Computational cognitive neuroscience: 5. Brain Areas

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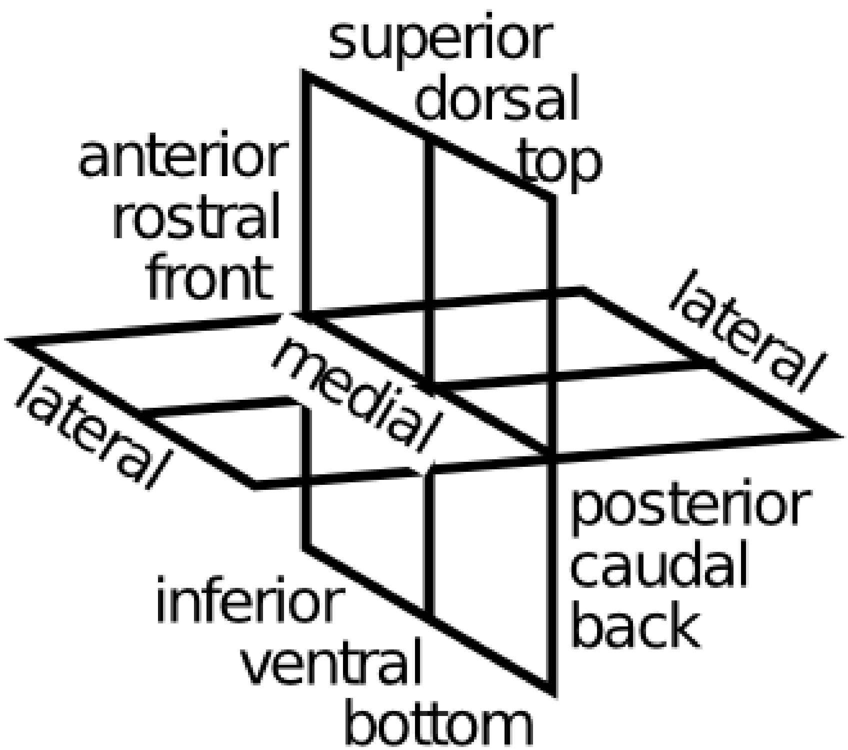
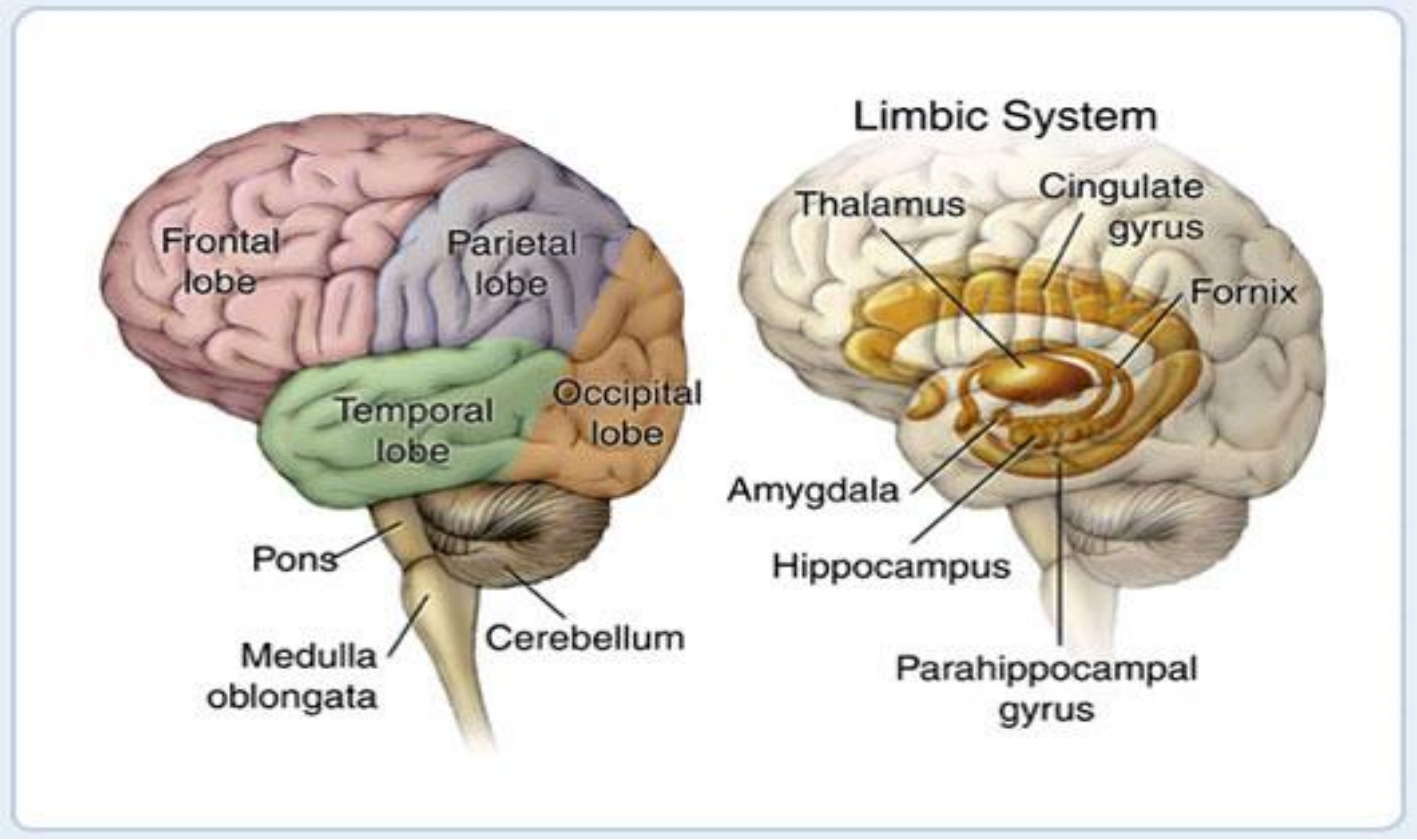
Brain areas

- Terminology for referring to different parts of the brain:
- For everything except lateral and medial, three different terms for the same spatial reference are used.

