511-2018-10-10-evo-devo-II

Rick Gilmore

Today's Topics

- Wrap-up on evolution
- The development of the nervous system

Prenatal brain development

Insemination

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

Fertilization

- Within ~ 24 hrs of ovulation

Implantation

- ~ 6 days after fertilization

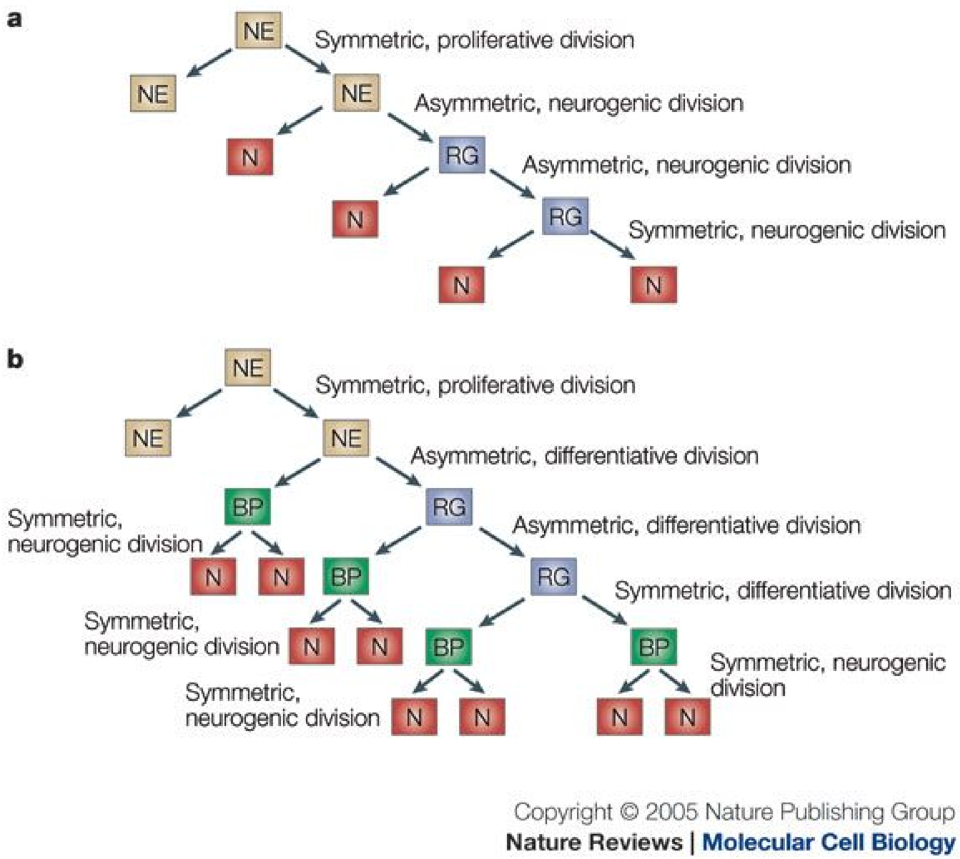
Early embryogenesis

Formation of *neural tube* (neurulation)

- Embryonic layers: ectoderm, mesoderm, endoderm
- ~18-26 days
- Failures of neural tube closure
  - Spina bifida
  - Anencephaly
- Neural tube becomes
  - Ventricles
  - Central canal of spinal cord

Neurogenesis and gliogenesis

- Neuroepithelium cell layer lines neural tube
- Neural stem cells
    - Undergo symmetric & asymmetric cell division
    - Generate glia, neurons, and basal progenitor cells



(Götz & Huttner, 2005)

Zika and microcephaly

Centers for Disease Control and Prevention
CDC 24/7: Saving Lives, Protecting People™

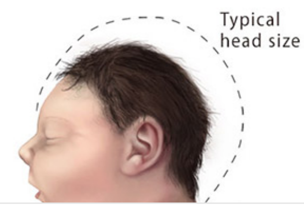
Facts about Microcephaly

Microcephaly is a birth defect where a baby's head is smaller than expected when compared to babies of the same sex and age. Babies with microcephaly often have smaller brains that might not have developed properly.

Baby with Typical Head Size

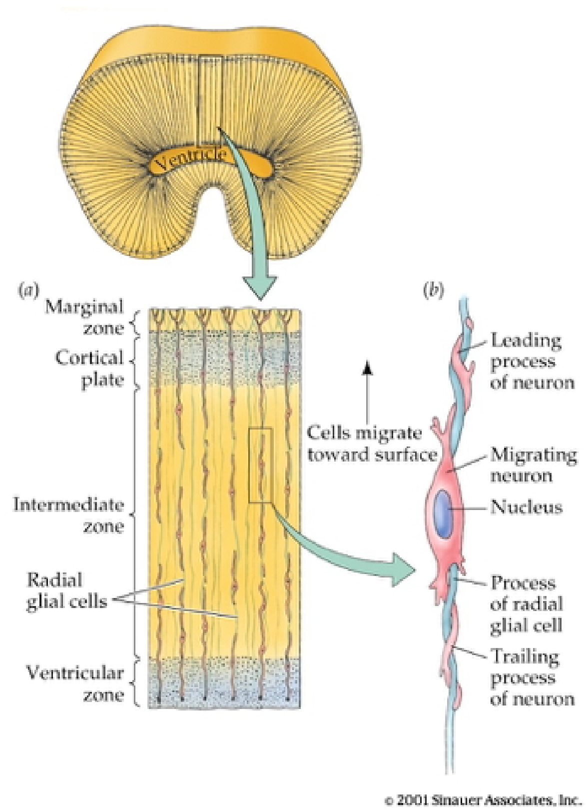
What is microcephaly?

Microcephaly is a condition where a baby's head is much smaller than expected. During pregnancy, a baby's head grows because the baby's brain grows. Microcephaly can occur because a baby's brain has not developed properly during pregnancy or has stopped growing after birth, which results in a smaller head size. Microcephaly can be an isolated condition, meaning that it can occur with no other major birth defects, or it can occur in combination with other major birth defects.



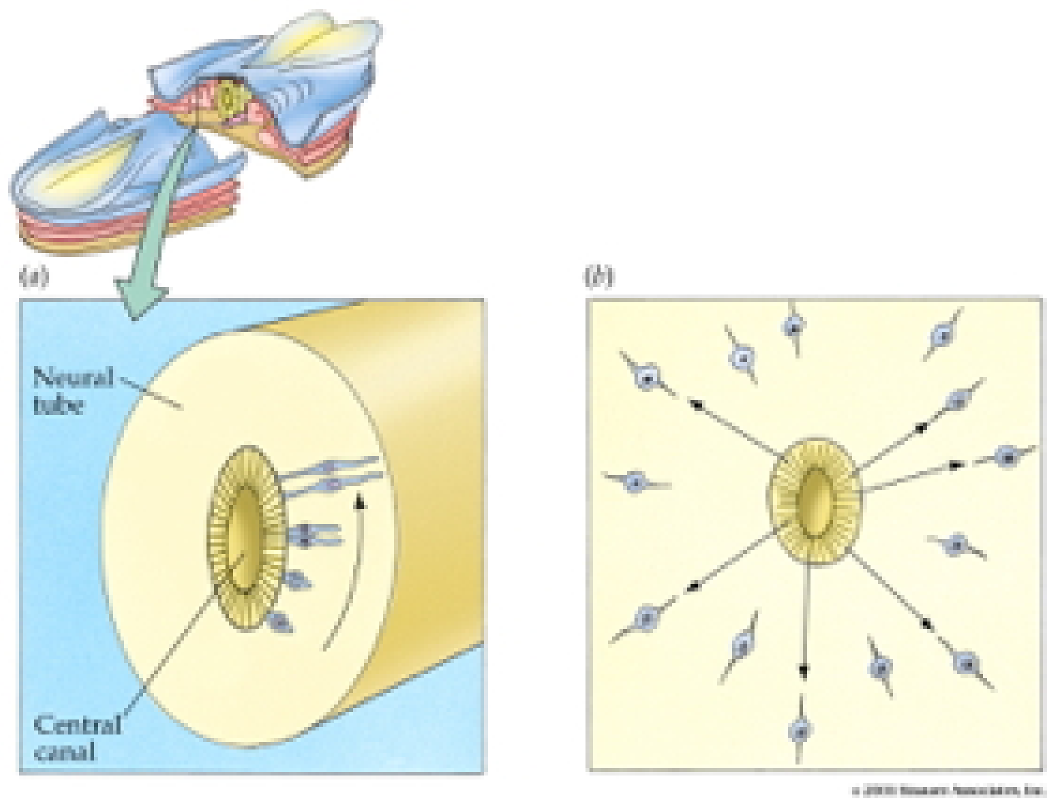
What is severe microcephaly?

