Ch 15. Development and Plasticity

Cognitive Neuroscience: The Biology of the Mind, 2nd Ed.,
M. S. Gazzaniga, R. B. Ivry, and G. R. Mangun, Norton, 2002.

Summarized by
B.-W. Ku, M.-O. Heo, and B.-T. Zhang
Biointelligence Laboratory, Seoul National University
http://bi.snu.ac.kr/

Contents

The Shaping of the Brain

The Shaping of the Brain

- *Critical periods*
  - Specific time ranges early in life when experience can maximally influence the organization and function of the nervous system
  - Likely correspond to specific stages of neural development
    - The formation of synaptic connections
    - The presence and activity of molecular cues for specifying neuronal connectiv
- *Plasticity*
  - The ability of the nervous system to change
  - Its effect on perceptual and cognitive processes in the developing, adult and diseased nervous system.

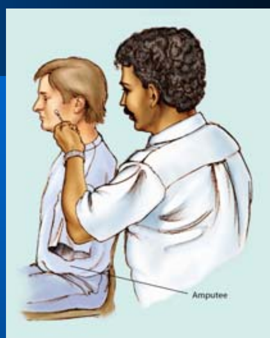


Figure 15.2 An example of mapping sensatioin.

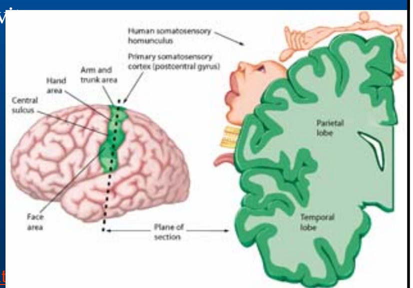


Figure 15.3 A human somatosensory homunculus

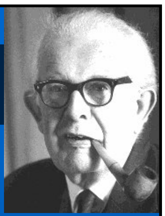
Perceptual and Cognitive Development

1. Piagetian theory
2. Development of Visual Cognition – Object Recognition
3. Maturation of Subcortical Visual Circuit
4. Language Acquisition During Development

Introduction – Two kinds of View

- Two kinds of view
  1. Newborns might have all the capabilities of adults but have not yet attained - via experience – the abilities of adults.
     - Possessing full-formed neural circuitry that simply awaits input in order for development to occur.
  2. Newborns may differ radically from adults in neural and cognitive capabilities, or both.
     - Newborns do not yet possess the neural and cognitive structures necessary to perform as adults do
     - Development will involve radical, qualitative change.
- The second has dominated theories of development based on both neural and psychological evidence.

Piagetian theory:
A Classic Theory of Cognitive Development (1)



- The Divisions of Cognitive Development in Humans as Formulated by *Jean Piaget*

Stage	Age	Characteristics
Sensory-motor intelligence	0-2 years	Unconnected sensations, representational thought
Preoperational period	2-7 years	Conservation of quantity and number, ego centrism
Concrete operations	7-11 years	Concrete concepts / no abstract thinking
Formal operations	11 years and older	Development of abstract thought

Piagetian theory:
A Classic Theory of Cognitive Development (2)

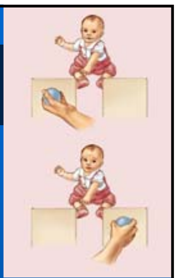


Figure 15.5 Testing a child's knowledge of the world-object permanence

- *The sensory-motor intelligence stage*
  - 0-2 years old
  - The newborn experienced a disconnected welter of ill-formed sensory perception and random motor acts.
  - Developing sensory-motor schemas: They learn to relate sensory inputs with motor acts and thus can purposively grasp objects they are looking at.
  - Not exhibit *object permanence*
  - Has some form of integration of sensory experiences across different sensory modalities.
    - Newborns can visually track sound moving across space.
    - Infants, a few months old, prefer to look at films of people speaking with soundtrack in proper synchronization with mouth movements.
  - Also evince knowledge of real-world objects.