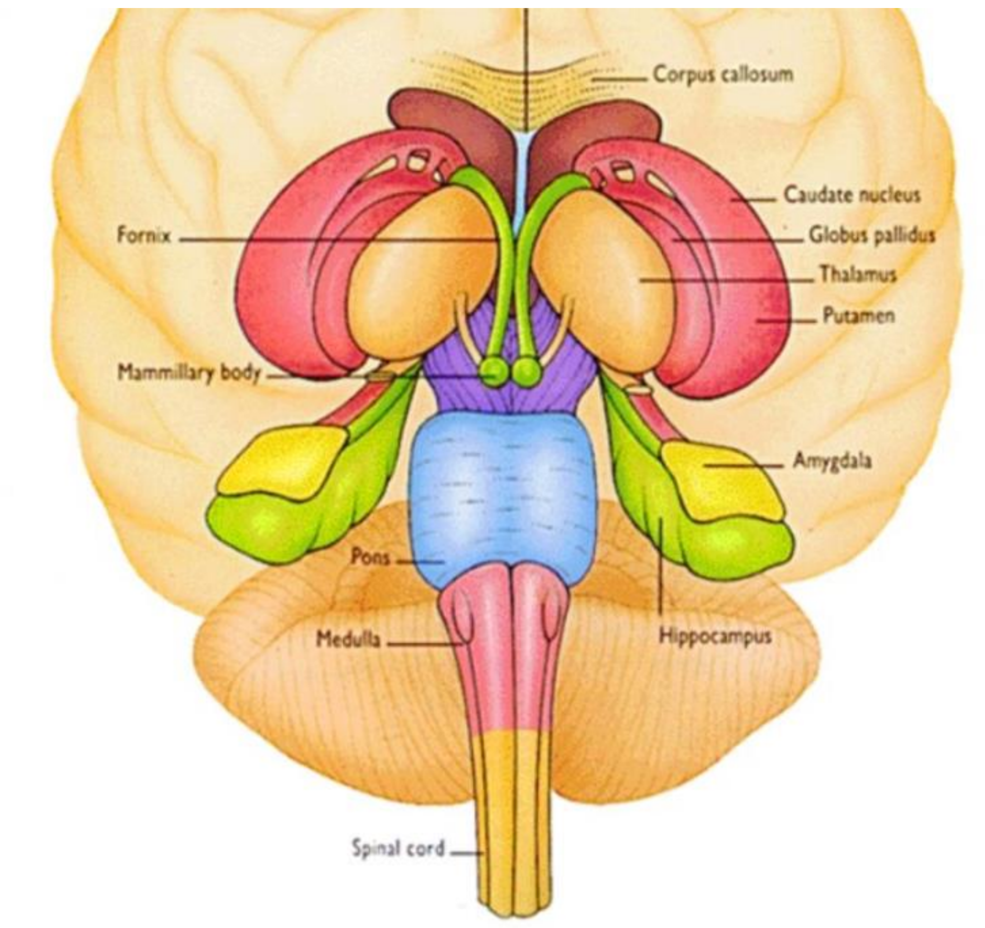


Gross anatomy of the brain

- Left panel shows the major lobes of the outer **neocortex** layer of the brain.
- Right panel shows some of the major brain areas internal to the neocortex (i.e. basal ganglia are not shown).



Subcortical areas

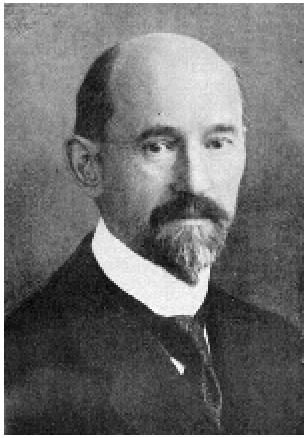


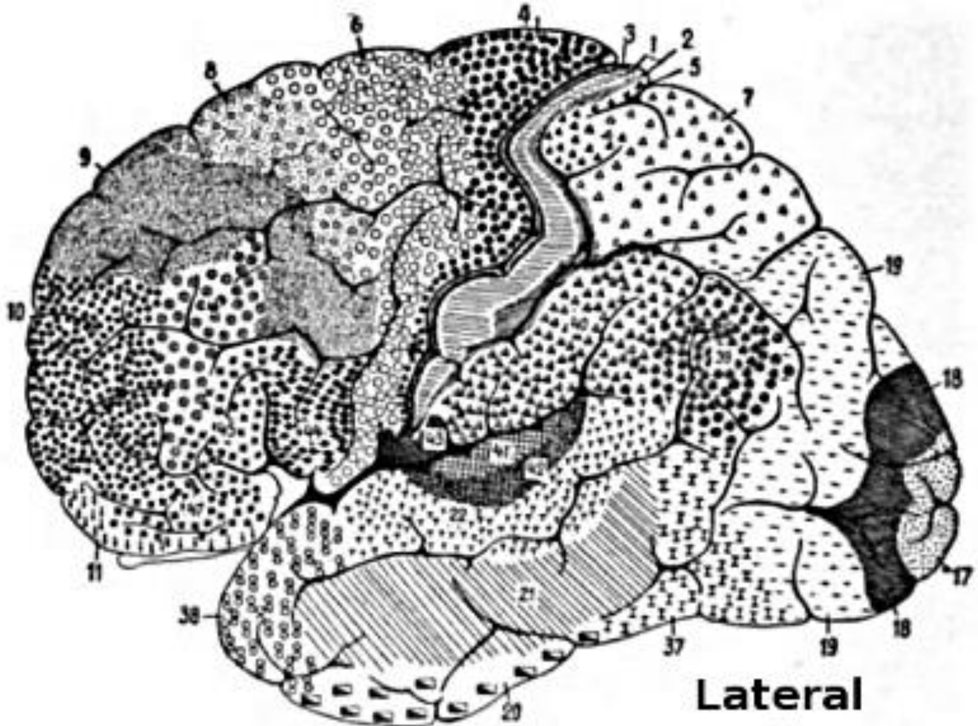
[The human mind explained, Susan Greenfield ed, 1996, p. 34.]

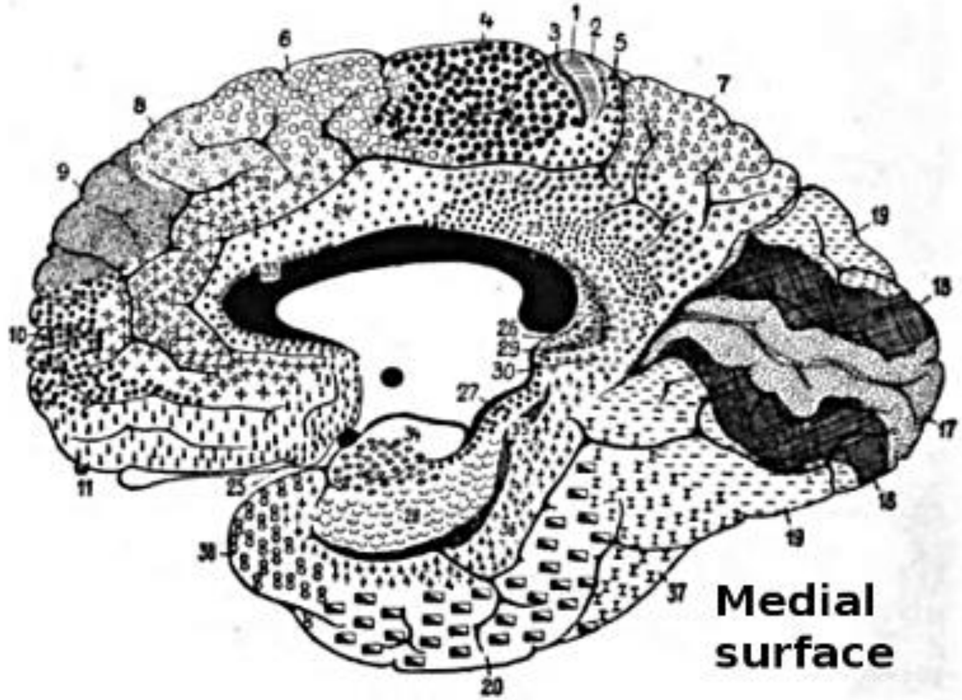
- **Hippocampus**: crucial for storing new episodic memories;
- **Amygdala**: recognizes emotionally important stimuli, and alerts the rest of the brain about them;
- **Cerebellum**: important role in motor coordination, and learning / remembering motor skills
- **Thalamus**: primary gateway for sensory information on its way to the neocortex;
- **Basal Ganglia**: critical role in motor control and executive functions.
- **Brainstem**: involuntary functions.

