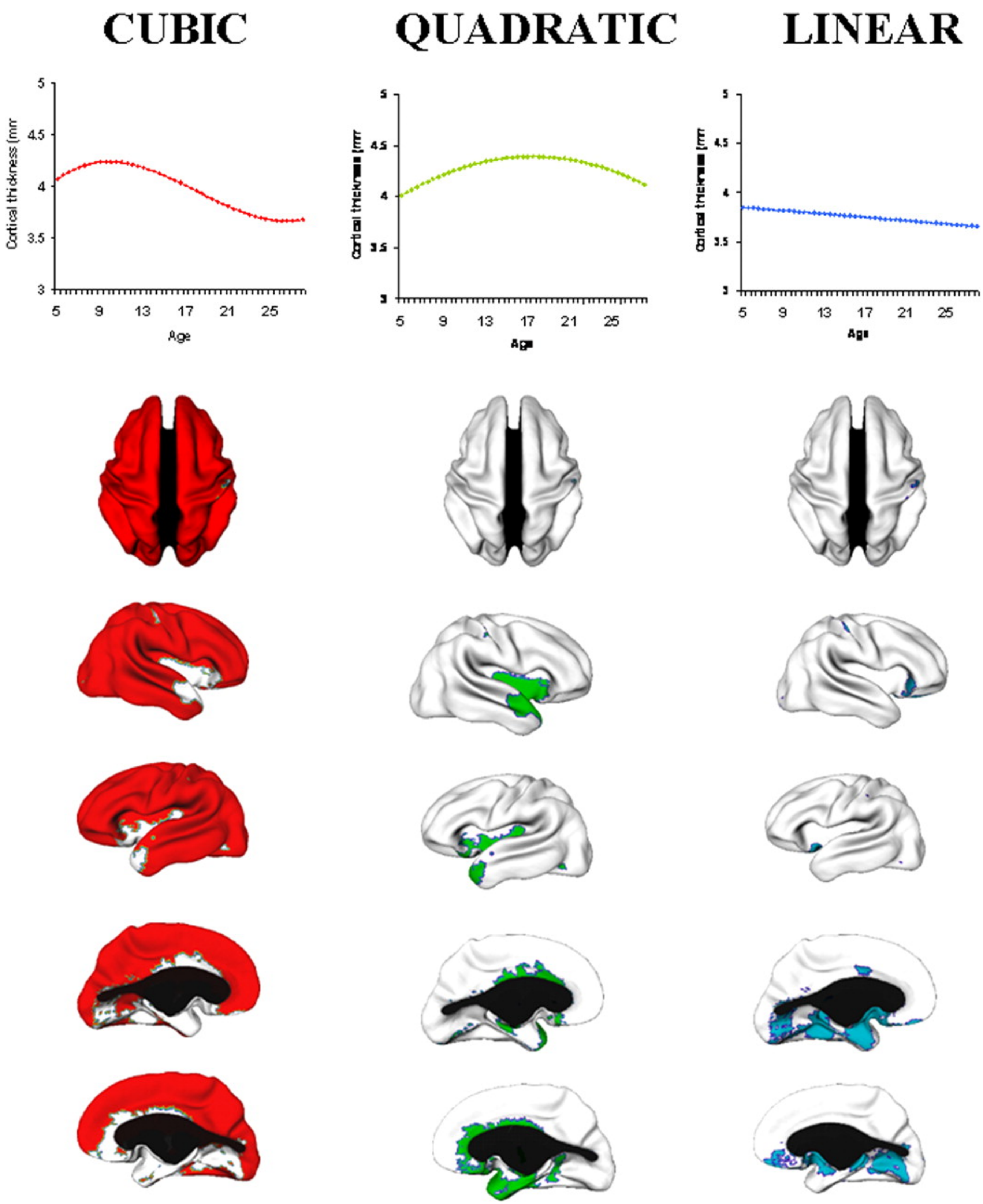
(Hagmann et al., 2010) (http://doi.org/10.1073/pnas.1009073107)