Radial glia

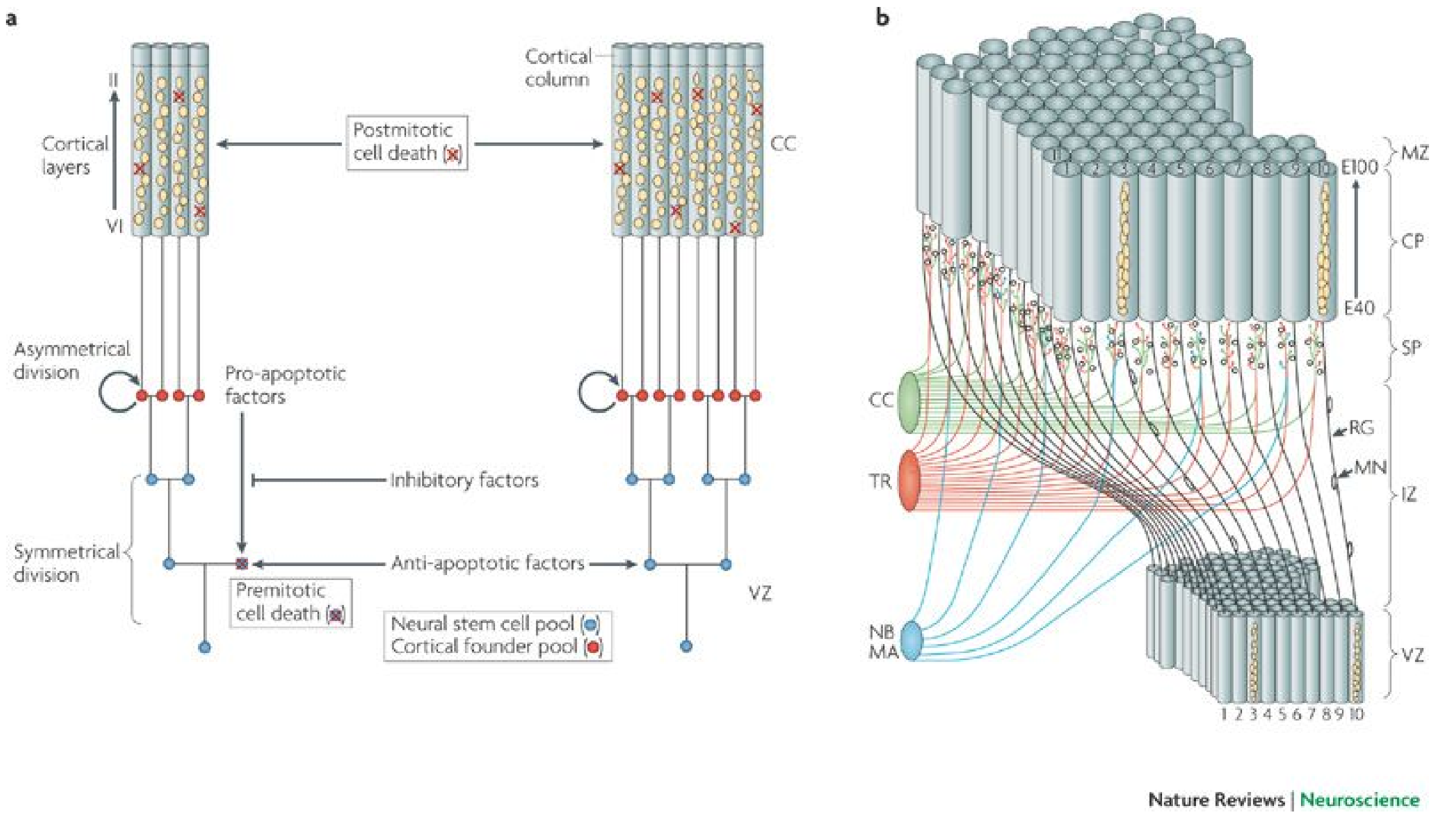


Ventricle
(a)
Marginal zone
Cortical plate
Intermediate zone
Radial glial cells
Ventricular zone
Cells migrate toward surface
(b)
Leading process of neuron
Migrating neuron
Nucleus
Process of radial glial cell
Trailing process of neuron
© 2001 Sinauer Associates, Inc.

Cell migration



Radial unit hypothesis

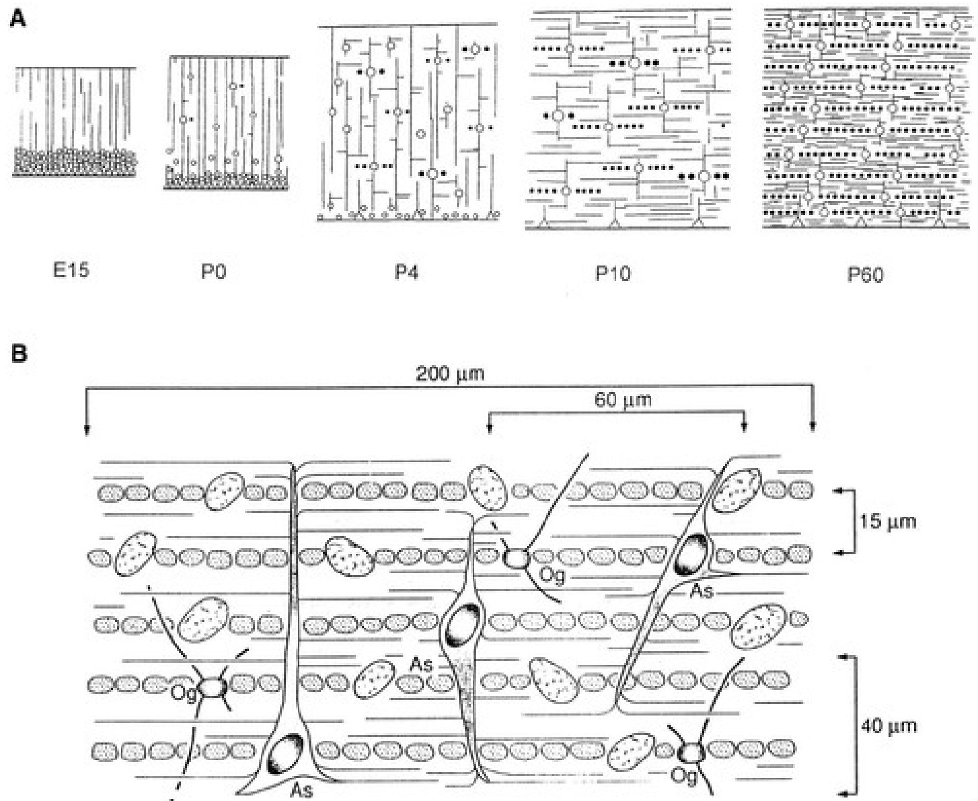


(Rakic, 2009)

Migration

Migration

Glial migration



(Baumann & Pham-Dinh, 2001)

Axon growth cone

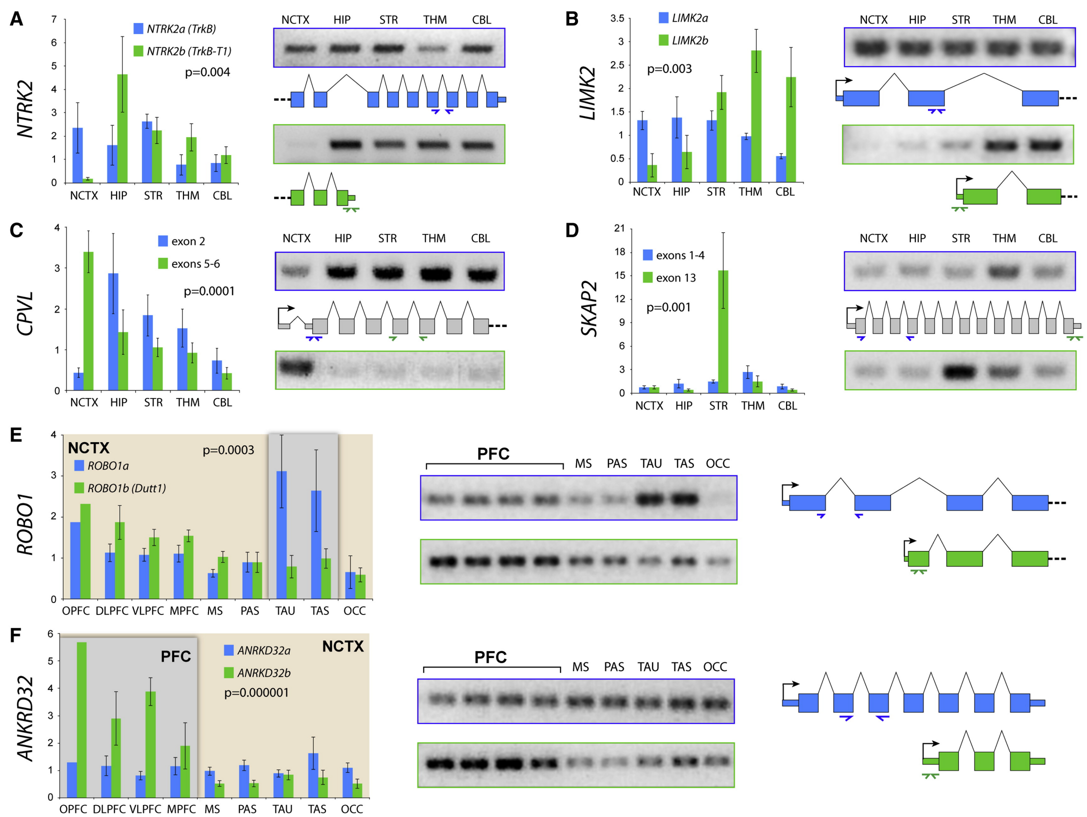
Axons follow

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

Differentiation

- Neuron vs. glial cell
- Cell type
- NTs released
- Where to connect

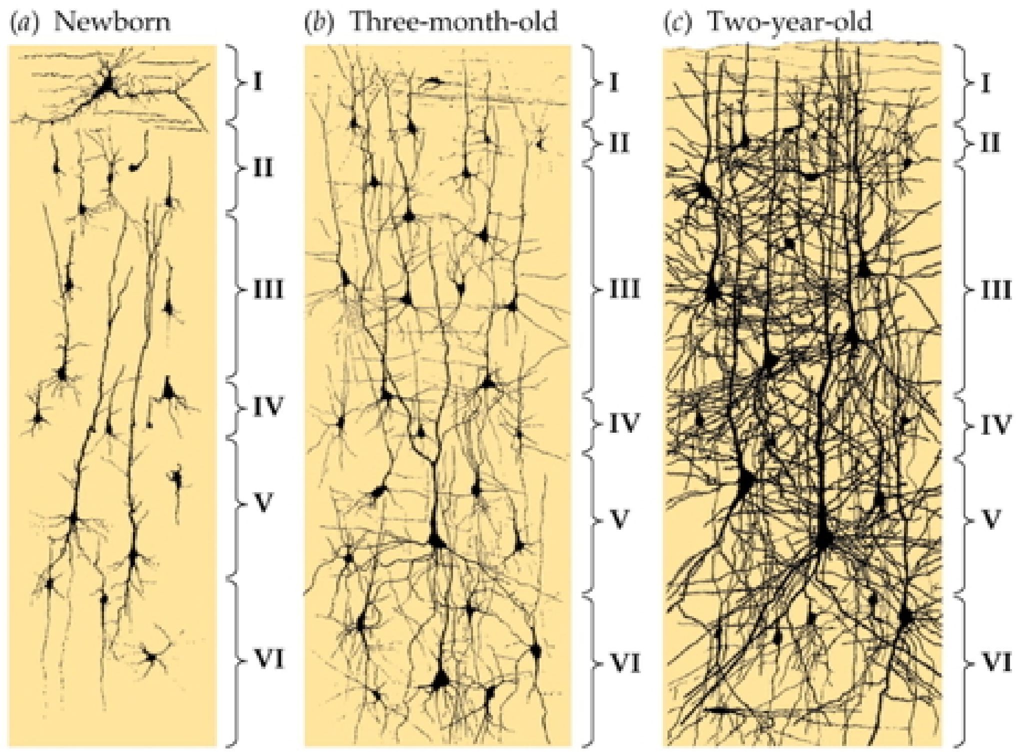
Differential gene expression in PFC vs. other