Cortical Brodmann's areas

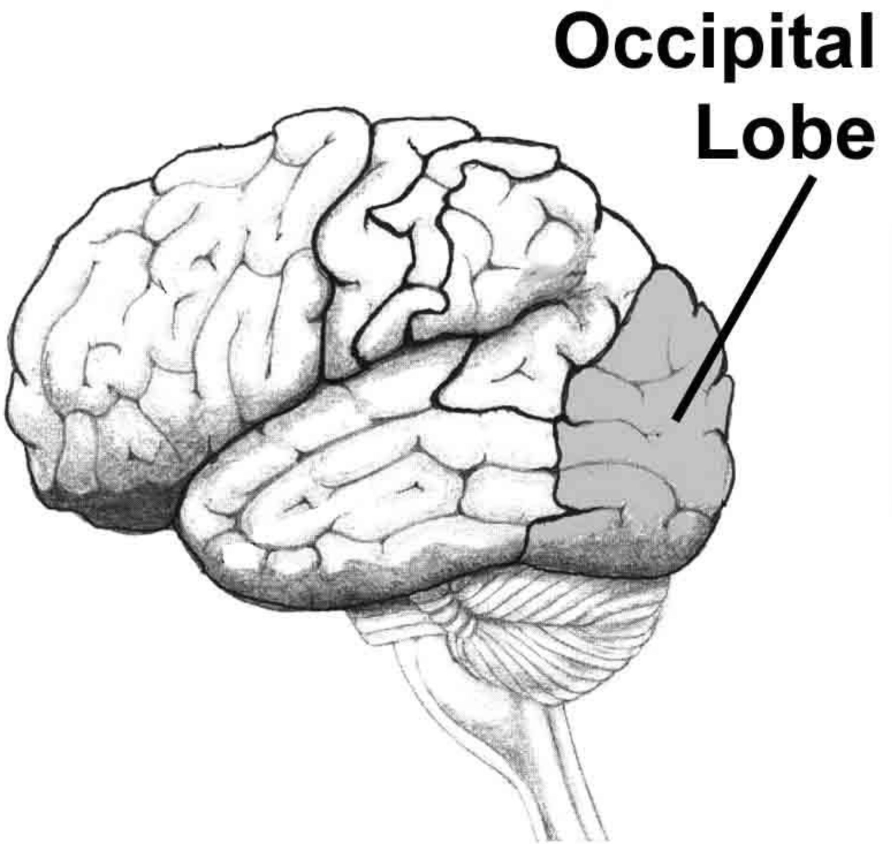
- Korbinian Brodmann (17.11.1868 – 22.08.1918), a German neurologist defined the cerebral cortex into 52 distinct regions based on their cytoarchitectonic characteristics, known as Brodmann areas.







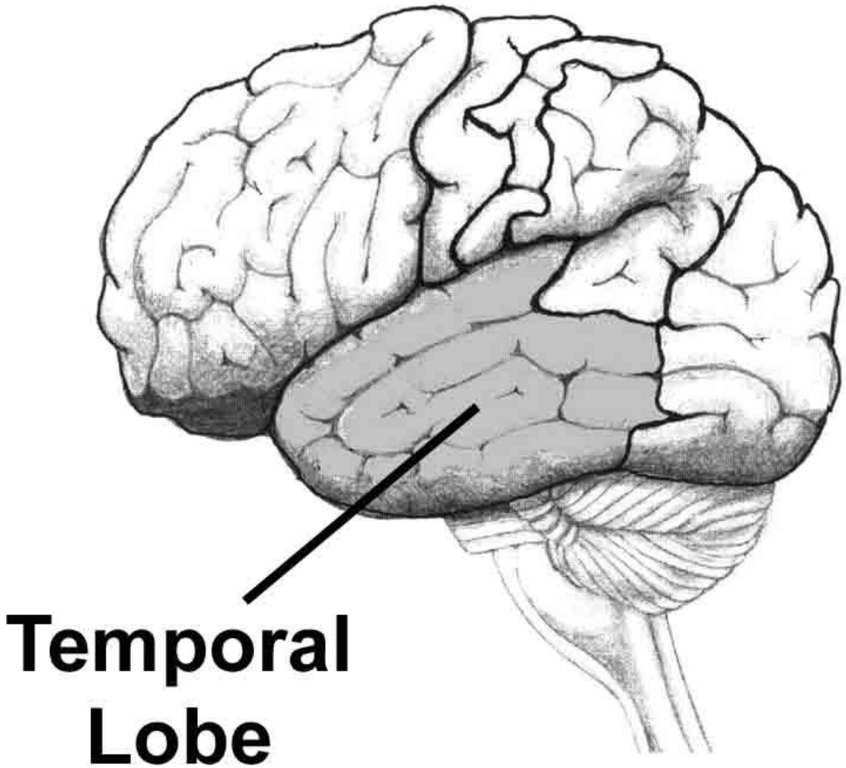
The occipital lobe: VISION



- Occipital lobe contains the primary visual cortex (V1) (Brodmann's area 17), located at the very back tip of the neocortex, and higher-level visual areas that radiate out (towards the more frontal areas) from it.