Synaptic rearrangment, myelination change cortical thickness

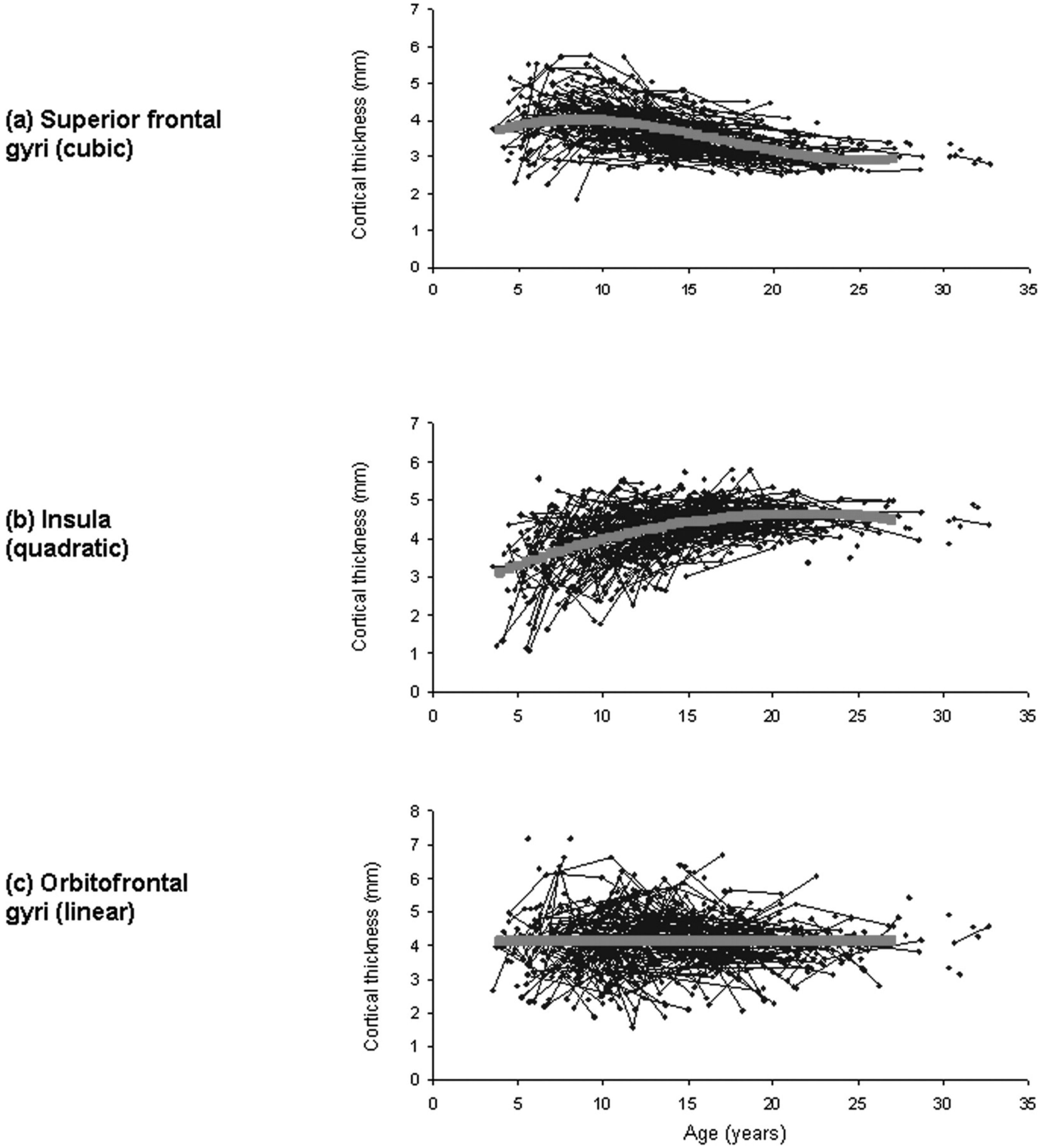
- Cortical thickness changes (Gogtay et al., 2004) (http://doi.org/10.1073/pnas.0402680101)



(Shaw et al., 2008) (https://doi.org/10.1523/JNEUROSCI.5309-07.2008)



(Shaw et al., 2008) (https://doi.org/10.1523/JNEUROSCI.5309-07.2008)



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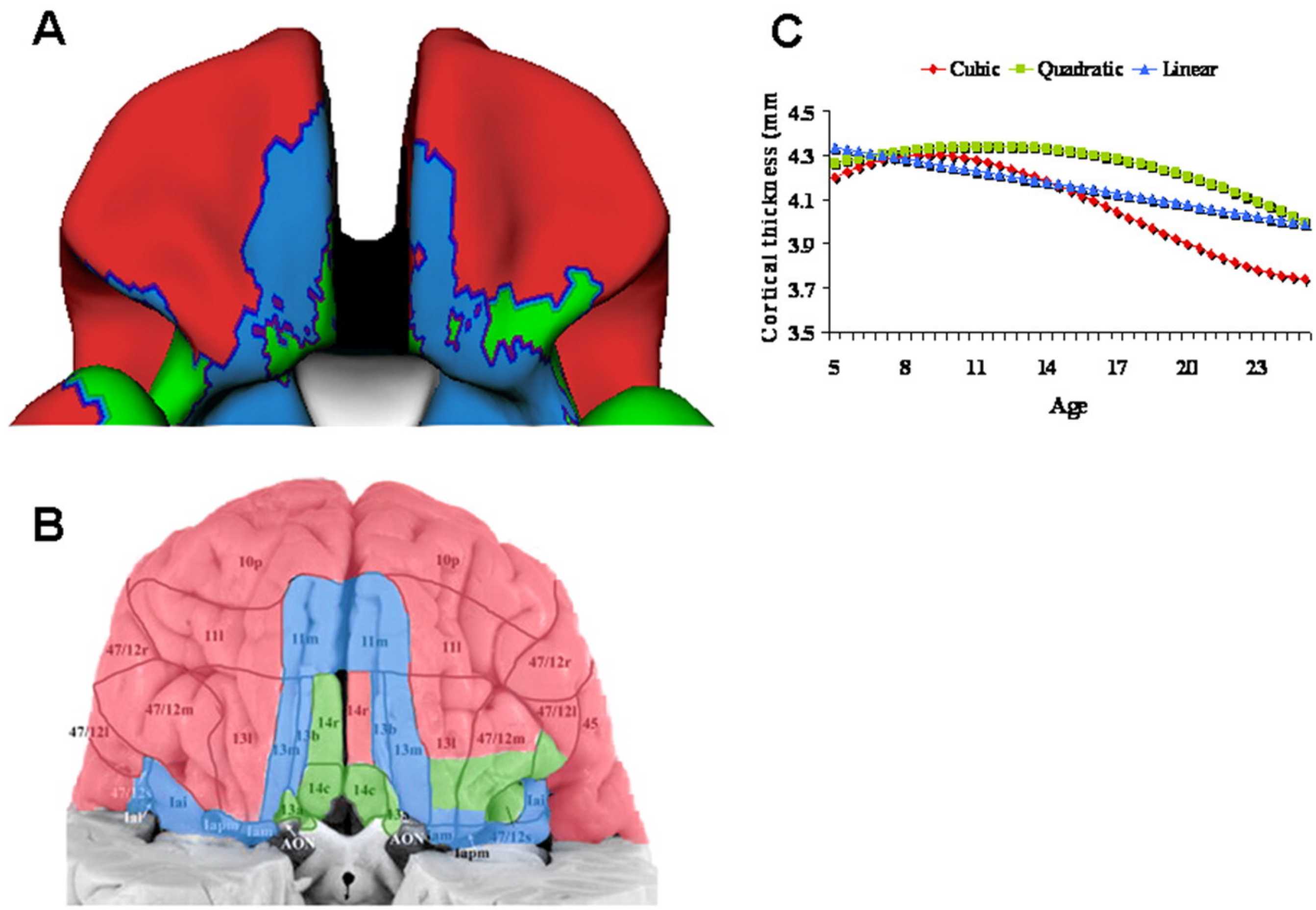
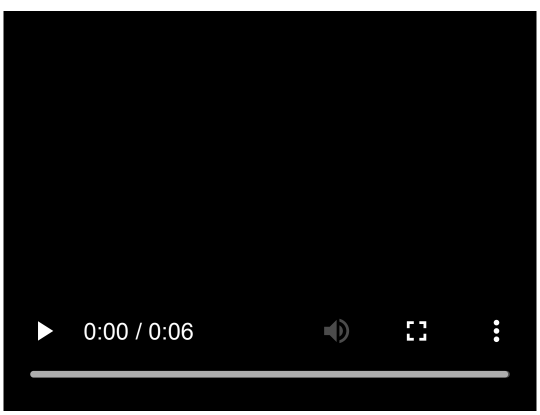