[johnson2009functional]

Infancy & Early Childhood

Synaptogenesis



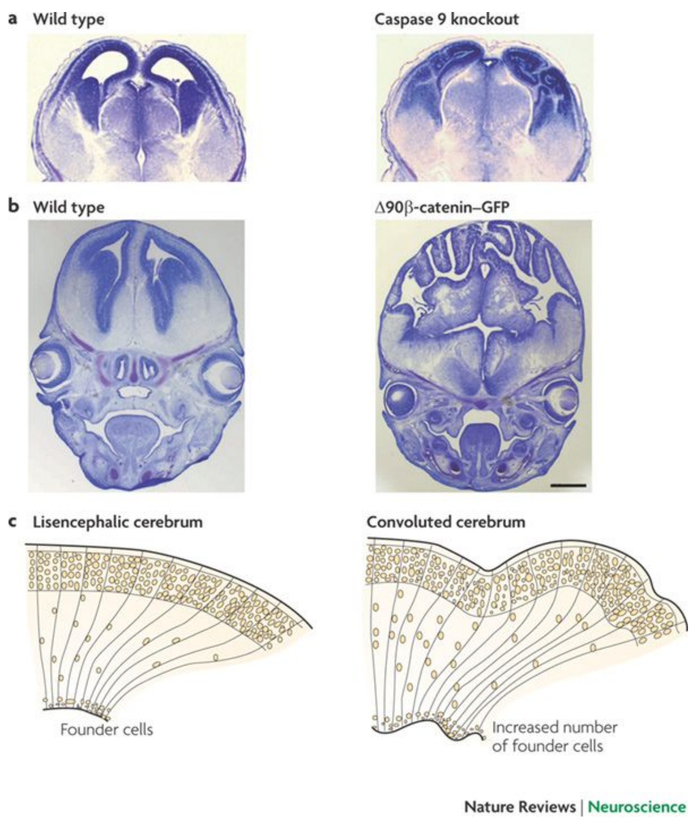
Proliferation, pruning

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

Apoptosis

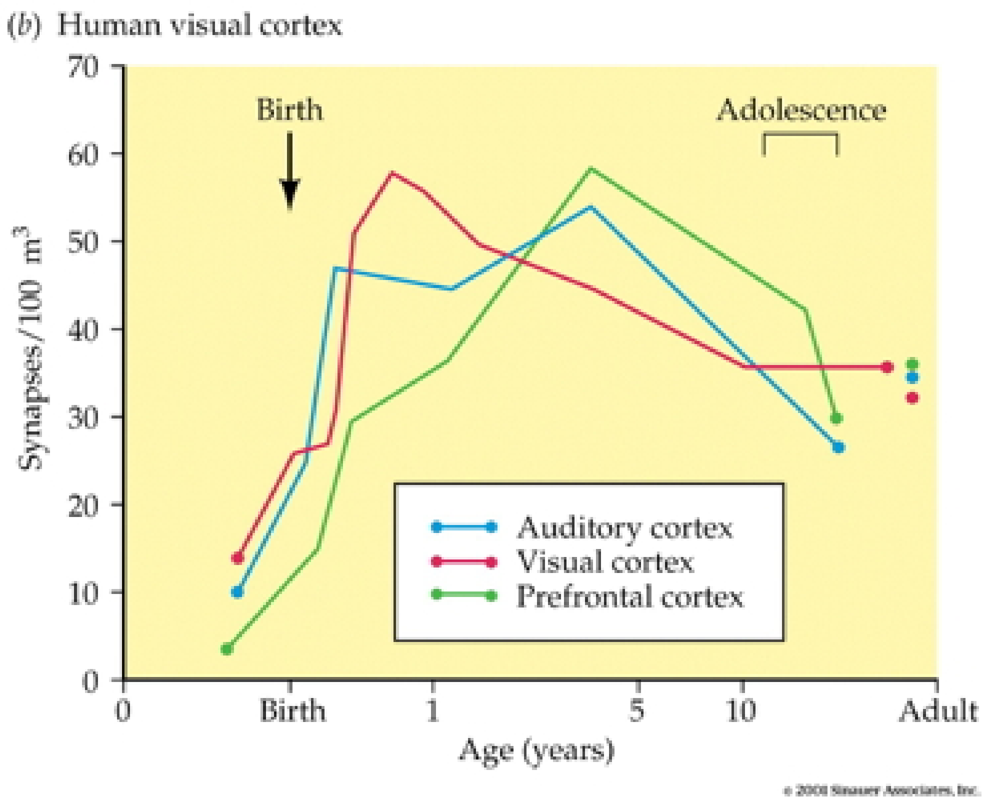
- Programmed cell death
- 20-80%, varies by area
- Spinal cord >> cortex
- Quantity of nerve growth factors (NGF) influences

Apoptosis and cortical expansion



(Rakic, 2009)