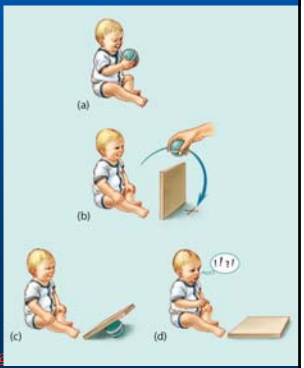


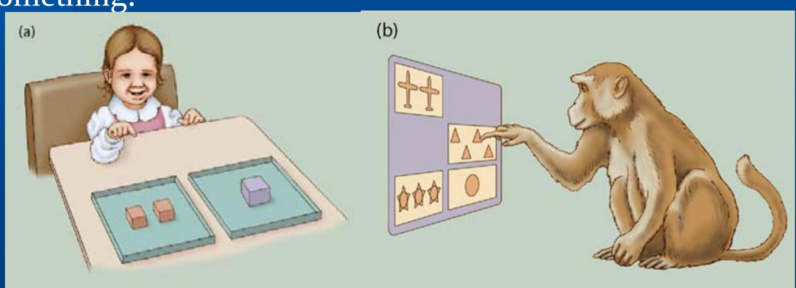
Figure 15.6 Physical reasoning in infants

Piagetian theory:
A Classic Theory of Cognitive Development (3)

- *The preoperational stage*
  - 2-7 years old
  - Representational thought, object permanence
  - Not show conservation of quantity, numbers
- *The concrete operation stage*
  - 7-11 years old
  - Perform quantitative operations only on concrete items or events
  - Fail to make abstract inferences
- *The formal operation stage*
  - From 11 years old
  - Learn to make abstract representations of relationships

Challenges to Piagetian theory:
A Classic Theory of Cognitive Development (4)

- New research challenges Piaget's conceptualization about last 3 stages.
- Infants show evidence of a rudimentary sense of number, or amount, very early in life.
- They can detect the difference between 2 and 3 of something.



p. 616~617 Development and Evolution of Numerical Ability

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Development of Visual Cognition – Object Recognition

- Looking time
  - Measure for scientific study.
  - It decreases over time when the same stimulus is presented repeatedly.
  - It increases when unexpected events than expected ones.
- How early after birth infants organize visual information into objects.
  - By the age of 4 months (P. Kellman and E. Spelke, 1983)
    - The common motions of objects – the same unit
    - The spatial separations between objects – separate units
  - By the age of 4 ½ months (A. Needham, 1999)
    - Differences in object shape – adjacent objects are actually separate pieces
    - Infants' visual world is richer and much better organized than suspected

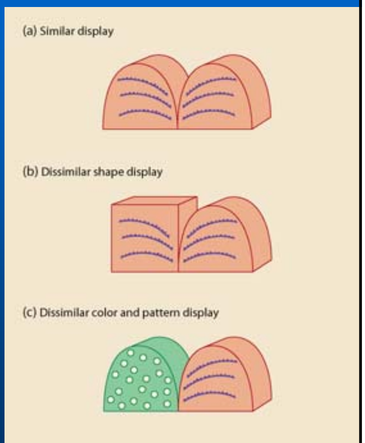


Figure 15.7 Testing showing that infants around 4½ months old can use object shape to segregate objects

Perceptual and Cognitive Development

Maturation of Subcortical Visual Circuits (1)

- Initial condition (at birth)
  - The foveal region is not mature.
  - The Peripheral retina is more developed.
  - The optic nerve is not myelinated completely.
- Development
  - Myelination occurs rapidly during the first 4 months and reaches adult patterns at about the age of 2 years.
  - LGN (Lateral Geniculate Nucleus): rapid growth in the first 6 months.
  - The time of maturation of the primary visual cortex varies w.r.t different cortical layers.

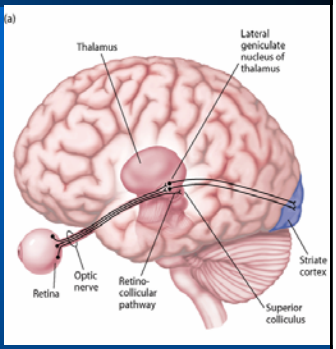
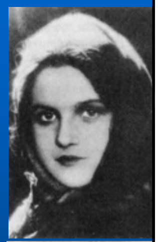


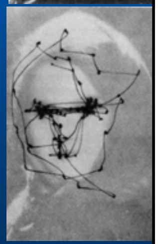
Figure 15.8 (a) Diagram of the visual system showing the separate retino-geniculostriate pathway