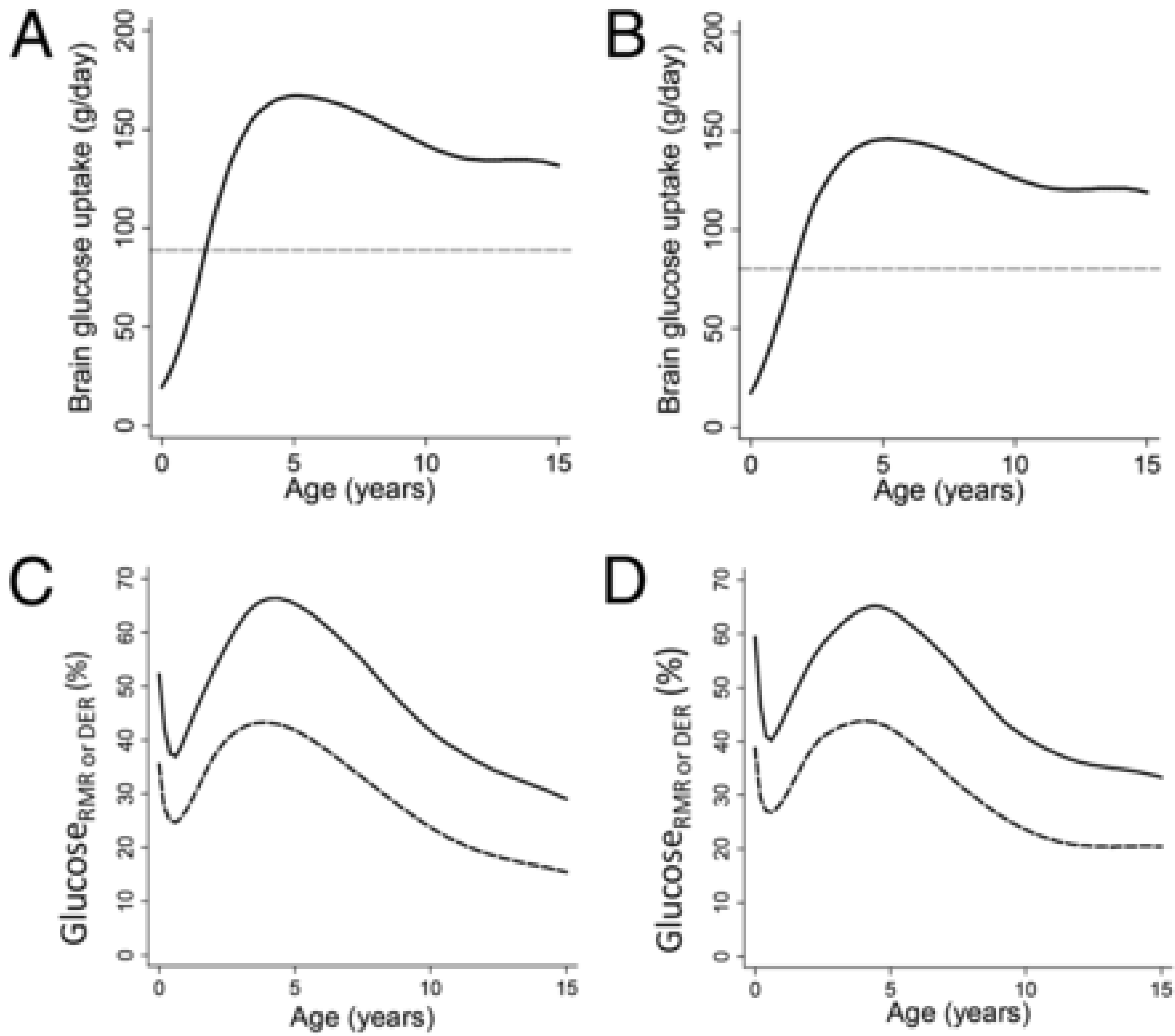
(Shaw et al., 2008) (https://doi.org/10.1523/JNEUROSCI.5309-07.2008)