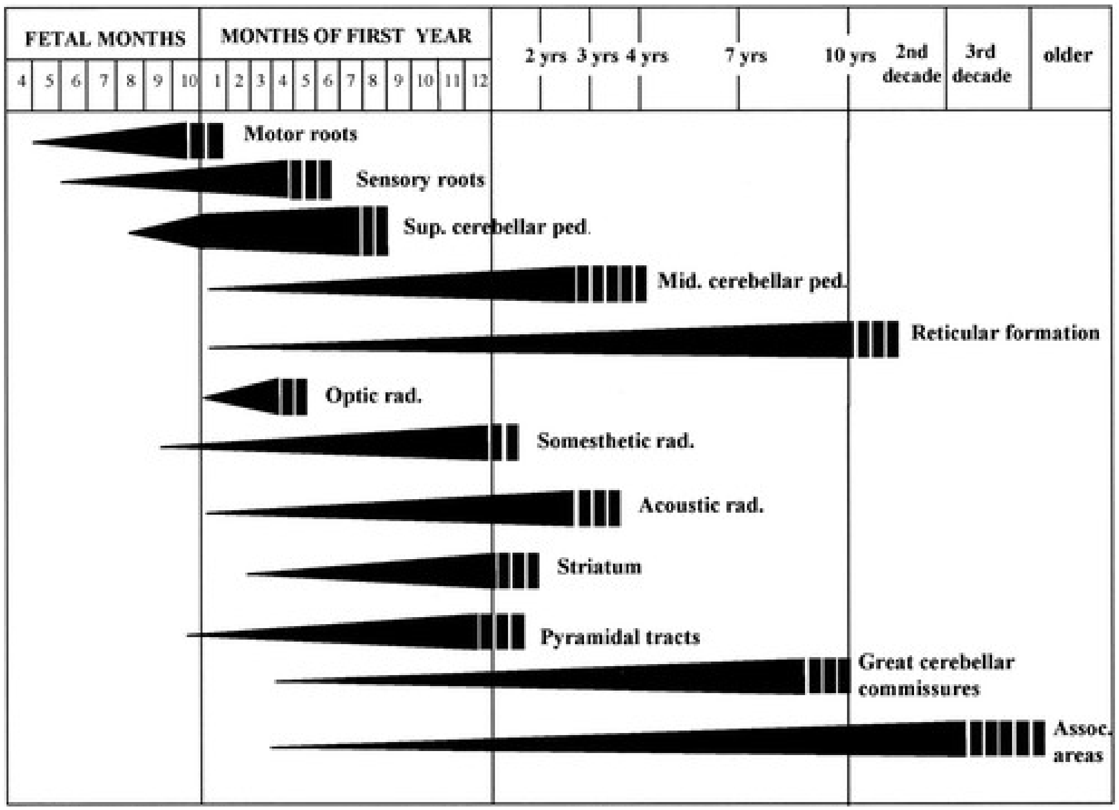
Synaptic rearrangement



Synaptic rearrangement

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

Myelination

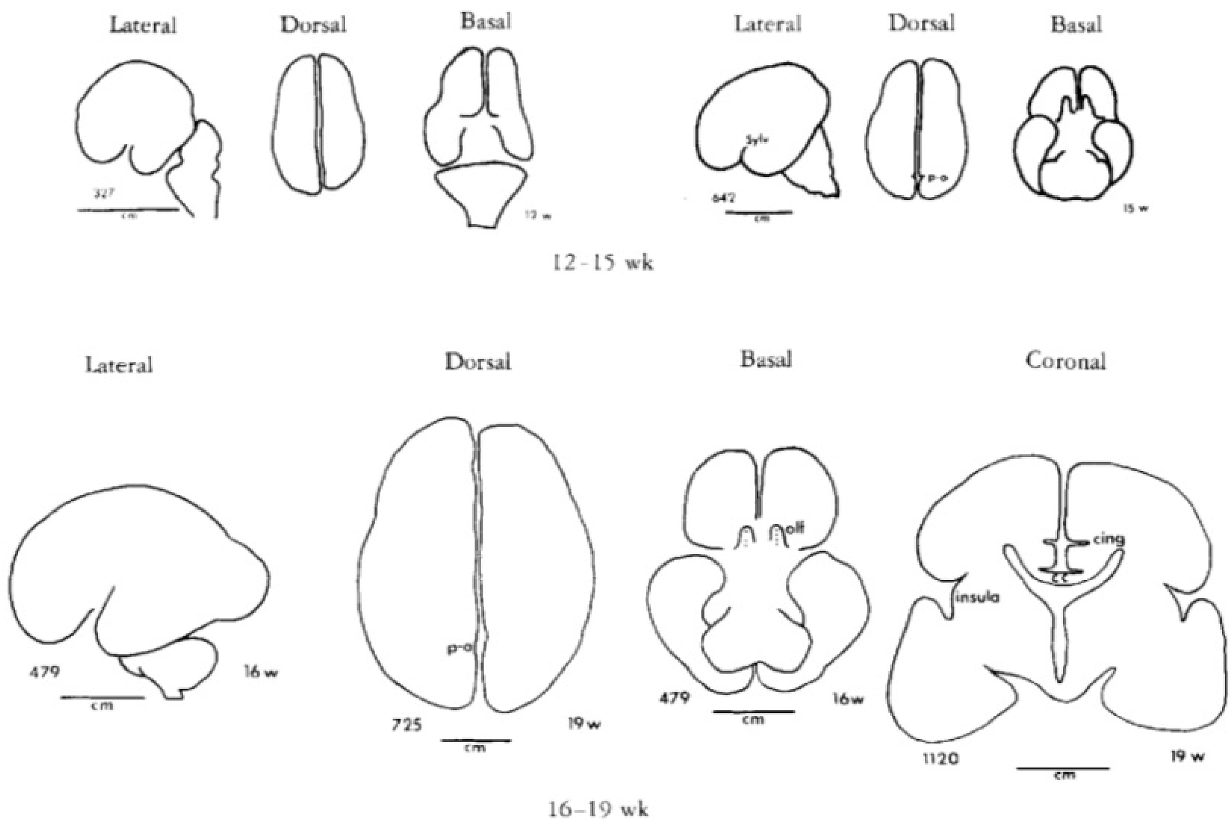


(Baumann & Pham-Dinh, 2001)

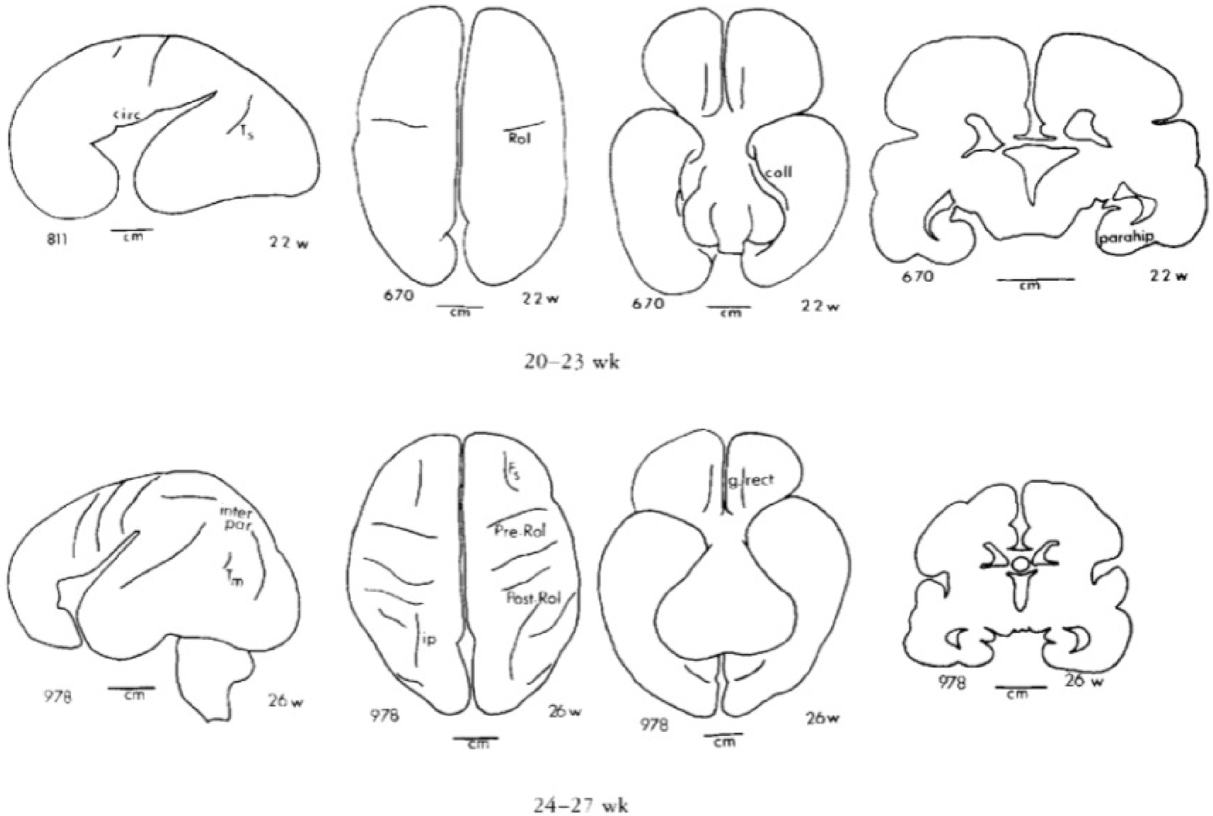
Myelination

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

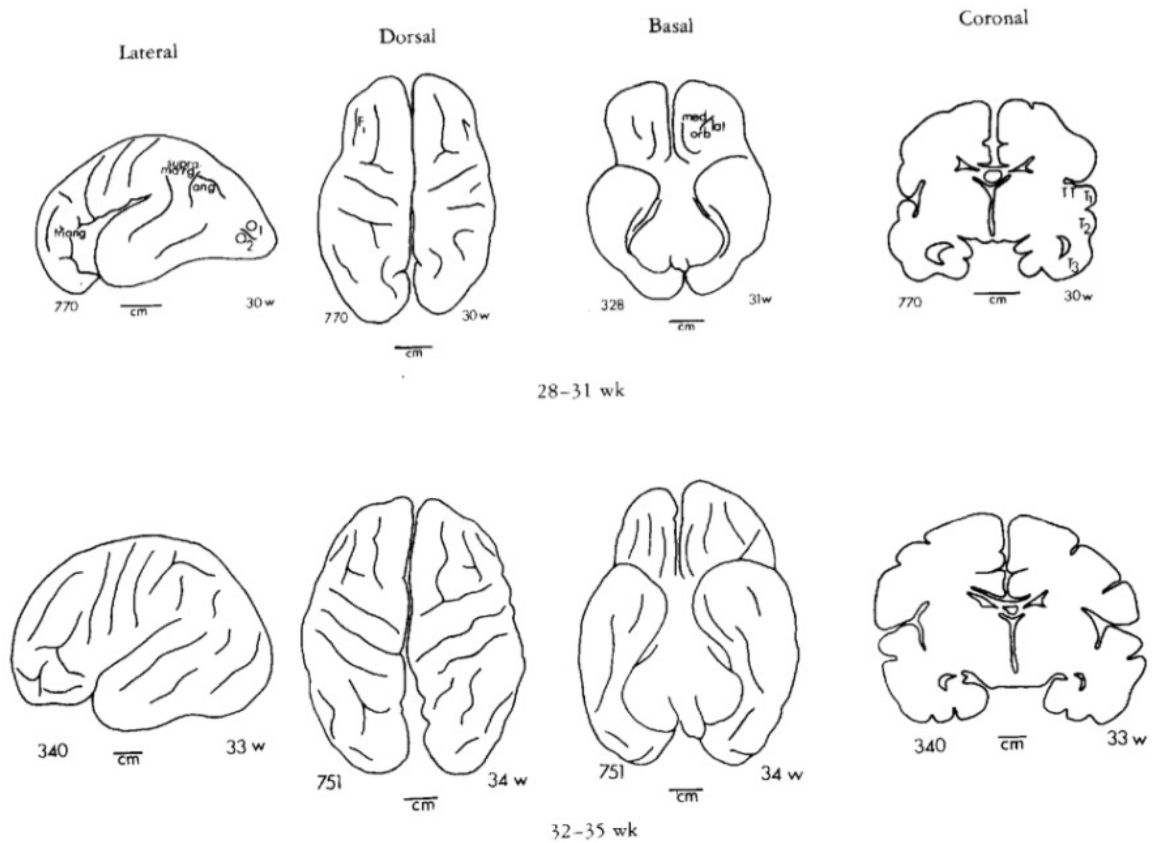
Gyral development



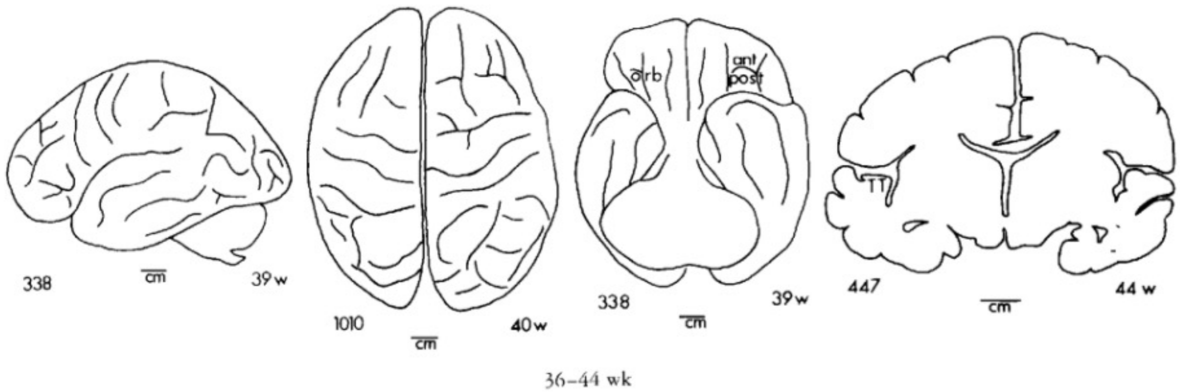
(Chi, Dooling, & Gilles, 1977)