- The superior colliculus
  - Primary subcortical target of retinal ganglion cells
  - Saccadic eye movements and involuntary oculomotor movements.
  - Has a virtually normal pattern of neuronal lamination before birth, and the retino-collicular projection are completely myelinated by 3 months postnatally.
  - The first neural circuit supporting visual behavior to develop and to become myelinated is the subcortical projection of the retina to the superior colliculus oculomotor system

Ref) Saccadic Eye Movements

- *Yarbus*, the Russian psycho-physicist (1950s)
  - Shows the trace of the gaze of a subject exploring the portrait.
    - Do not scan a scene in a raster-like fashion.
    - Perform *jumps*, known as **saccades**, between the different points of interest, on which **fixation** is maintained for a short period.
- The saccadic pattern depends on the cognitive task to be performed.
  - *Do not* use saccades to paint a complete internal representation of a visual scene.
  - Experiments
    - We rather rely on the external word for storing information and only remember *pointers* to relevant locations in the scene.
    - Use saccades to retrieve the information as we need it.
    - *Saccades constitute a way to select task relevant information.*
- Most of the time is spent looking at the eyes and the mouth.
  - Other studies show that these are the regions we mostly rely on for face recognition.





Maturation of Subcortical Visual Circuits (2)

- The visuomotor behaviors of newborns
  - Track moving objects, but not display smooth pursuit eye movements.
  - Use saccadic pattern eye movements.
  - More likely to elicit overt orienting of the head and eyes – project to more strongly to the superior colliculus.
  - Newborn visual behavior is driven primarily *by the subcortical visuomotor system*.
- Obligatory overt attention (the age of 1 month)
  - Fixating the eyes on objects for long periods
  - The development of projections from striate cortex to subcortical structures that *inhibit* activity in the superior colliculus
  - The superior colliculus is less able to effect saccadic eye movements.

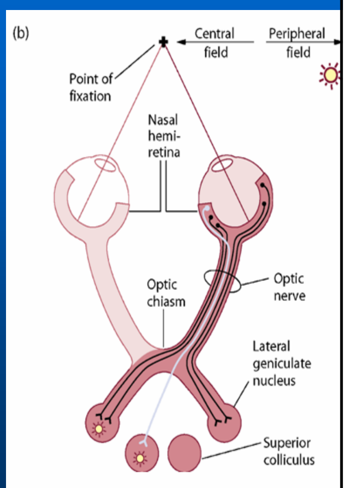


Figure 15.8 (b) Infants show a greater tendency to orient to stimuli in the temporal visual field of each eye.

Maturation of subcortical visual circuits (3)

- By 2 months
  - Smooth pursuit tracking of moving objects
  - The projections:
    the striate cortex → the middle temporal motion areas of the extrastriate cortex
  - Normal orienting to new stimuli – improving acuity within the visual fields central regions
- 3 ~ 6 months
  - Anticipatory eye movements
  - The projection:
    Upper layers of striate cortex → the frontal eye fields (voluntary eye movement)
  - Fully normal acuity, binocular vision
    - In part because of maturation of striate cortex and experience-dependent tuning of ocular dominance columns
    - Behavioral consequences, particularly for face processing

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Language Acquisition During Development

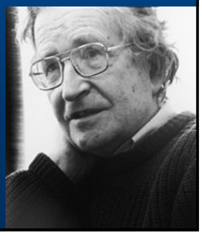
- Humans are not born with the ability to speak and understand a language. So, they must learn it through exposure.
- Criteria for what qualifies as an ***innate*** ability
  1) Present in all normal individuals in a population
  2) A common course of development among different individuals
  3) Without overt training of one individual by another.
  4) A genetic component
  5) Expressed in specific brain areas that are the same across individuals

Commonality of language in humans

- Some, like Noam Chomsky, argued that all human languages are similar to one another.
- One such view:
  - A ***universal grammar*** is common to all languages and built into each person's language system.
  - Differences in local characteristics of the grammar
- This is consonant with some knowledge about the neural substrates for language.