Video depictions

Right hemisphere | Left hemisphere | Superior | Inferior

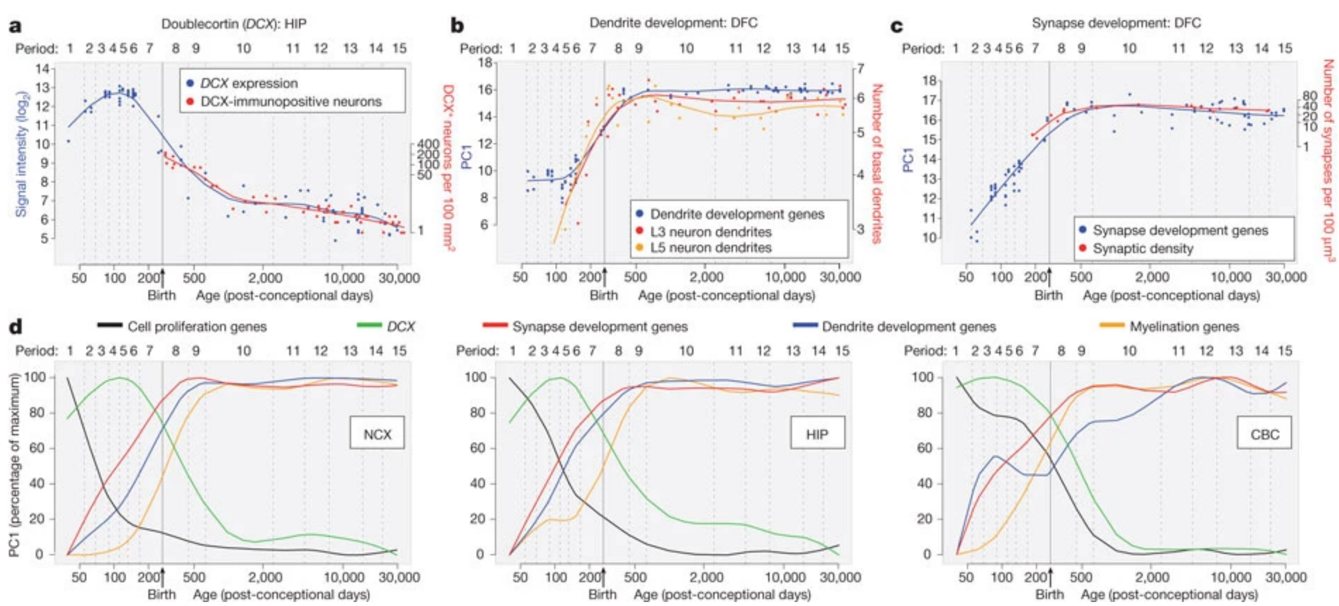


Changes in brain energetics (glucose utilization)



(Kuzawa et al., 2014) (http://doi.org/10.1073/pnas.1323099111)

Gene expression across development



(Kang et al., 2011) (http://doi.org/10.1038/nature10523)

> a, Comparison between DCX expression in HIP and the density of DCX-immunopositive cells in the human dentate gyrus36. b, Comparison between transcriptome-based dendrite development trajectory in DFC and Golgi-method-based growth of basal dendrites of layer 3 (L3) and 5 (L5) pyramidal neurons in the human DFC41. c, Comparison between transcriptome-based synapse development trajectory in DFC and density of DFC synapses calculated using electron microscopy42. For b and c, PC1 for gene expression was plotted against age to represent the developmental trajectory of genes associated with dendrite (b) or synapse (c) development. Independent data sets were centred, scaled and plotted on a logarithmic scale. d, PC1 value for the indicated sets of genes (expressed as percentage of maximum) plotted against age to represent general trends and regional differences in several neurodevelopmental processes in NCX, HIP and CBC.

Summary of developmental milestones

Prenatal

- Neuro- and gliogenesis
- Migration
- Synaptogenesis begins
- Differentiation
- Apoptosis
- Myelination begins
- Infant gene expression ≠ Adult