(Chi et al., 1977)

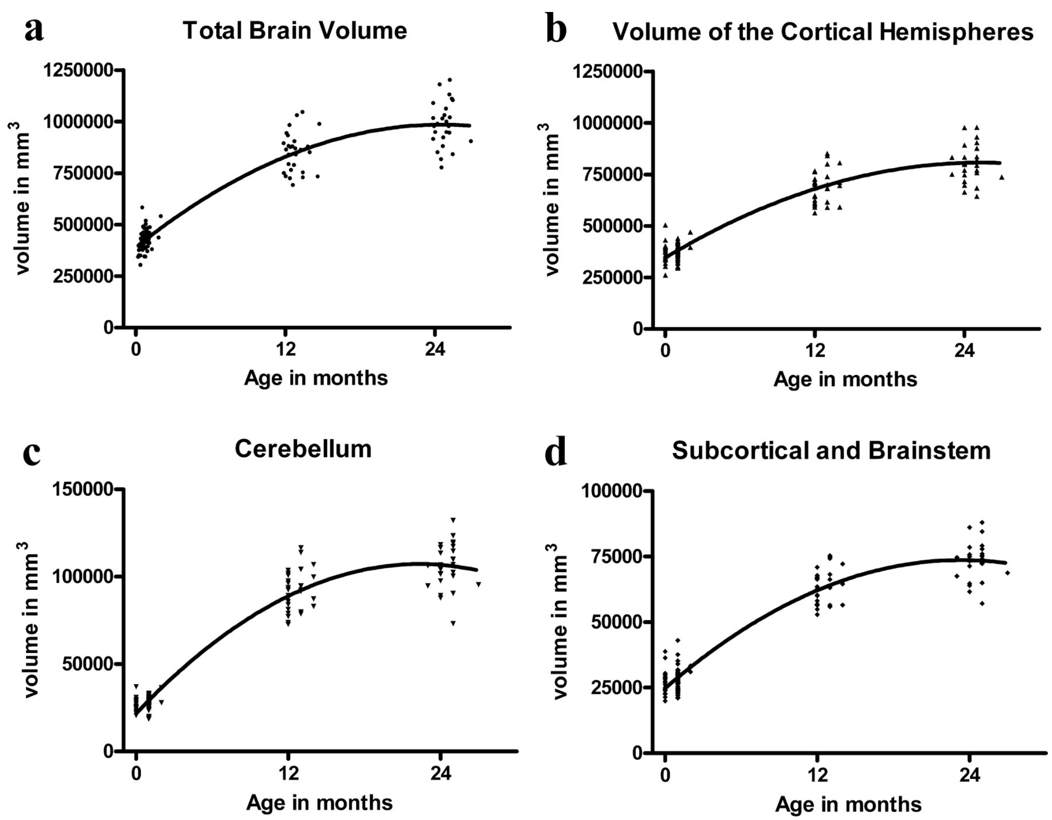


(Chi et al., 1977)



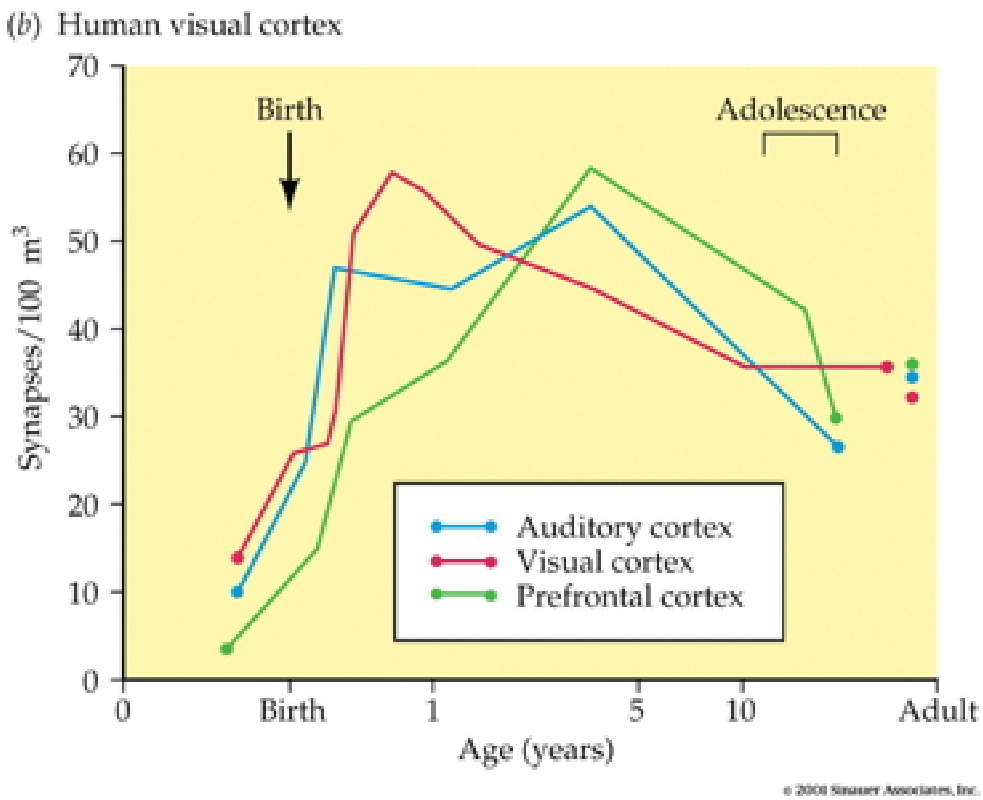
(Chi et al., 1977)

Structural development

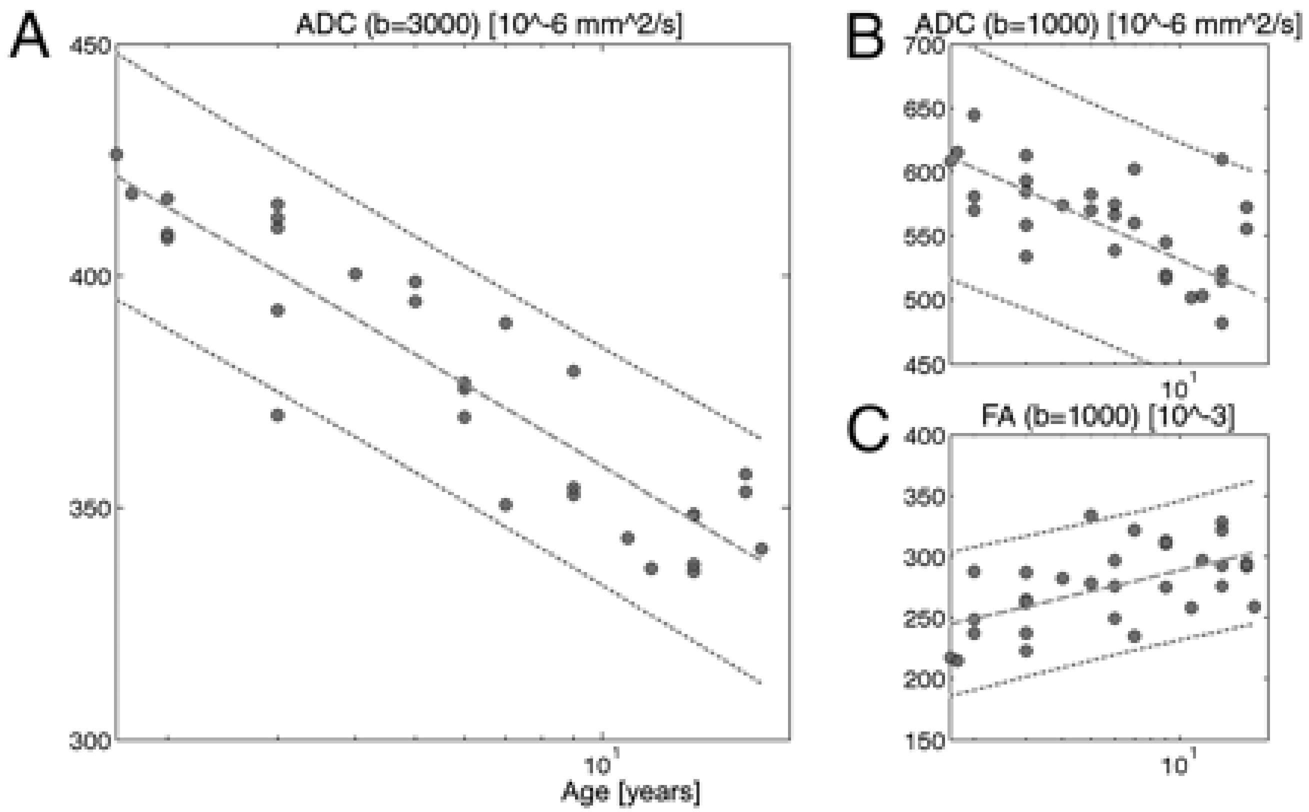


(Knickmeyer et al., 2008)