Ref) Universal Grammar

- Principles of grammar shared by all languages, thought to be innate to humans.
  - Does not claim that all human languages have the same grammar, or that all humans are "programmed" with a structure that underlies all surface expressions of human language.
  - Proposes a set of rules that would explain how children acquire their language(s), or how they construct valid sentences.
- Noam Chomsky's theory
  - An assumption: All languages have a common structural basis.
  - Human brain contains a limited set of rules for organizing language.
  - Supports:
    - Creole language
    - Future and past tense
    - Multiple negation to deny or negate.
    - When a question can be implemented, similar intonation.



Language acquisition is similar in everyone (1)

- All normal individuals acquire language in a similar way
  - Slowly gain about fifty more words – over the next half year
  - The *naming explosion* – over the next 6 to 12 months
    - The acquisition of new words speeds up tremendously
  - Lateralized to the left hemisphere
  - The use of words in combination
  - Complete sentences – between of 3-4 years
  - Children begin to acquire the mental grammar of a language, and they learn these rules at similar ages.
  - Their errors are also strikingly similar.
    - Ex) mouses (instead of mice)
  - Acquiring categories for words begins early, when children learn to categorize words as verbs or nouns

Language acquisition is similar in everyone (2)

- S. Pinker proposed that:
  - Semantic bootstrapping permits children to learn the differences between nouns and verbs.
  - The brain comes equipped to know that objects, actions, and attributes are different; we need only observe and infer the syntactic category of words.
- Word categories can bias children's attention to different features of objects and events.
  - Ex) noun – shape, adjective – color

Language acquisition is similar in everyone (3)

- Testing the idea that linguistic knowledge is innate rather than acquired?
  - Answer: to examine situations *where language errors predict whether a general rule is being applied.*
  - One example
    - Lexical and auxiliary verbs are quite similar in meaning and syntax and in their lexical form.
    - A person learning these might confuse them and make predictable errors (ex: “She have should eaten”). However, this does not occur.
    - Humans do not have and innate ability to distinguish between lexical and auxiliary verbs per se; instead, the brain apparently can distinguish between lexical and functional categories.
  - So we have at least one form of innate linguistic knowledge.

Development of the Nervous System

DEVELOPMENT OF THE NERVOUS SYSTEM

- How do the complex brain (especially, the neocortex) develops prenatally?
- The precise and complex circuits arise from a careful developmental plan.

Overview of Gross Development

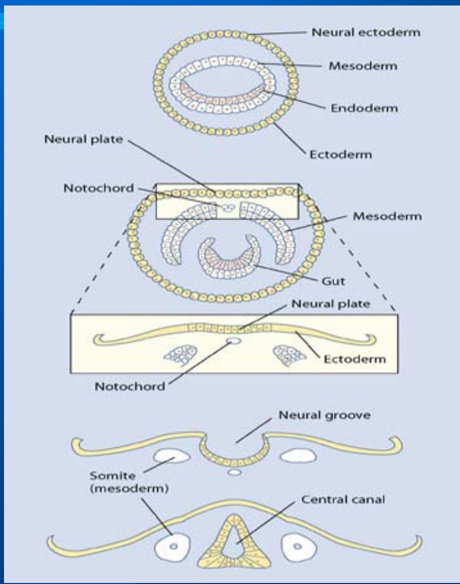


Figure 15.10 Development of the vertebrate nervous system

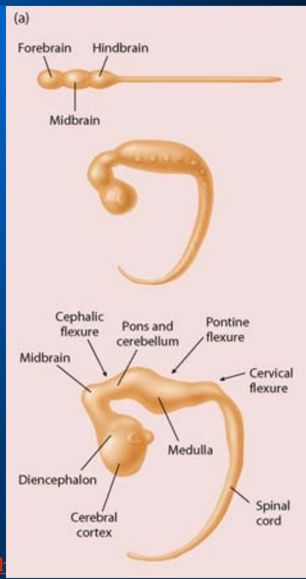


Figure 15.11 (a) Diagram of a developing embryo

Genesis of the Cerebral Cortex

- *Neuronal proliferation*
- *Neuronal migration*
- *Neuronal determination and differentiation*
- *Synaptogenesis*
- *Synapse elimination*

Neuronal Proliferation

- When are in the course of prenatal and postnatal development neurons in the brain "born"?
- For monkeys or humans, virtually the entire adult pattern of gross and cellular anatomical features is present at birth, with exception of complete myelination of axons.
- In the primate cortex
  - All neurons are derived within 1 to 2 months after the process begins, depending on the cortical regions.
  - The middle third of the gestational period accounts for the production of all cortical neurons present at birth.
- In the other mammalian
  - Continue until after birth, or during a different circumscribed period in gestation.