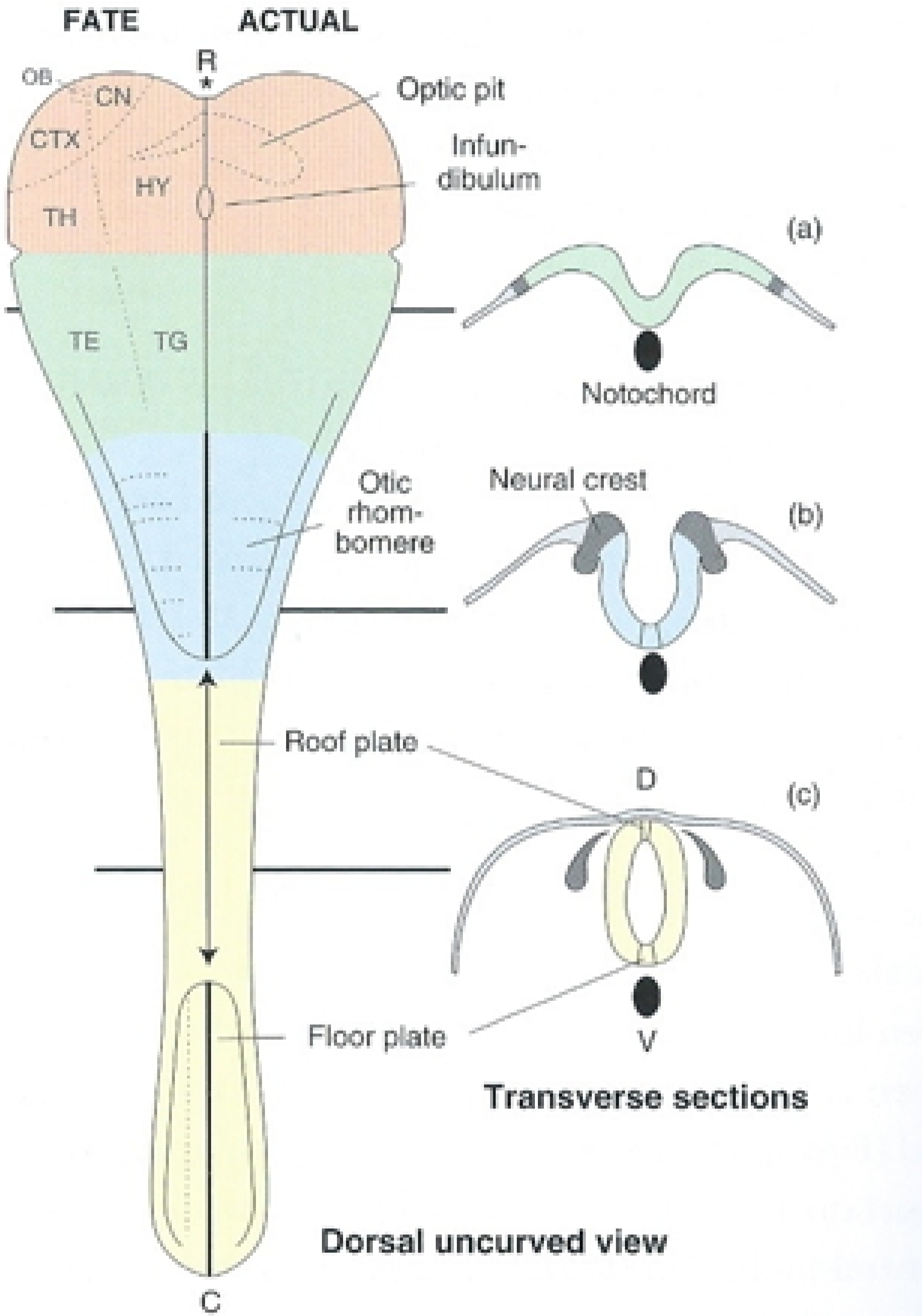
Postnatal

- Synaptogenesis
- Cortical expansion, activity-dependent change
- Then cubic, quadratic, or linear declines in cortical thickness
- Myelination
- Connectivity changes (esp within networks)

- Prolonged period of postnatal/pre-reproductive development (Konner, 2011) (http://www.hup.harvard.edu/catalog.php?isbn=9780674062016)