Postnatal patterns of synaptogenesis

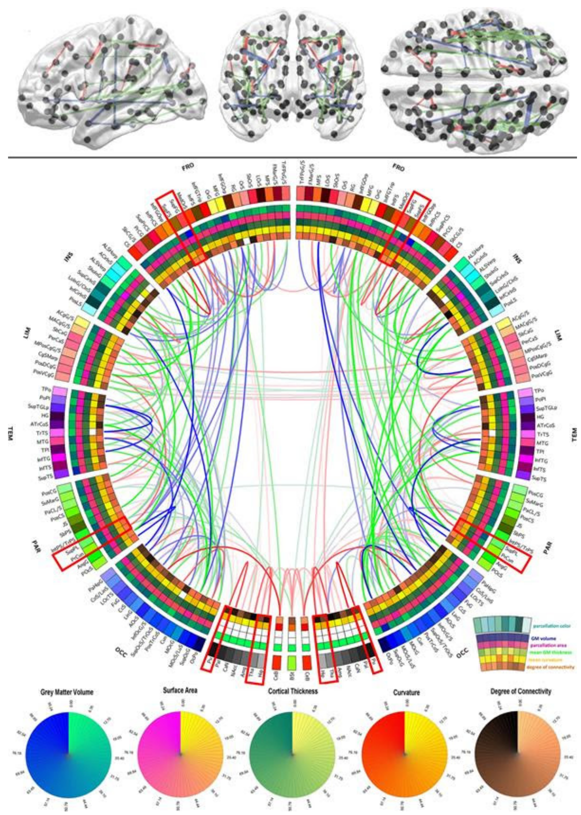


Myelination across human development



(Hagmann et al., 2010)

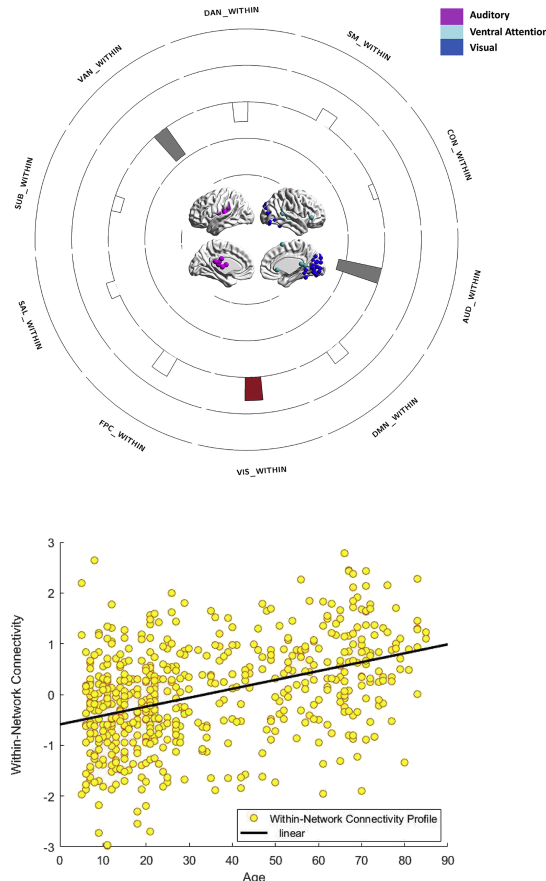
Networks in the brain



(Irimia & Van Horn, 2014)

Functional connectivity

- Age-related increases within visual-related areas (Petrican, Taylor, & Grady, 2017)



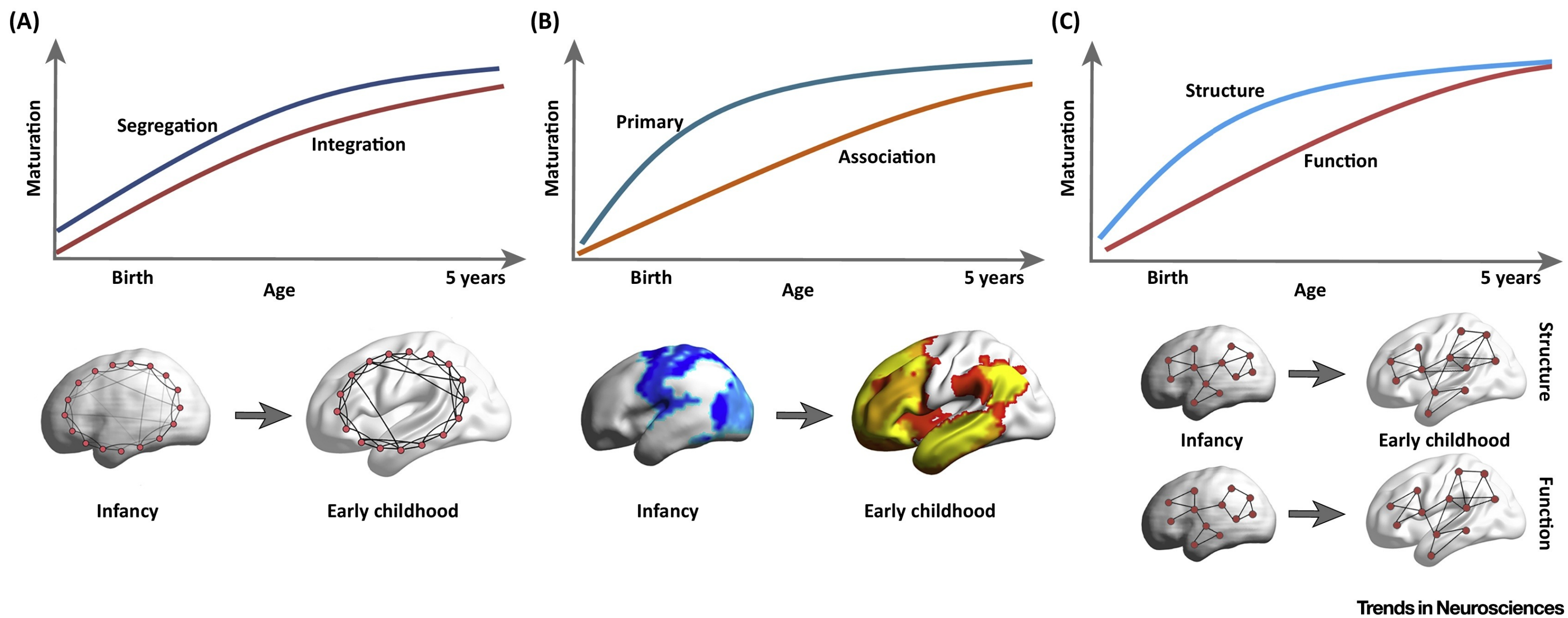
DAN_WITHIN
SM_WITHIN
CON_WITHIN
AUD_WITHIN
DMN_WITHIN
VIS_WITHIN
FPC_WITHIN
SAL_WITHIN
SUB_WITHIN
VAN_WITHIN
Auditory
Ventral Attention
Visual
Within-Network Connectivity
Age
Within-Network Connectivity Profile
linear

(a)

Age-related profiles in connectivity among "control networks."

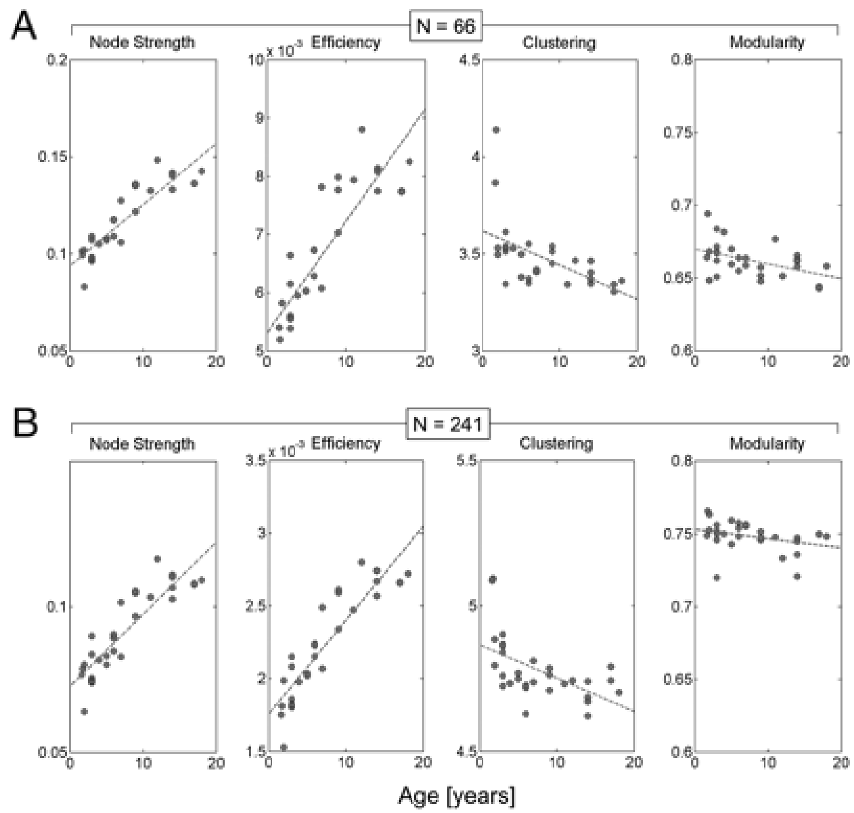
Age-related profiles in connectivity among "non-control networks."