Neuronal Migration

- *Precursor cell*
  - Are *undifferentiated cells* from which neurons or glial cell are produced.
  - They arise from a layer of cells called *ventricular zone.*
- *The radial glia* (Cajal, at the end of 19th)
  - After mitosis on VZ, they migrate outward by moving along the radial glia.
- Once the migrating neurons approach the surface of the developing cortex – a point known as the *cortical plate* – they stop short of the surface.
- The cortex is built from the inside out.

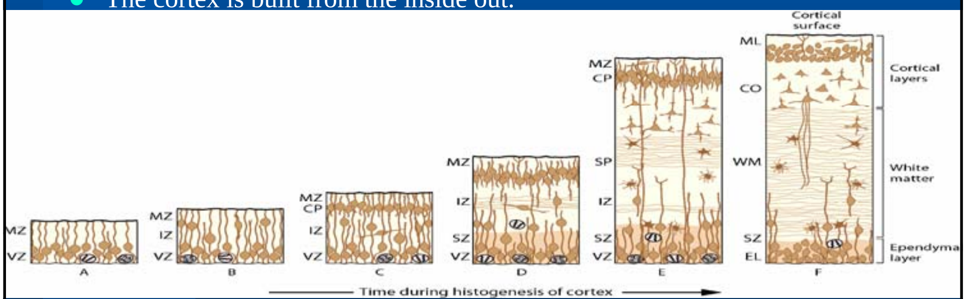


Figure 15.13 Histogenesis of the cerebral cortex

Determination and Differentiation of Neuronal Types in the Cortex

- Through cell division and differentiation…
  - All cortical cells, including neuronal subtypes and glial cells, arise from the precursor cells of the ventricular zone.
- For the first 5 to 6 weeks of gestation, the cells in the ventricular zone divide in a symmetrical fashion.
- After this time, asymmetrical division begins: one of the two cells present after division becomes a migratory cell.
- For mammalian cortical neurons, a prespecification of neuronal properties takes place long before the migrating neuron reaches its destination.

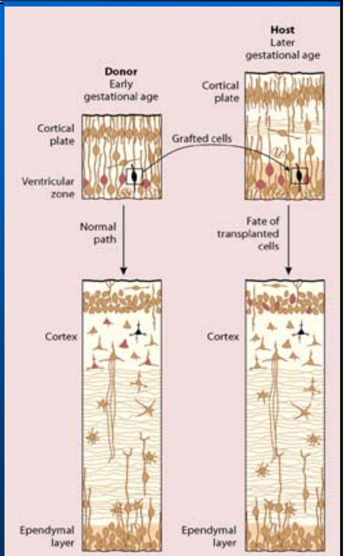


Figure 15.15 Determination of neuronal types in cortex

The Radial Unit Hypothesis (1995, P. Rakic)

- A topographic relation between precursor and proliferating neurons in the ventricular area
- The cortical column
  - A developmental history
  - Functional consequences
  - A principal unit of organization

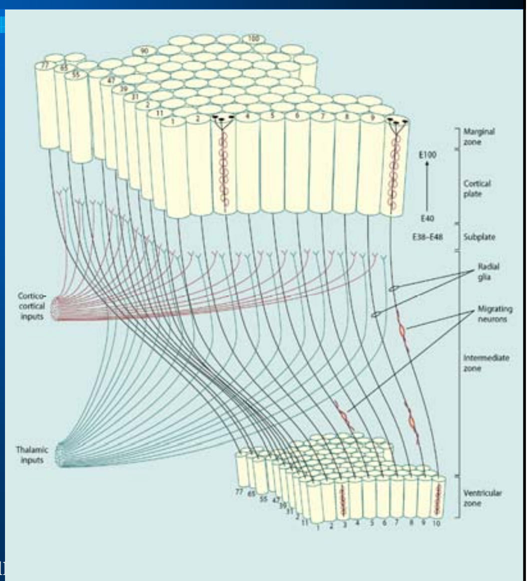


Figure 15.16 Diagram of radial unit hypothesis

Cytoarchitectonic Variation Across Cortical Areas (1)

- *The protomap hypothesis (1995, Rakic)*
  - Prespecified instructions inherent in the developing neurons interact with signals derived from neuronal inputs from subcortical brain regions.
  - Genetic factors predetermine the organization.– normal cortical organization is possible without experience.
  - Ex) Animals born without eyes show normal development.