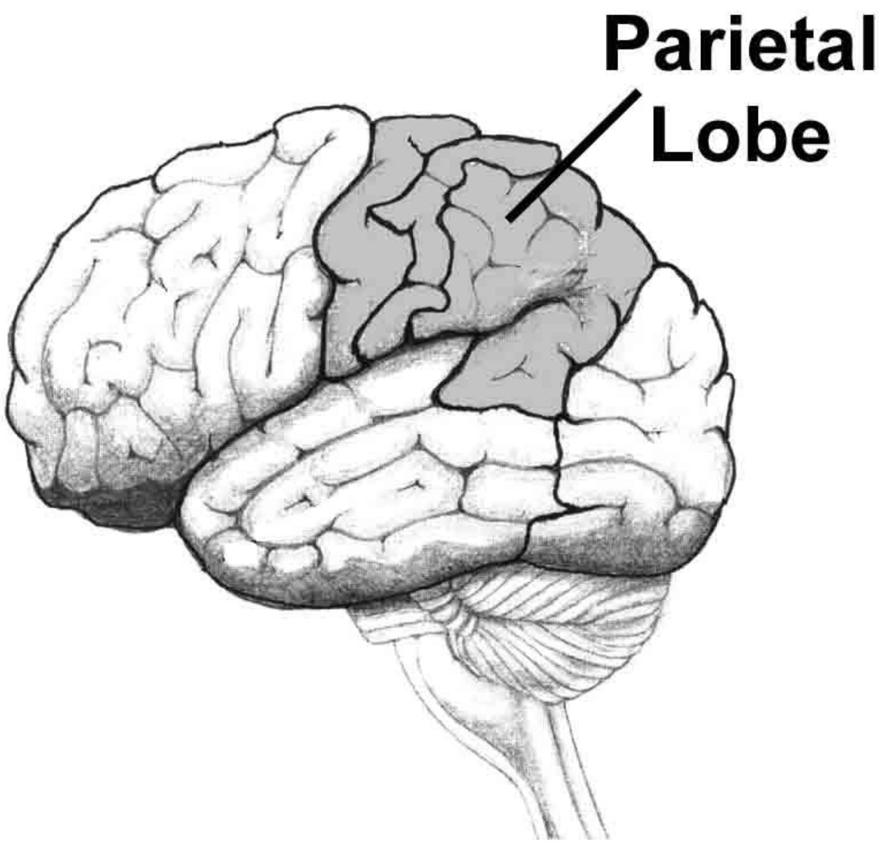
- This entire lobe is devoted to visual processing.

The temporal lobe: AUDITION



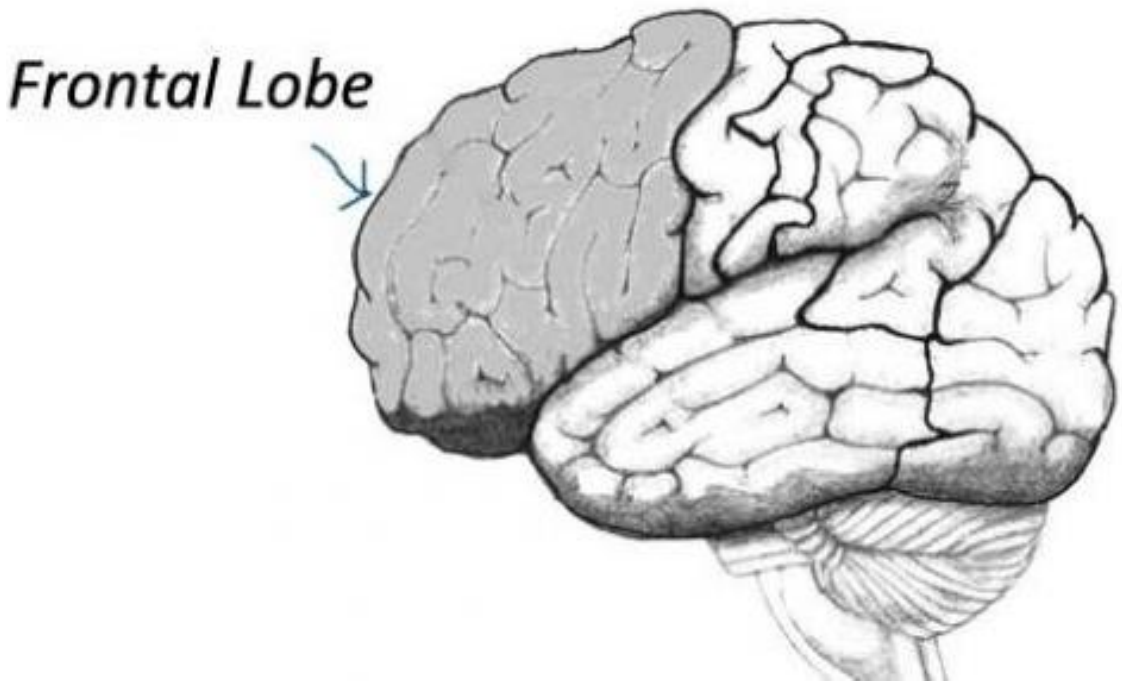
- Contains the primary auditory cortex (A1), and associated higher-level auditory areas.
- In addition, visual appearance of objects gets translated into verbal labels (and vice-versa), and also where we learn to read.
- The inferior region of the temporal lobes is important for the 'what' visual pathway and semantic knowledge.

The parietal lobe: SPACE



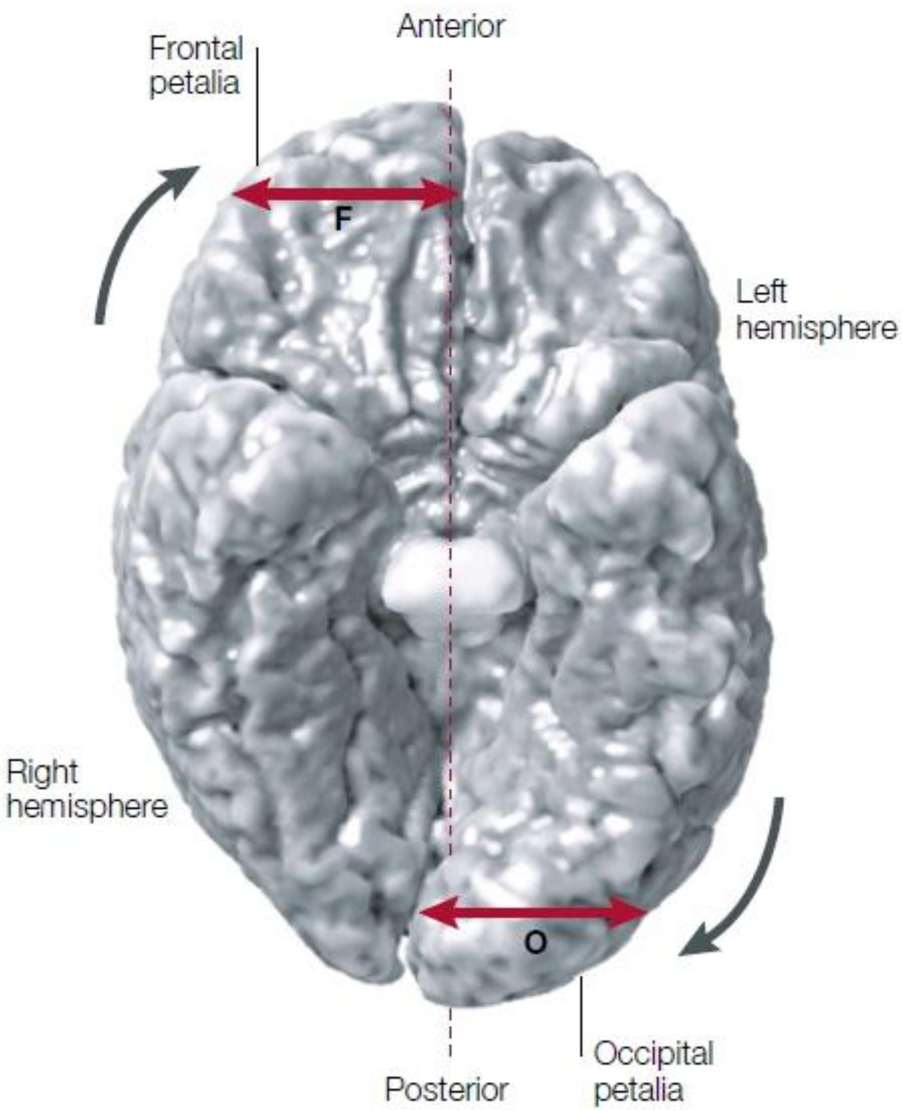
- Contains the somatosensory cortex, which processes somatosensory input and guides the motor actions as well.
- In some parts, neurons translate between different frames of reference, and between somatosensory and visual coordinates.
- Contains the 'where' visual pathway.
- Left parietal lobe contains Wernicke's area.