The "development" of developmental connectomics



(Cao, Huang, & He, 2017)

Myelination changes "network" properties



(Hagmann et al., 2010)

Synaptic rearrangment, myelination change cortical thickness

- (Gogtay et al., 2004)
- Areal differences in cortical thickness change

(Gogtay et al., 2004)

Sampling in Shaw et al 2008 study

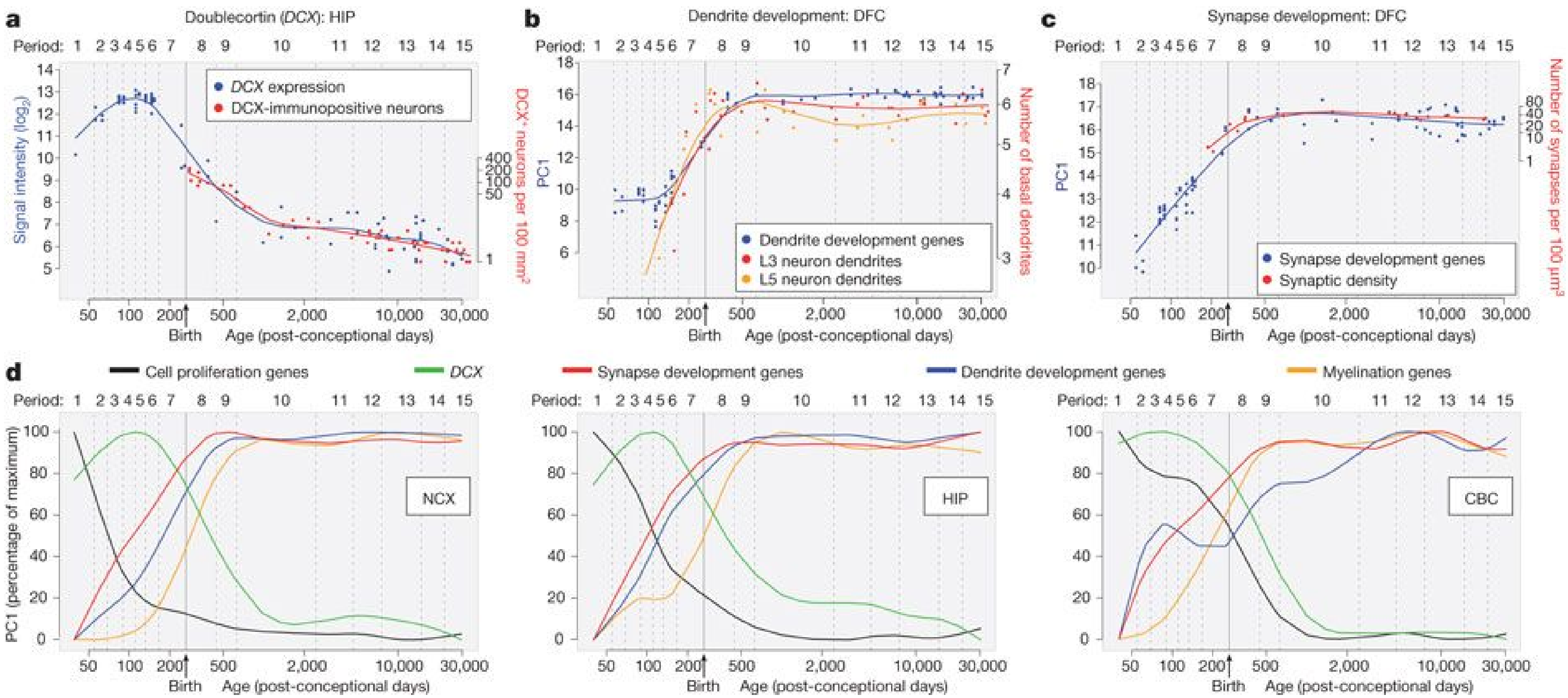
Illustrations of cubic, quadratic, and linear changes in cortical thickness.

Illustrations of cubic, quadratic, and linear changes in cortical thickness from Shaw et al. 2008.

Illustrations of cubic, quadratic, and linear changes in medial frontal lobe cortical thickness from Shaw et al. 2008.

Glucose utilization across age.

Gene expression across development



(H. J. Kang et al., 2011)

Summary of developmental milestones

Prenatal

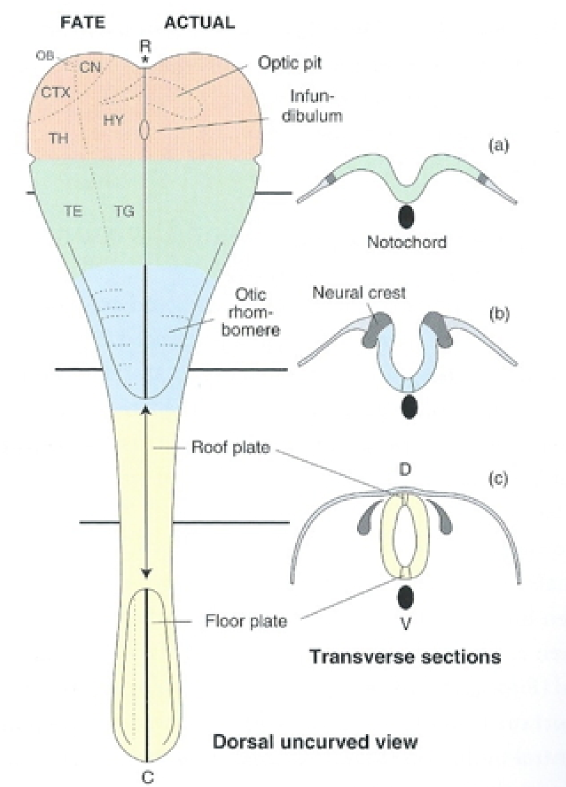
- Neuro- and gliogenesis
- Migration
- Synaptogenesis begins
- Differentiation
- Apoptosis
- Myelination begins
- Infant gene expression ≠ Adult

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)

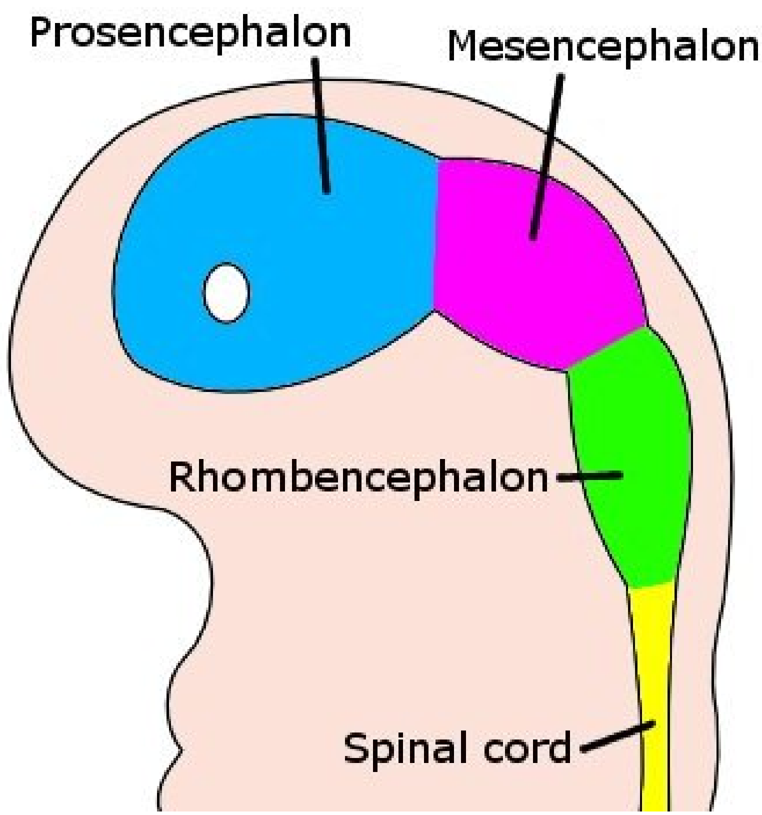
How brain development clarifies anatomical structure

3-4 weeks



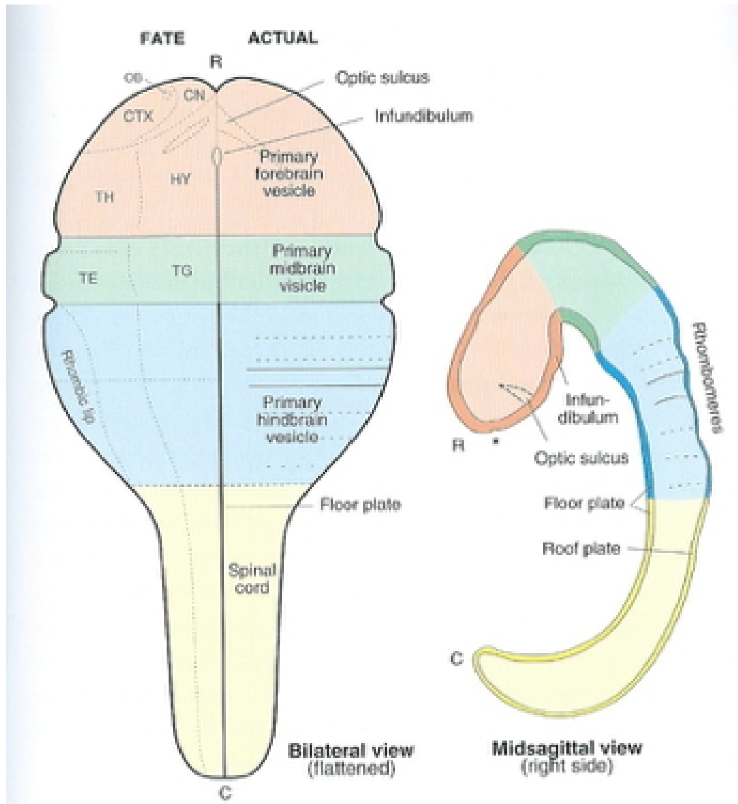
FATE
ACTUAL
R
OB
CN
CTX
HY
TH
Optic pit
Infun-
dibulum
(a)
TE
TG
Notochord
Otic
rhom-
bomere
Neural crest
(b)
Roof plate
D
(c)
Floor plate
V
Transverse sections
Dorsal uncurved view
C