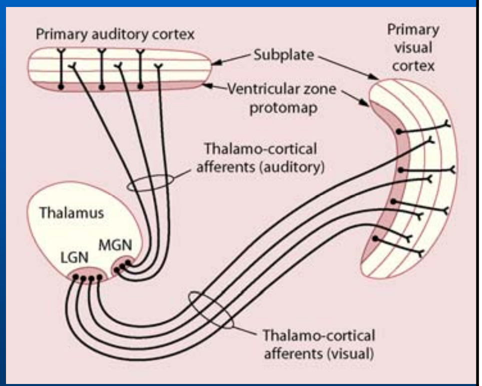


Figure 15.17 The protomap hypothesis of cytoarchitectonic diversity

Cytoarchitectonic Variation Across Cortical Areas (2)

- Although the genetic and biochemical properties of neurons may well be prespecified very early in the developmental process, these prespecifications reflect the final phenotype of the neurons can be influenced by the environment.

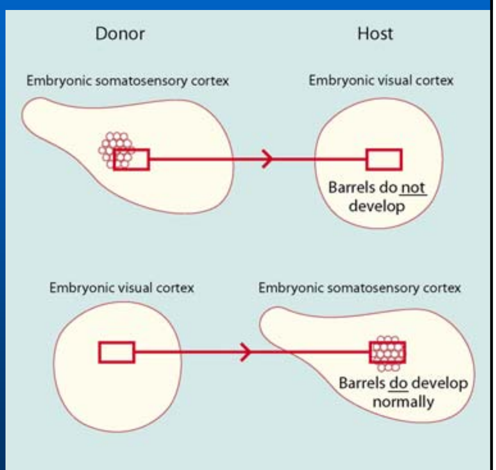


Figure 15.18 Transplanted tissue interacts with host neurons.

Birth of New Neurons Throughout Life

- Recent findings are challenging the strongly held belief that the adult brain produces no new neurons.
- In the adult macaque monkey brain
  - The number of new neurons correlates positively with learning or enriched experience
- In the adult human brain
  - Our brains renew themselves throughout life to an extent not previously thought possible.

Postnatal Brain Development

- Synaptogenesis
  - Reach peak density during the first 15 months of life
- Synapse elimination (*pruning*)
  - The fine-tuning of neural connectivity
- The time course of human synaptogensis and synapse elimination is hypothesized to differ in different cortical regions.
- The significant increase in brain volume during the first 6 years
- The role of experience in the postnatal brain development

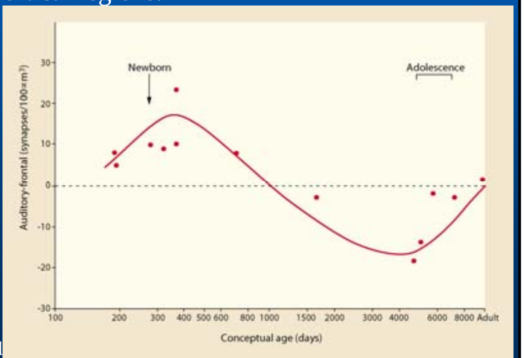


Figure 15.16 Plot of the difference score obtained by subtracting density in the frontal cortex, as a function of the conceptual age of humans.