The frontal lobe: ACTION



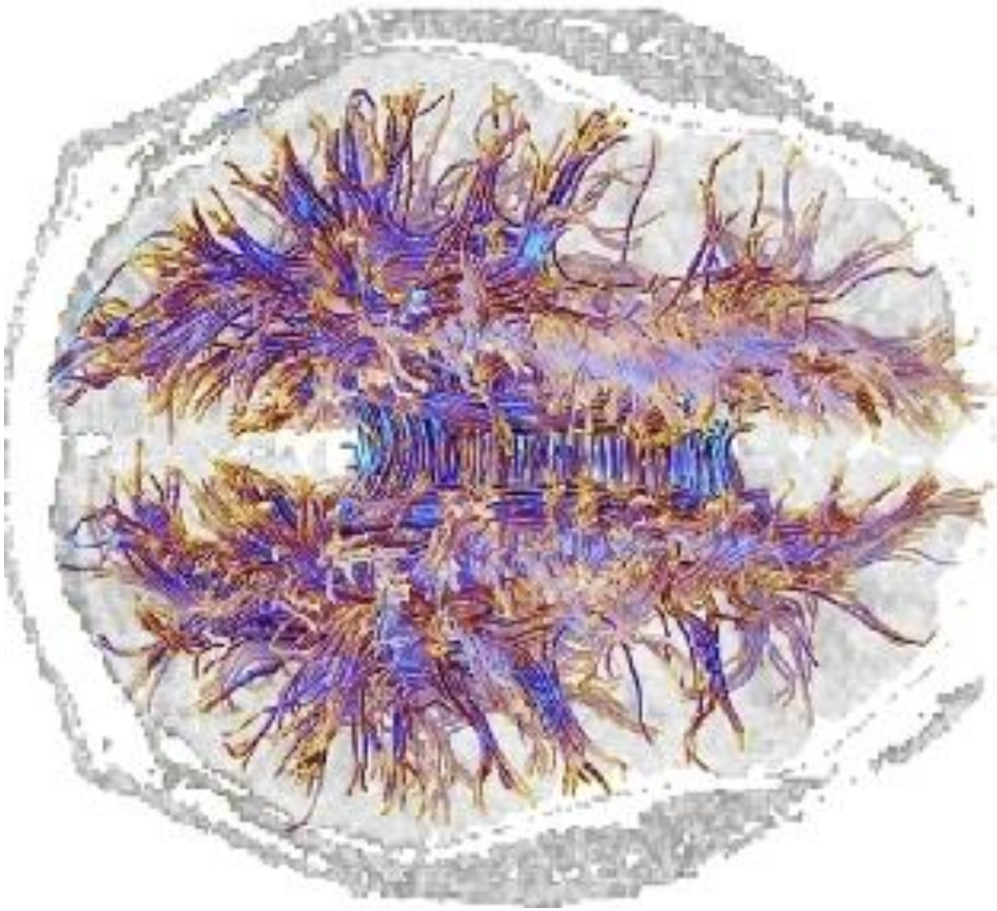
- Contains the primary and higher-level motor areas including the planning areas for output actions.
- Integrates information from sensory areas as well as emotional areas.
- "Seat" of motivation, goal planning, associations, abstract thoughts, etc.
- Contains Broca's language and speech area.

Two hemispheres: anatomical structures come in pairs



- The vertebrate cerebrum (brain) is formed by two cerebral hemispheres that are separated by a groove, the medial longitudinal fissure.
- The brain can thus be described as being divided into the left and right cerebral hemispheres.
- Macroscopically the hemispheres are roughly mirror images of each other, with some subtle differences such as the **Yakovlevian torque** seen in the human brain, which is a slight warping of the right side, bringing it just forward of the left side.

White matter: the pathways of communication



- Projection tracts that extend vertically between hierarchically higher and lower brain areas and the spinal cord.
- Commissural tracts cross from one cerebral hemisphere to the other through bridges called commissures, corpus callosum + anterior and posterior commissures.
- Association tracts that connect different regions within the same hemisphere of the brain.

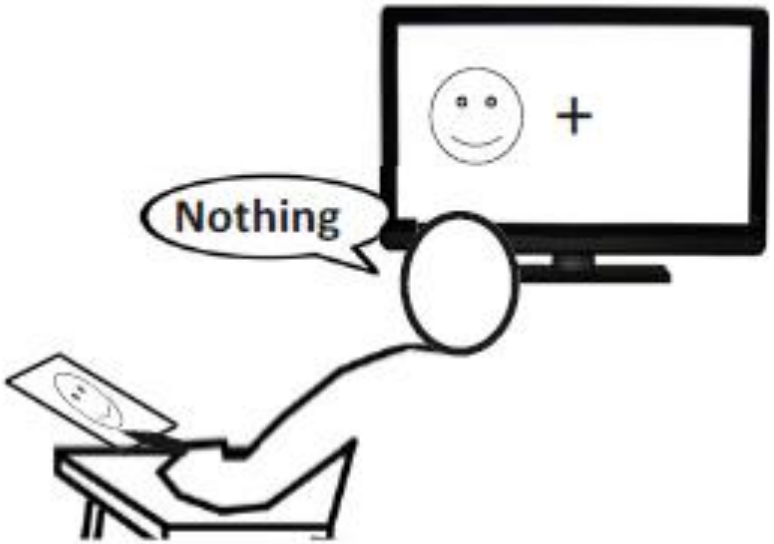
Split-brain phenomenon

- The split-brain phenomenon is caused by the surgical cutting of the corpus callosum, the main route of communication between the two hemispheres.
- The split-brain patients behave normally and report to feel unchanged after the operation. However, research has revealed a multitude of marked, and sometimes dramatic, changes.
- It turns out, after the right and left brain are separated, each hemisphere has its own separate perception, concepts, and impulses to act.
- This research was pioneered by Roger Sperry (Nobel Prize in 1981) and his PhD student Michael Gazzaniga at the University of California, USA.