How brain development clarifies anatomical structure

3-4 weeks



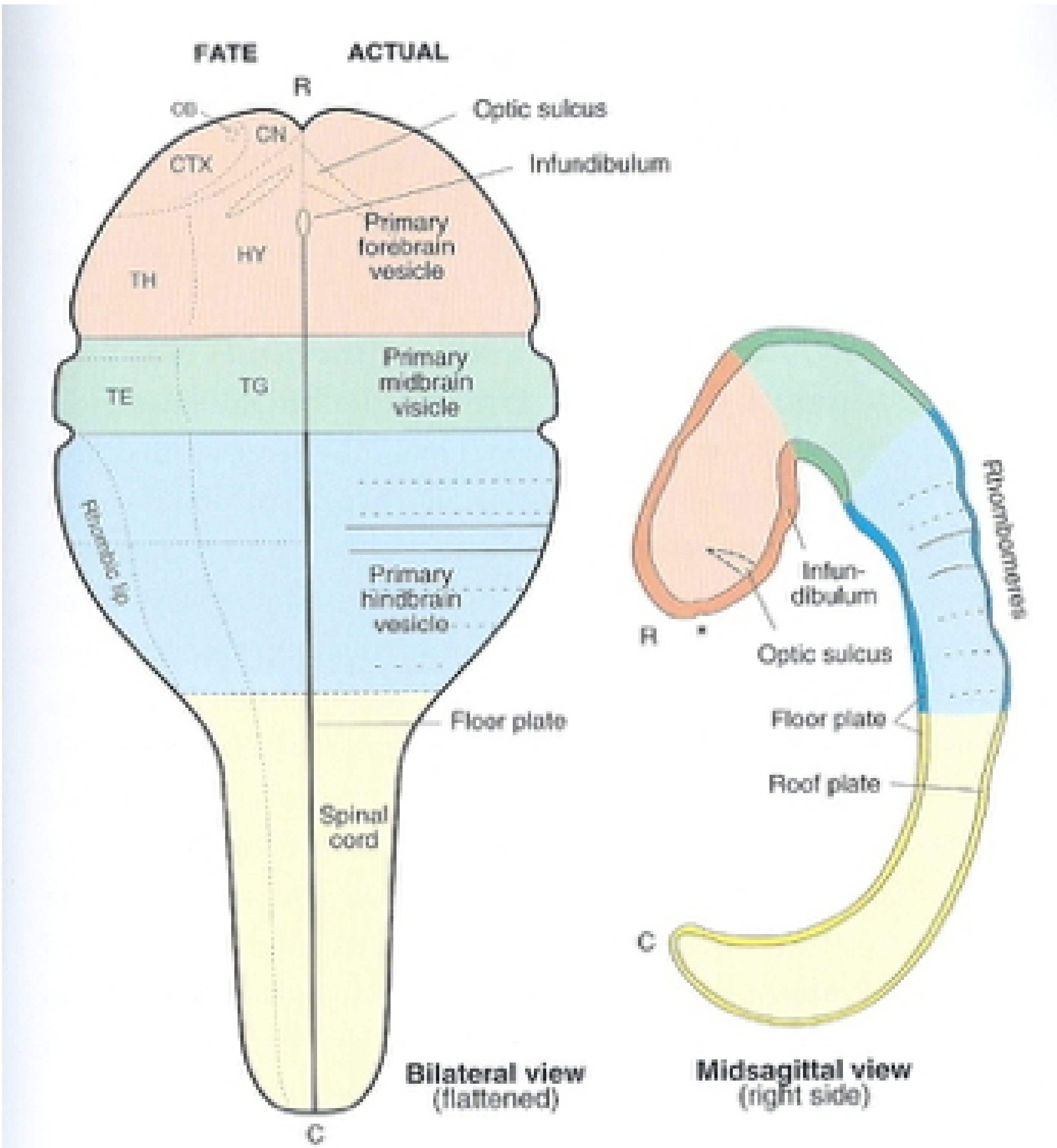
Source: Swanson

4 weeks

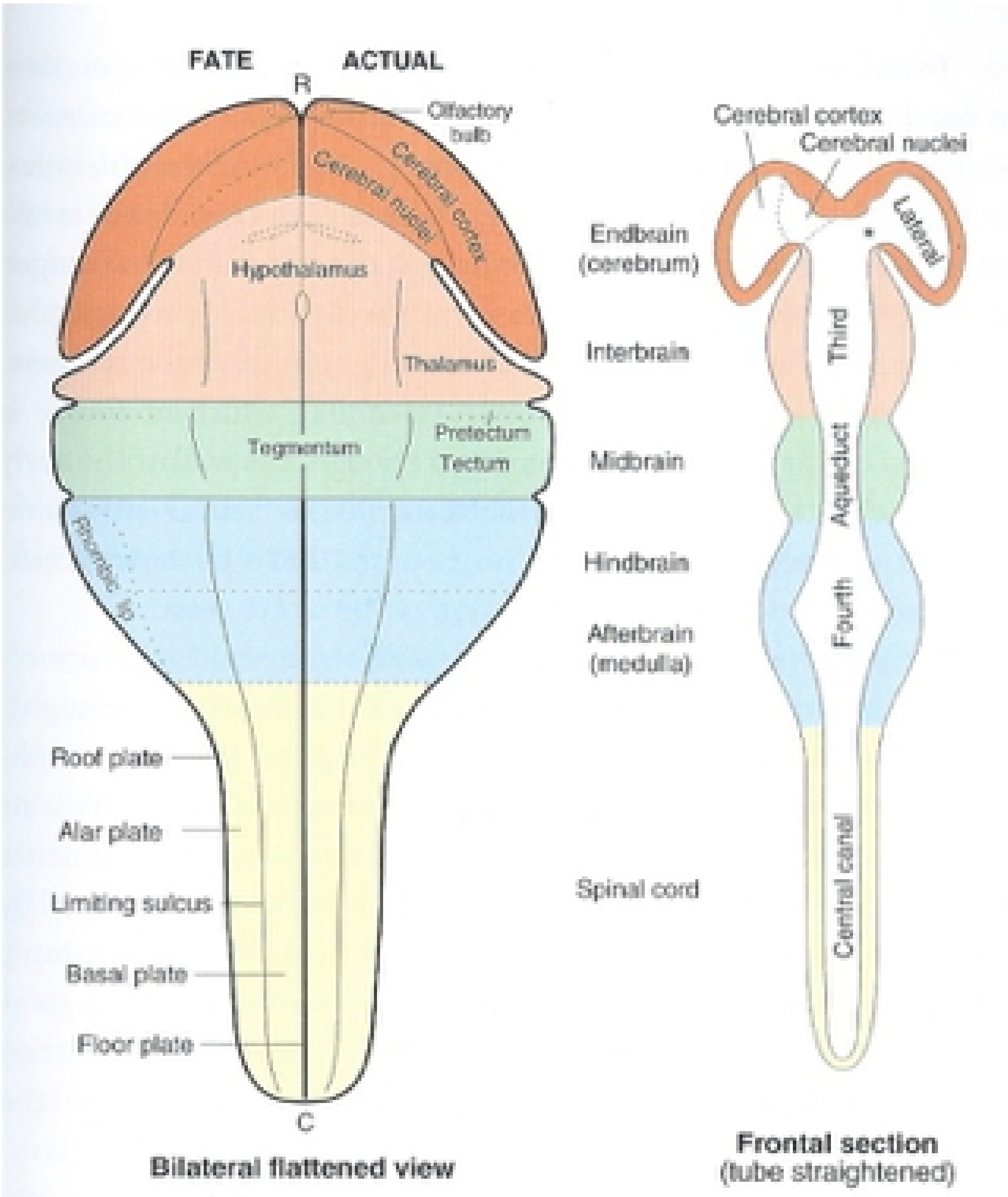
https://upload.wikimedia.org/wikipedia/commons/4/4c/4_week_embryo_brain.jpg

https://upload.wikimedia.org/wikipedia/commons/4/4c/4_week_embryo_brain.jpg
(https://upload.wikimedia.org/wikipedia/commons/4/4c/4_week_embryo_brain.jpg)