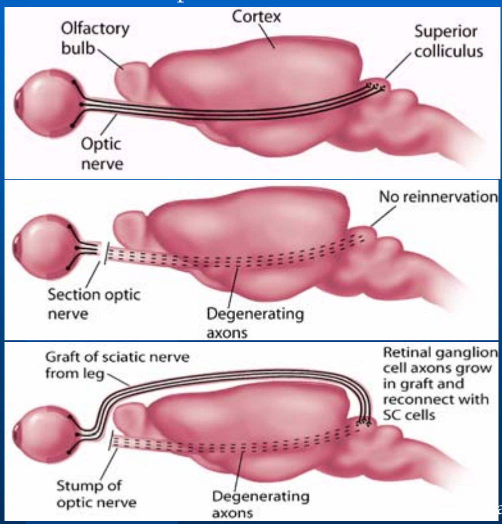
Plasticity in the Nervous System

Plasticity in the Nervous System (1)

- Plasticity
  - Tremendously plastic during development
  - Postnatal plasticity is limited: Cells are not free to new areas or to make large changes in long-distance connectivity.
- *Sensitive periods*
  - During *sensitive periods*
    - Local cortical connectivity can be affected when extrinsic influences can alter brain organization.
  - After *sensitive periods*
    - Neurons in the CNS do not regenerate damaged connections nor does the brain replace lost neurons

Plasticity in the Nervous System (2)

- Two experiments.



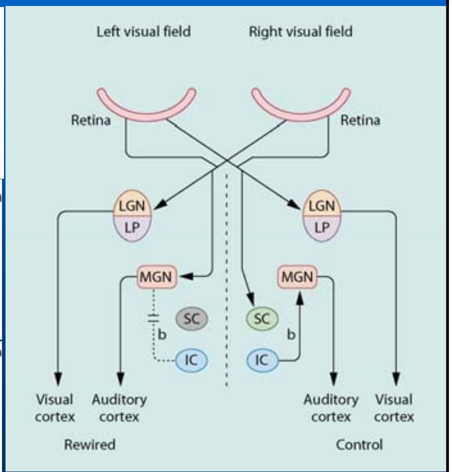


Figure 15.23 Surgical rewiring of visual inputs in the ferret brain.

Figure 15.22 Inducing regeneration in the central nervous system (CNS).

Cortical Maps and Experience

- Cortical maps
  - ♦ Somatotopic, tonotopic or retinotopic organization
- Somatotopic maps are change after peripheral receptors and nerves have been manipulated in adult animals. (1991,Kandel, et al.)
  - ♦ When sewing fingers together
  - ♦ *Filling in* – when a finger of a monkey is denervated

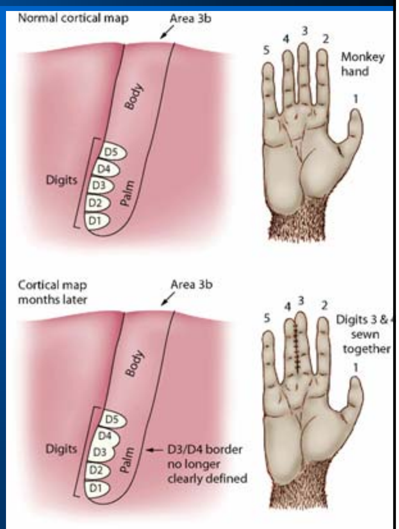


Figure 15.24 Reorganization of sensory maps in the primate cortex.

Cortical Maps and Experience (2)

- The auditory and visual systems also can have such changes.

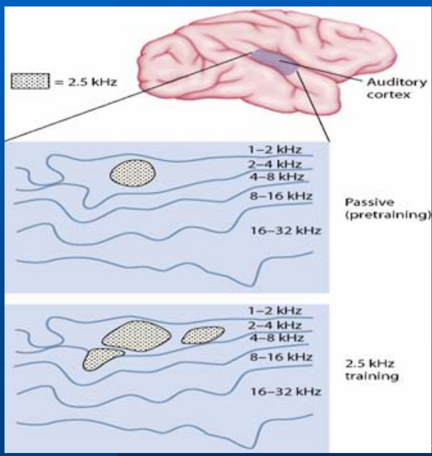


Figure 15.25 Changes in auditory frequency mapping with training.