Split-brain phenomenon: split perception

- When a visual stimulus appears only in the left visual field, the patient verbally reports that he/she saw nothing yet draws the image with his/her left hand.
- They can verbally report only on the stimuli in the right visual field.
- At the same time, they react with their left hand, but not verbally, to the stimuli in the left visual field.

I: Response x visual field interaction

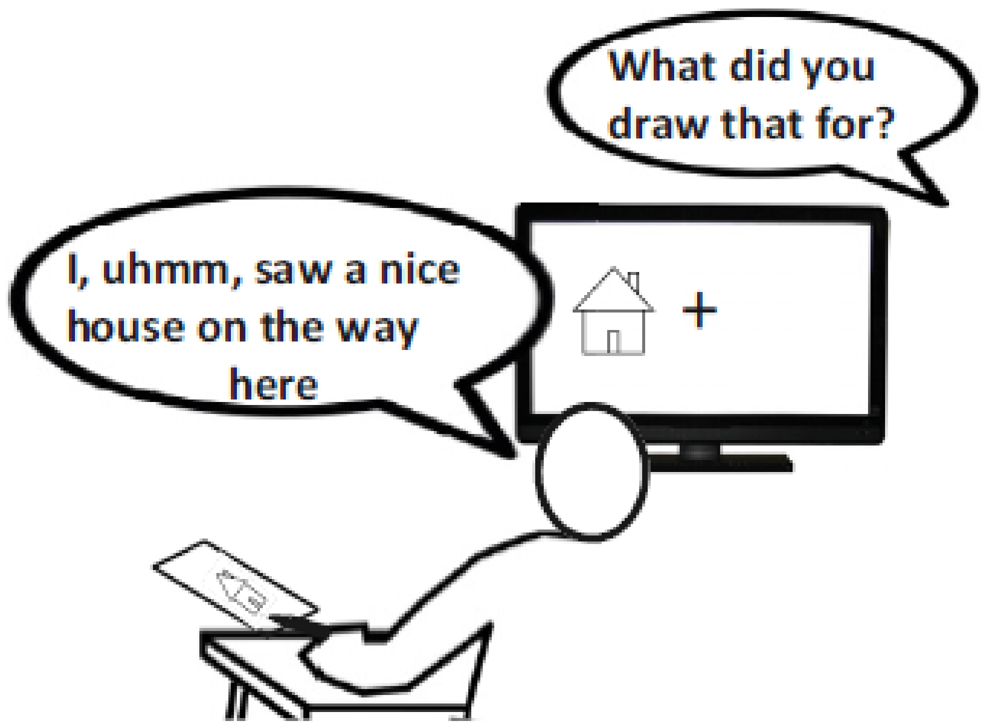


Split-brain phenomenon: confabulation

- The second striking phenomenon is that split-brain patients confabulate wildly when asked to explain actions of their left hand (controlled by the mute right hemisphere).

- The notion here is that the left hemisphere creates an independent cognitive agent, which is unaware of the right hemisphere processing. Therefore, the left hemisphere resorts to *ad hoc* confabulations.

II: Left hemisphere confabulation

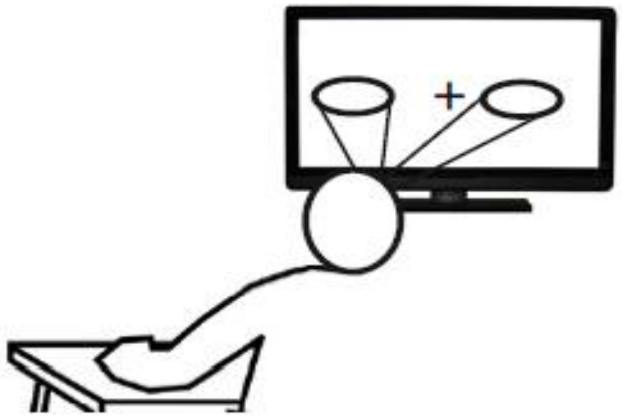


Split attention focus and lack of comparison

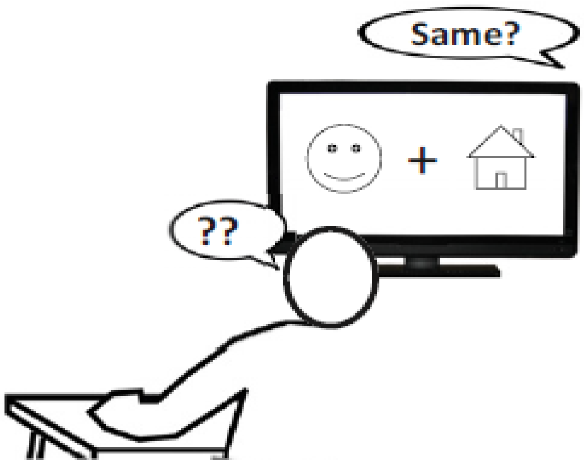
- Third, in split-brain patients, each hemisphere seems to have its own focus of attention. Object-based and space-based attention are situated in the left and right hemispheres, respectively.

- Fourth, split-brain patients cannot compare stimuli across the midline. Thus, they cannot say whether they are the same or different. However, he/she can do so when both stimuli are presented within one visual field.

III : Split attention



IV: Cannot compare across midline



Split-brain phenomenon: consciousness

- Altogether these observations have led to three hypotheses of consciousness of split-brain patients.

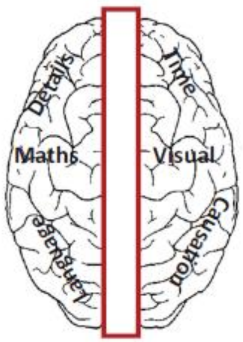
- 'partial consciousness' hypothesis: only the left hemisphere gives rise to consciousness, while the right hemisphere only processes information in an unconscious manner.