4 weeks



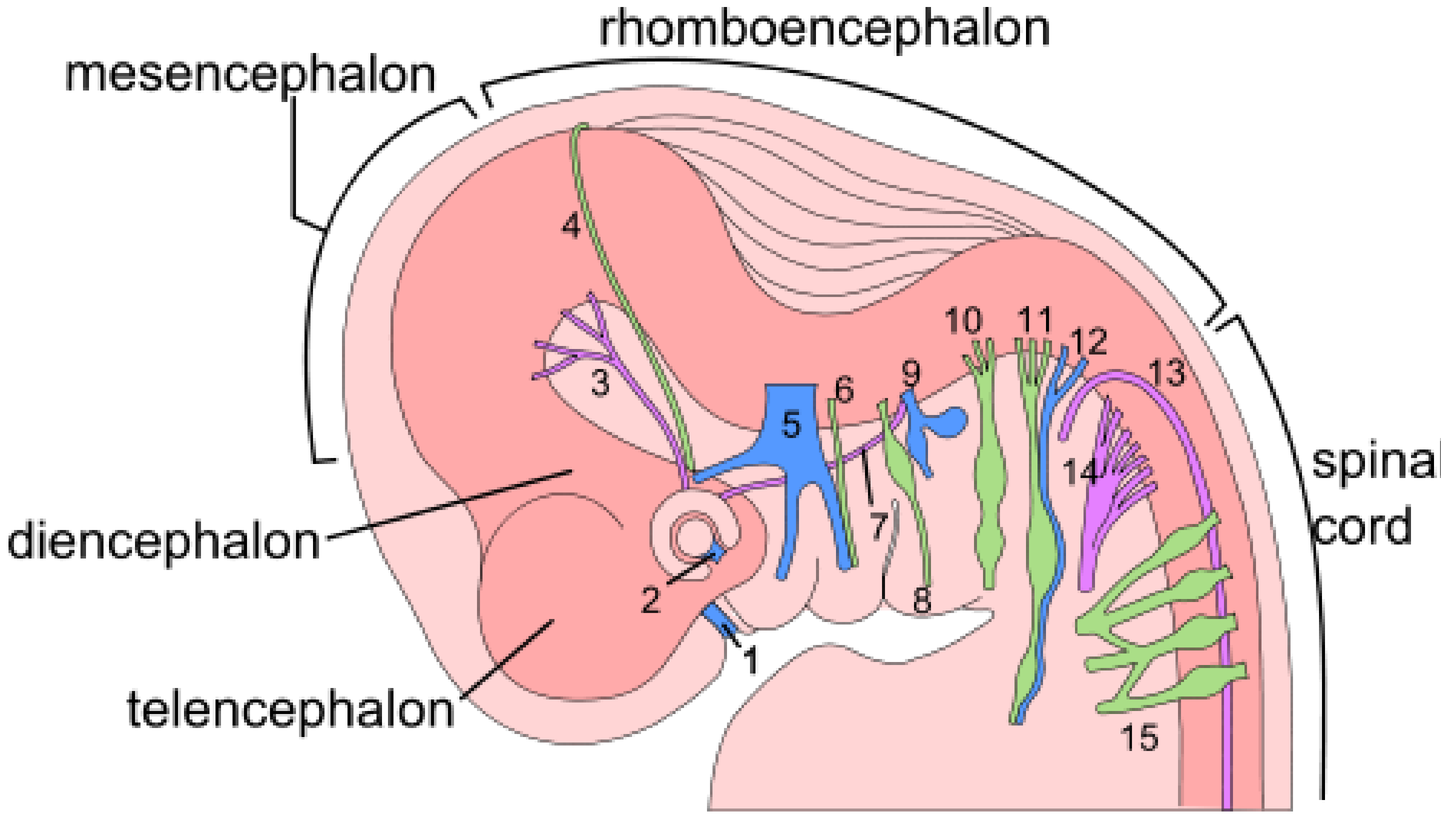
https://upload.wikimedia.org/wikipedia/commons/4/4c/4_week_embryo_brain.jpg

~4 weeks



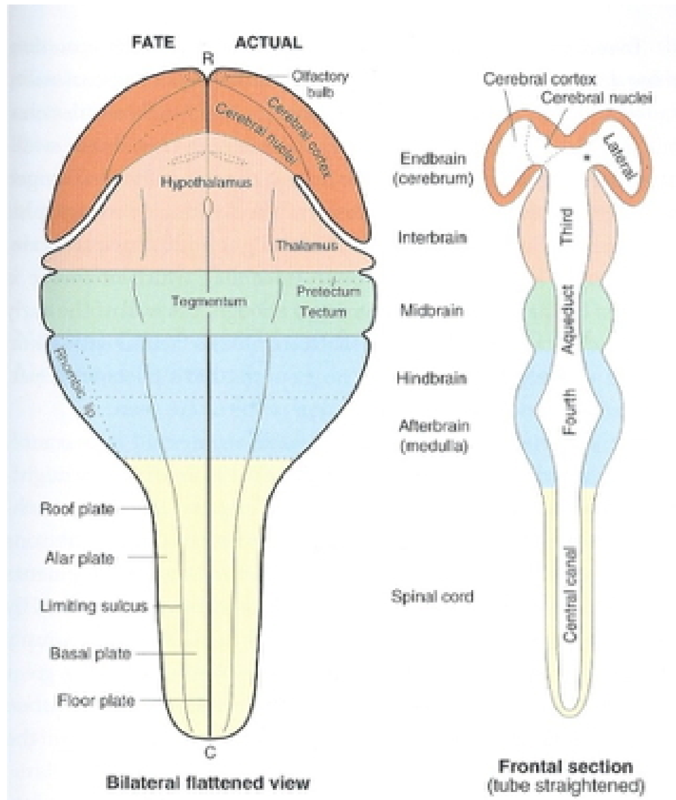
FATE
ACTUAL
R
OB
CN
CTX
Optic sulcus
Infundibulum
TH
HY
Primary forebrain vesicle
TE
TG
Primary midbrain visicle
Rhombic lip
Primary hindbrain vesicle
Floor plate
Spinal cord
C
Bilateral view (flattened)
Rhombomeres
R
Infun-dibulum
Optic sulcus
Floor plate
Roof plate
C
Midsagittal view (right side)

6 weeks



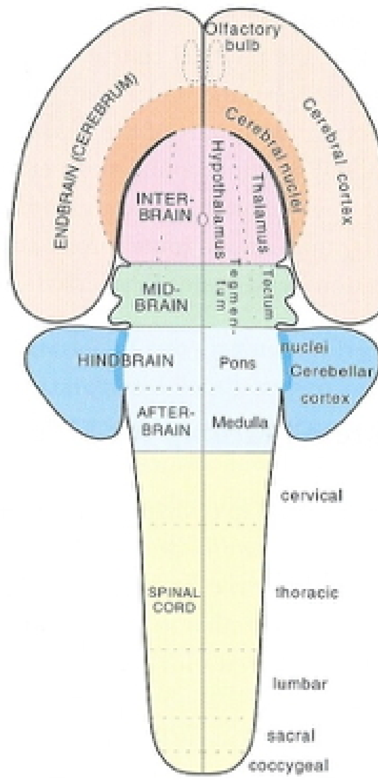
https://upload.wikimedia.org/wikipedia/commons/thumb/3/33/6_week_human_embryo_nervous_system.svg/5
6_week_human_embryo_nervous_system.svg.png

~6 weeks



FATE
ACTUAL
R
Olfactory bulb
Cerebral cortex
Cerebral nuclei
Hypothalamus
Thalamus
Tegmentum
Pretectum
Tectum
Rhombic lip
Roof plate
Alar plate
Limiting sulcus
Basal plate
Floor plate
C
Bilateral flattened view
Endbrain (cerebrum)
Interbrain
Midbrain
Hindbrain
Afterbrain (medulla)
Spinal cord
Cerebral cortex
Cerebral nuclei
Lateral
Third
Aqueduct
Fourth
Central canal
Frontal section (tube straightened)

Beyond



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

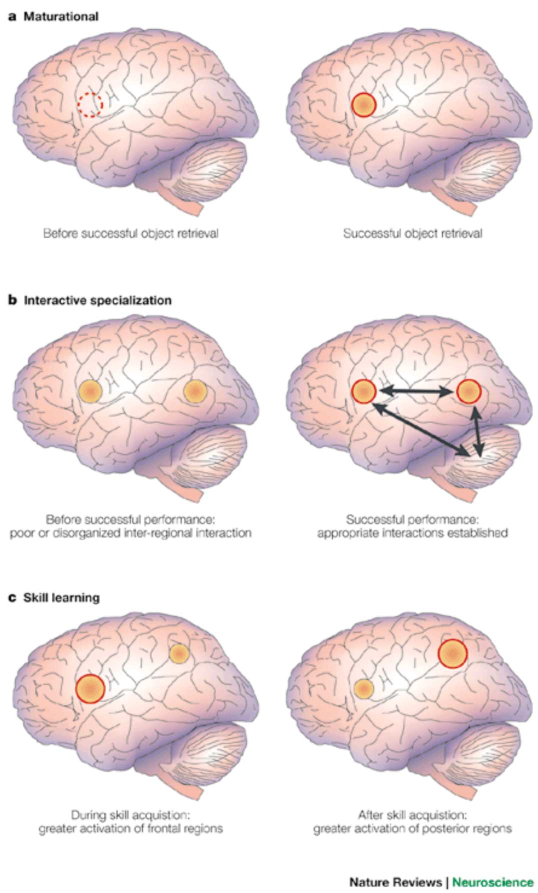
Organization of the brain

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

Organization of the brain

Major division	Ventricular Landmark	Embryonic Division	Structure
Hindbrain	4th	Metencephalon	Cerebellum, pons
	–	Mylencephalon	Medulla oblongata

From structural development to functional development



(M. H. Johnson, 2001)

Next time…

- Perception

References

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

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

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

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

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

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

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

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

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