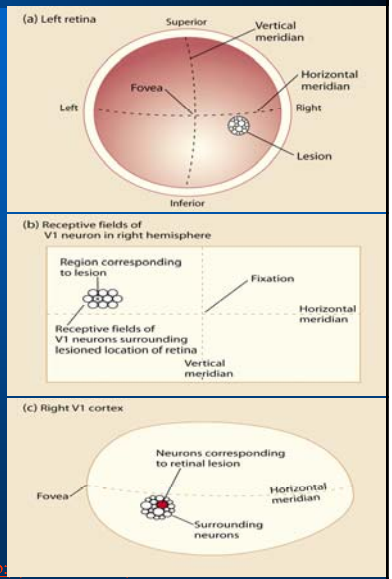


Figure 15.26 Reorganization of cortical visual receptive fields in response to retinal damage.

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Reorganization in Human Cortex (1)

- Several reports…
  - When a Q-tip was brushed lightly against an amputee's face, he reported feeling his amputated hand being touched.
  - A larger cortical area was dedicated to representing the sensations from the fingers of string musicians.
  - When stimulating the musicians' fingers, the size of cortical response correlated with the age at which they began their musical training.

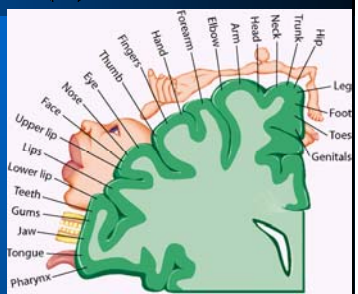

Figure 15.27 Map of a human homunculus in somatosensory cortex

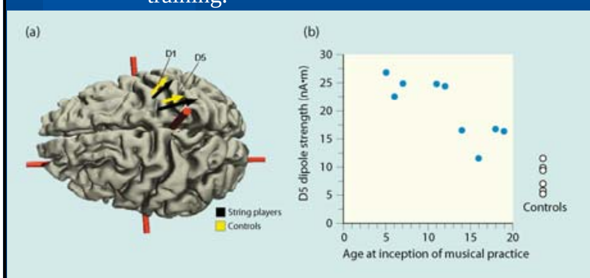

Figure 15.29 Changes in the cortical representation of the human fingers in musicians who play string instruments.

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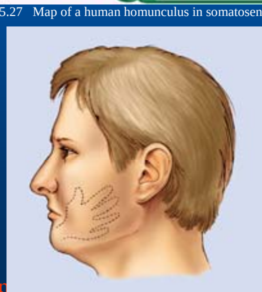

Figure 15.28 The drawing shows the hand representation sketched on the face of the amputee studied by Prof. Ramachandran

Reorganization in Human Cortex (2)

- In the normal brain, motor skill training can induce relatively rapid changes in cortical organization.
  - Finger-thumb touching task
- Functional plasticity

Summary

- Plastic changes
  - The brain and body form during embryogenesis.
- Permanent changes occur by the loss or alternation of sensory inputs during sensitive periods of early life.
- Even in the adult, plastic changes occur, as capable of learning throughout life.

Key Terms

corticogenesis	neural plate	Piagetian theory	somatotopy
critical periods	neuronal determination and differentiation	plasticity	synapse elimination
ectoderm	neuronal migration	precursor cells	synaptogenesis
Innate	neuronal proliferation	radial glia	universal grammar
looking time		sensitive periods	

Thought Questions(1)

1. How do developing neurons migrate from the locations where they are dividing and being "born" to where they must finally reside in cortex?

2. Can a visual neuron process auditory information if it is transplanted from visual to auditory cortex? If so, when must such transplantation occur and what does it tell us about developmental specification?

3. Infants born anywhere in the world to parents of any racial or ethnic group can learn their native language and become speakers of their native language. However, if they move to another country later in life, they have accents in their speech. But why is it that if they move to another country when young enough, they can learn to speak like a native speaker? Is this merely a practice effect because of the extra time spent in the new country? What happens in the latter case to their ability to learn their native language if they move back later in life?

Thought Questions(2)

4. Once the human brain is past the critical period in development and is fully developed, damage has less impact on its organization. But how would a person losing a limb, and why might this be triggered by stimulation of the remaining body parts?
5. Expert violinists may have larger regions of the brain dedicated to somatomotor processing in the hand and finger region of the brain. Are these individuals born with more cortex dedicated to somatomotor processing? What evidence in animals helps resolve the story of this form of plasticity?