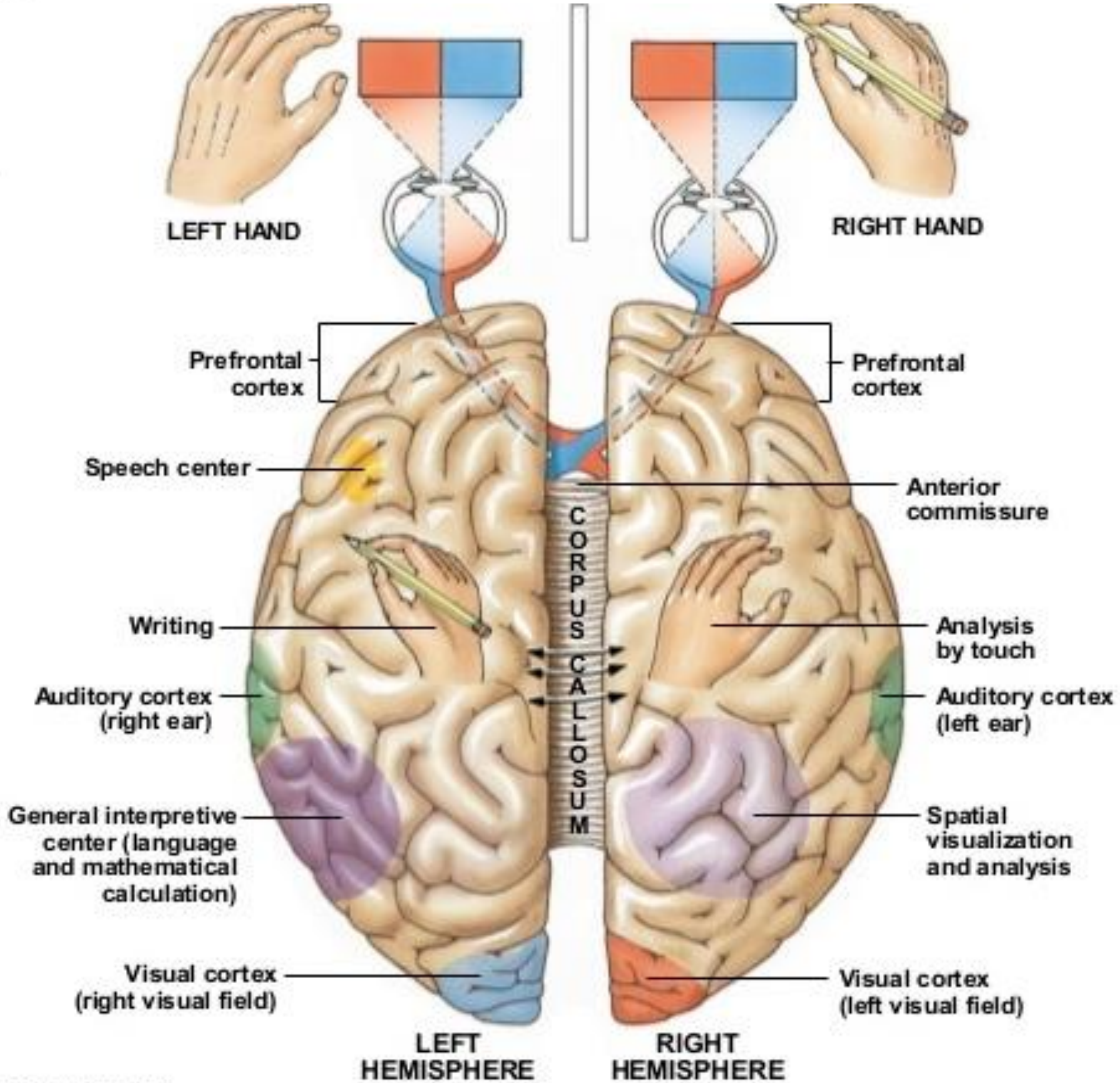
- 'split consciousness' hypothesis: each hemisphere has its own consciousness, independent of the other hemisphere.

- 'conscious unity, split perception' hypothesis: consciousness is unified in split-brain patients. This can explain why these patients feel normal and behave normally. They have not become half blind (Pinto et al., 2017).

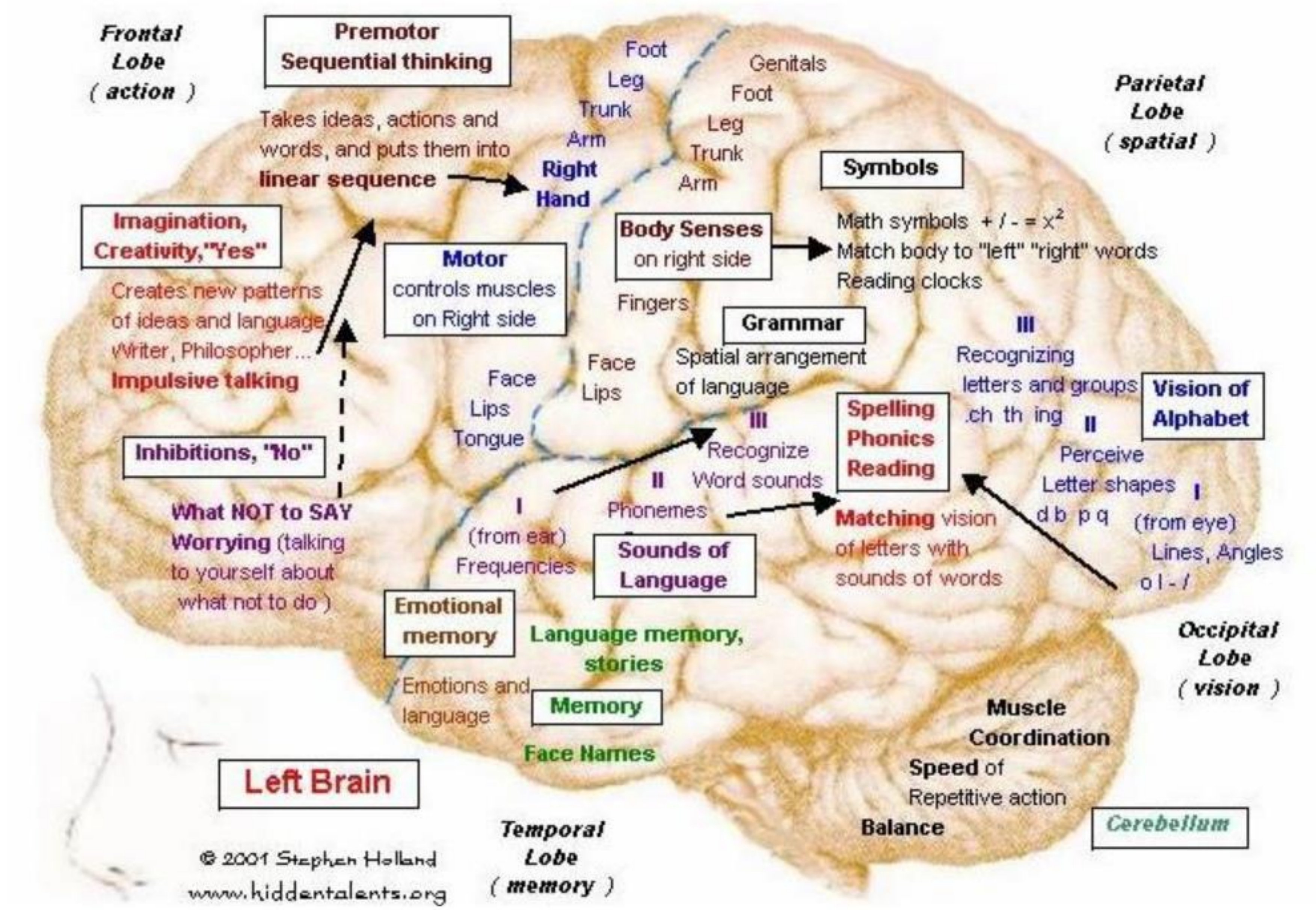
Specialization of the left and right hemispheres