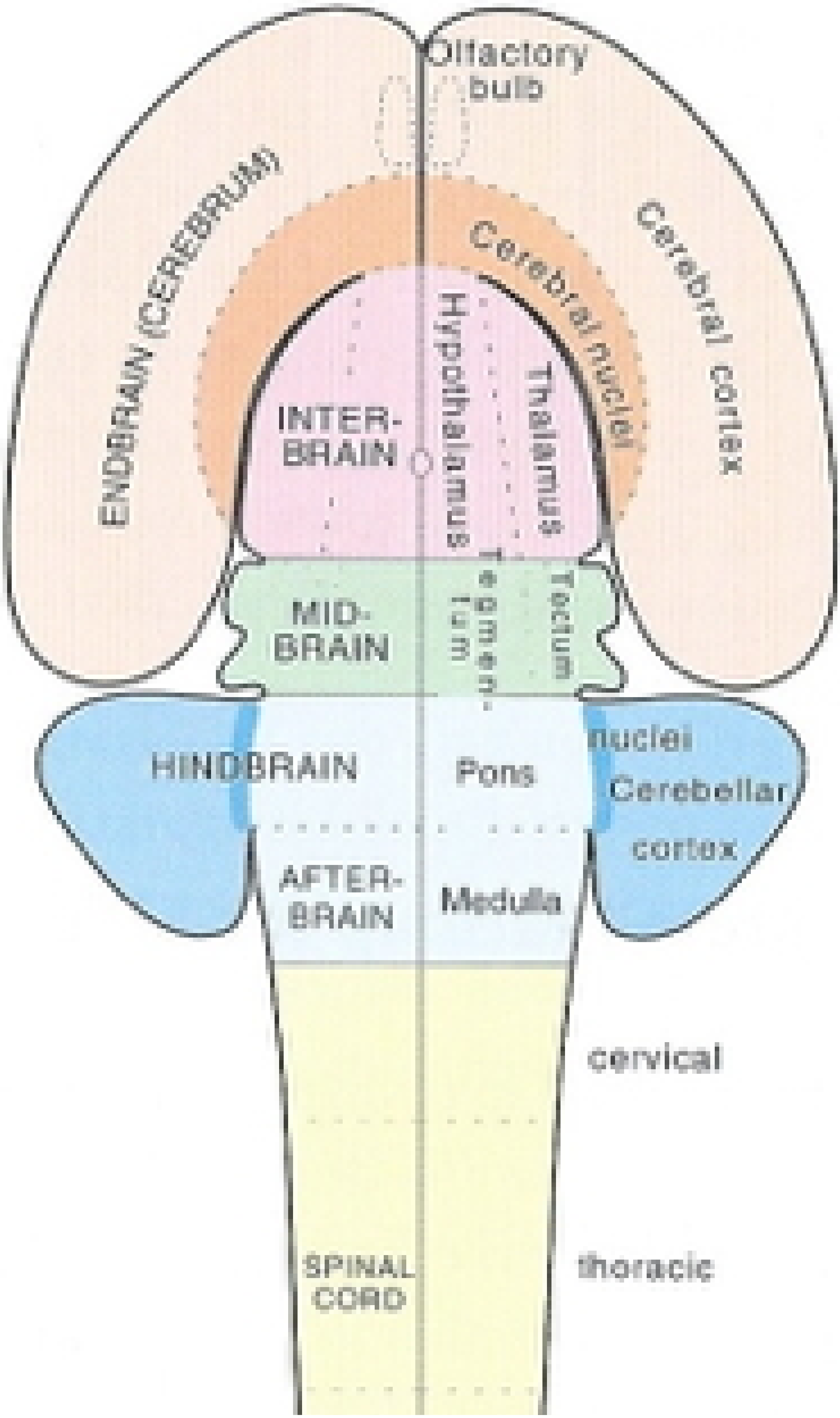
~4 weeks



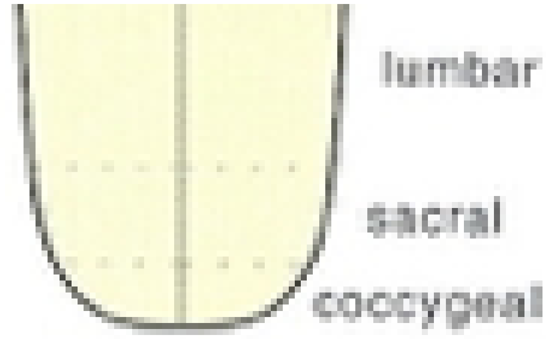
6 weeks



Beyond 6+ weeks



Olfactory bulb
ENDBRAIN (CEREBRUM)
Cerebral nuclei
Cerebral cortex
INTER-BRAIN
Hypothalamus
Thalamus
MID-BRAIN
Tegmen-tum
Tectum
HINDBRAIN
Pons
nuclei
Cerebellar
cortex
AFTER-BRAIN
Medulla
cervical
SPINAL CORD
thoracic



Organization of the brain

Major division	Ventricular Landmark	Embryonic Division	Structure
Forebrain	Lateral	Telencephalon	Cerebral cortex
			Basal ganglia
			Hippocampus, amygdala
	Third	Diencephalon	Thalamus
			Hypothalamus
Midbrain	Cerebral Aqueduct	Mesencephalon	Tectum, tegmentum
Hindbrain	4th	Metencephalon	Cerebellum, pons
	–	Mylencephalon	Medulla oblongata

From structural development to functional development

[[@Johnson2001-yy]](http://doi.org/10.1038/35081509)

(Johnson, 2001) (http://doi.org/10.1038/35081509)

References

Arendt, D., Tosches, M. A., & Marlow, H. (2016). From nerve net to nerve ring, nerve cord and brain — evolution of the nervous system. *Nature Reviews Neuroscience*, *17*(1), 61–72. https://doi.org/10.1038/nrn.2015.15 (https://doi.org/10.1038/nrn.2015.15)

Baumann, N., & Pham-Dinh, D. (2001). Biology of oligodendrocyte and myelin in the mammalian central nervous system. *Physiological Reviews*, *81*(2), 871–927. https://doi.org/10.1152/physrev.2001.81.2.871 (https://doi.org/10.1152/physrev.2001.81.2.871)

Cao, M., Huang, H., & He, Y. (2017). Developmental connectomics from infancy through early childhood. *Trends in Neuroscience*, *40*(8), 494–506. https://doi.org/10.1016/j.tins.2017.06.003 (https://doi.org/10.1016/j.tins.2017.06.003)

Chi, J. G., Dooling, E. C., & Gilles, F. H. (1977). Gyral development of the human brain. *Ann. Neurol.*, *1*(1), 86–93. https://doi.org/10.1002/ana.410010109 (https://doi.org/10.1002/ana.410010109)

Dobzhansky, T. (1973). Nothing in biology makes sense except in the light of evolution. *The American Biology Teacher*, *35*(3), pp. 125–129. Retrieved from http://www.jstor.org/stable/4444260 (http://www.jstor.org/stable/4444260)

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., … Thompson, P. M. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proc. Natl. Acad. Sci. U. S. A.*, *101*(21), 8174–8179. https://doi.org/10.1073/pnas.0402680101 (https://doi.org/10.1073/pnas.0402680101)

Götz, M., & Huttner, W. B. (2005). The cell biology of neurogenesis. *Nat. Rev. Mol. Cell Biol.*, *6*(10), 777–788. https://doi.org/10.1038/nrm1739 (https://doi.org/10.1038/nrm1739)

Hagmann, P., Sporns, O., Madan, N., Cammoun, L., Pienaar, R., Wedeen, V. J., … Grant, P. E. (2010). White matter maturation reshapes structural connectivity in the late developing human brain. *Proceedings of the National Academy of Sciences*, *107*(44), 19067–19072. https://doi.org/10.1073/pnas.1009073107 (https://doi.org/10.1073/pnas.1009073107)

Herculano-Houzel, S. (2012). The remarkable, yet not extraordinary, human brain as a scaled-up primate brain and its associated cost. *Proceedings of the National Academy of Sciences of the United States of America*, *109 Suppl 1*, 10661–10668. https://doi.org/10.1073/pnas.1201895109 (https://doi.org/10.1073/pnas.1201895109)

Herculano-Houzel, S. (2016). *The human advantage: A new understanding of how our brain became remarkable*. MIT Press. Retrieved from https://market.android.com/details?id=book-DMqpCwAAQBAJ (https://market.android.com/details?id=book-DMqpCwAAQBAJ)

Herculano-Houzel, S. (2017). Numbers of neurons as biological correlates of cognitive capability. *Current Opinion in Behavioral Sciences*, *16*(Supplement C), 1–7. https://doi.org/10.1016/j.cobeha.2017.02.004 (https://doi.org/10.1016/j.cobeha.2017.02.004)

Hofman, M. A. (2014). Evolution of the human brain: When bigger is better. *Frontiers in Neuroanatomy*, *8*. https://doi.org/10.3389/fnana.2014.00015 (https://doi.org/10.3389/fnana.2014.00015)

Irimia, A., & Van Horn, J. (2014). Systematic network lesioning reveals the core white matter scaffold of the human brain. *Frontiers in Human Neuroscience*, *8*, 51. https://doi.org/10.3389/fnhum.2014.00051 (https://doi.org/10.3389/fnhum.2014.00051)

Johnson, M. H. (2001). Functional brain development in humans. *Nat. Rev. Neurosci.*, *2*(7), 475–483. https://doi.org/10.1038/35081509 (https://doi.org/10.1038/35081509)

Kang, H. J., Kawasawa, Y. I., Cheng, F., Zhu, Y., Xu, X., Li, M., … Šestan, N. (2011). Spatio-temporal transcriptome of the human brain. *Nature*, *478*(7370), 483–489. https://doi.org/10.1038/nature10523 (https://doi.org/10.1038/nature10523)

Knickmeyer, R. C., Gouttard, S., Kang, C., Evans, D., Wilber, K., Smith, J. K., … Gilmore, J. H. (2008). A structural MRI study of human brain development from birth to 2 years. *J. Neurosci.*, *28*(47), 12176–12182. https://doi.org/10.1523/JNEUROSCI.3479-08.2008 (https://doi.org/10.1523/JNEUROSCI.3479-08.2008)

Konner, M. (2011). *The Evolution of Childhood*. Belknap Press of Harvard University Press. Retrieved from http://www.hup.harvard.edu/catalog.php?isbn=9780674062016 (http://www.hup.harvard.edu/catalog.php?isbn=9780674062016)

Kuzawa, C. W., Chugani, H. T., Grossman, L. I., Lipovich, L., Muzik, O., Hof, P. R., … Lange, N. (2014). Metabolic costs and evolutionary implications of human brain development. *Proc. Natl. Acad. Sci. U. S. A.*, *111*(36), 13010–13015. https://doi.org/10.1073/pnas.1323099111 (https://doi.org/10.1073/pnas.1323099111)

Miller, J. D., Scott, E. C., & Okamoto, S. (2006). Public acceptance of evolution. *SCIENCE-NEW YORK THEN WASHINGTON-*, *313*(5788), 765. https://doi.org/10.1126/science.1126746 (https://doi.org/10.1126/science.1126746)

Northcutt, R. G. (2002). Understanding vertebrate brain evolution. *Integr. Comp. Biol.*, *42*(4), 743–756. https://doi.org/10.1093/icb/42.4.743 (https://doi.org/10.1093/icb/42.4.743)

Petrican, R., Taylor, M. J., & Grady, C. L. (2017). Trajectories of brain system maturation from childhood to older adulthood: Implications for lifespan cognitive functioning. *Neuroimage*. https://doi.org/10.1016/j.neuroimage.2017.09.025 (https://doi.org/10.1016/j.neuroimage.2017.09.025)

Rakic, P. (2009). Evolution of the neocortex: A perspective from developmental biology. *Nature Reviews Neuroscience*, *10*(10), 724–735.

Shaw, P., Kabani, N. J., Lerch, J. P., Eckstrand, K., Lenroot, R., Gogtay, N., … Others. (2008). Neurodevelopmental trajectories of the human cerebral cortex. *Journal of Neuroscience*, *28*(14), 3586–3594. https://doi.org/10.1523/JNEUROSCI.5309-07.2008 (https://doi.org/10.1523/JNEUROSCI.5309-07.2008)

Wrangham, R. (2009). *Catching fire: How cooking made us human*. Basic Books. Retrieved from https://market.android.com/details?id=book-ebEOupKz-rMC (https://market.android.com/details?id=book-ebEOupKz-rMC)