II: Hemispheric specialization

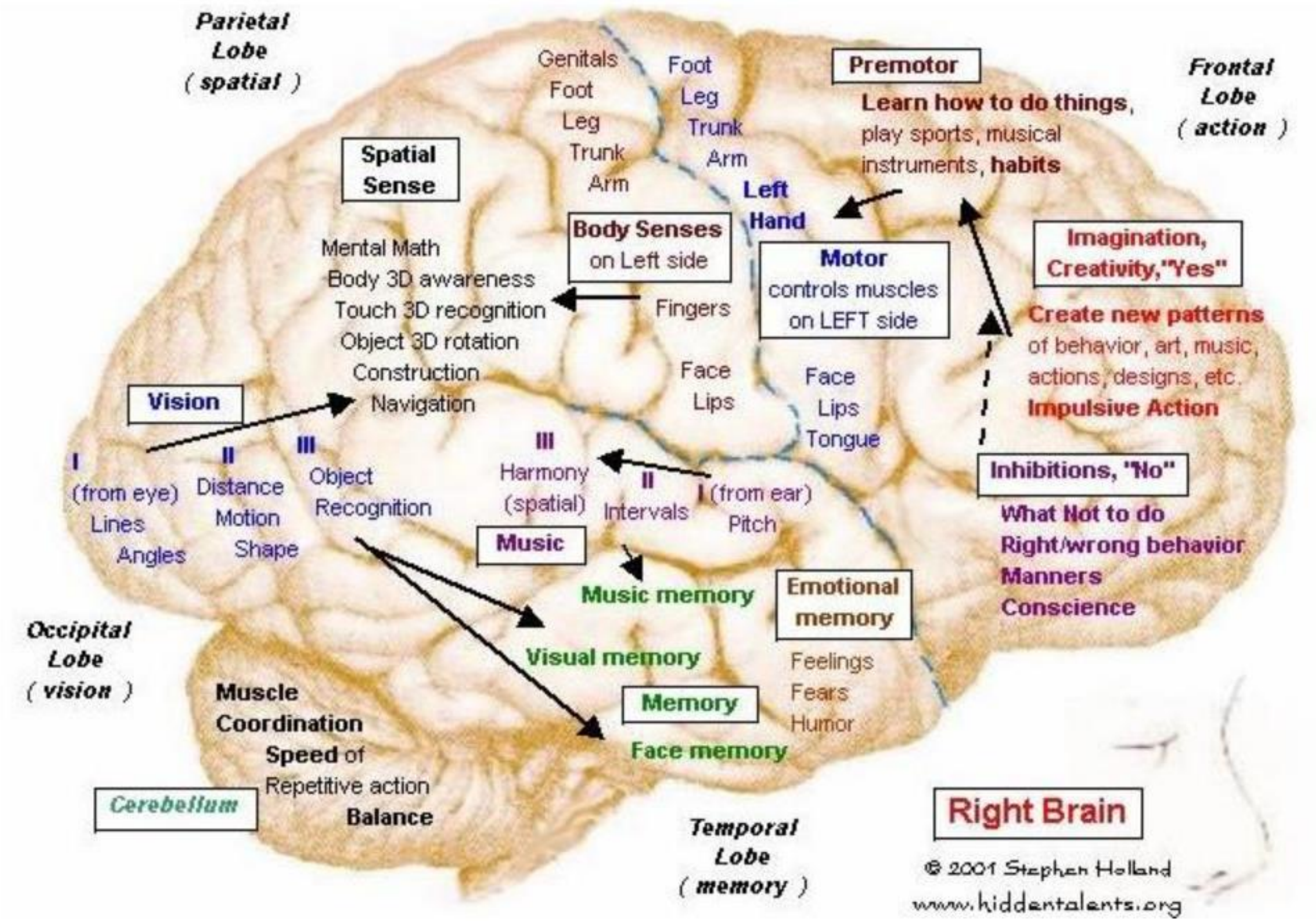




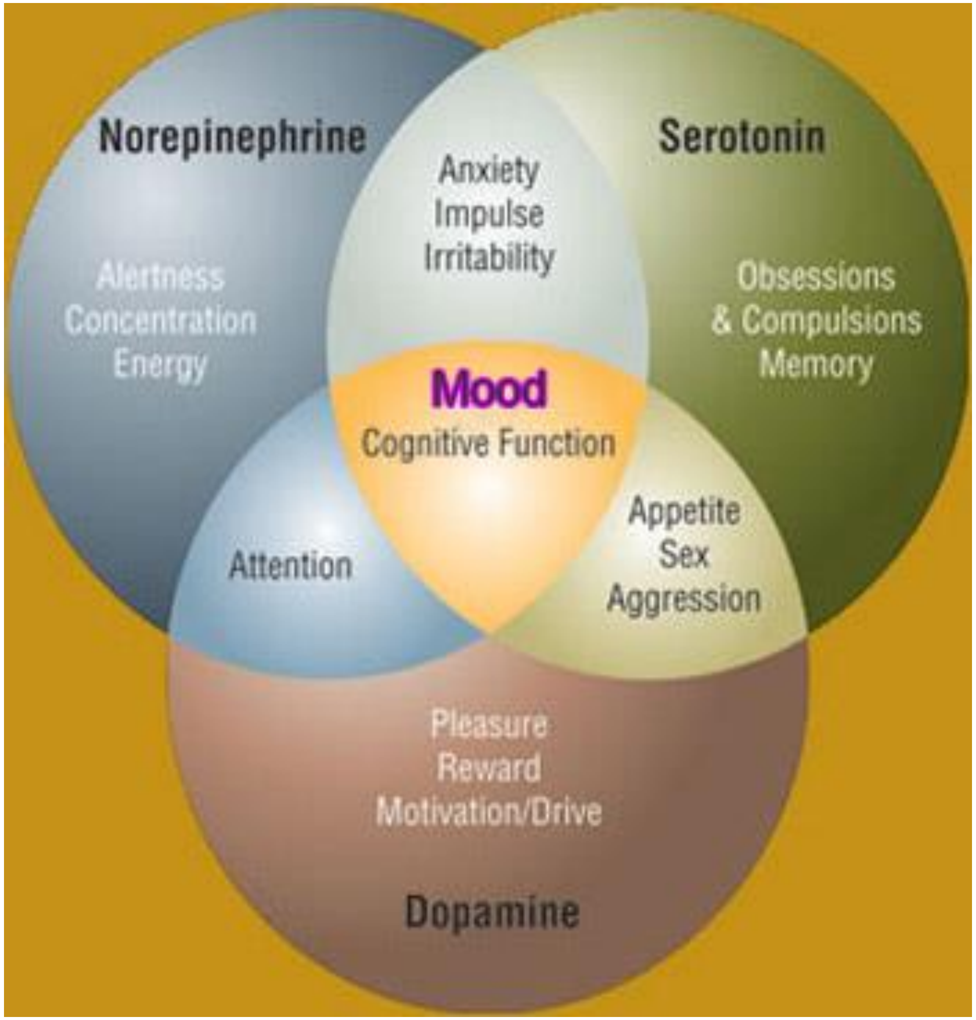
Left hemisphere



Right hemisphere



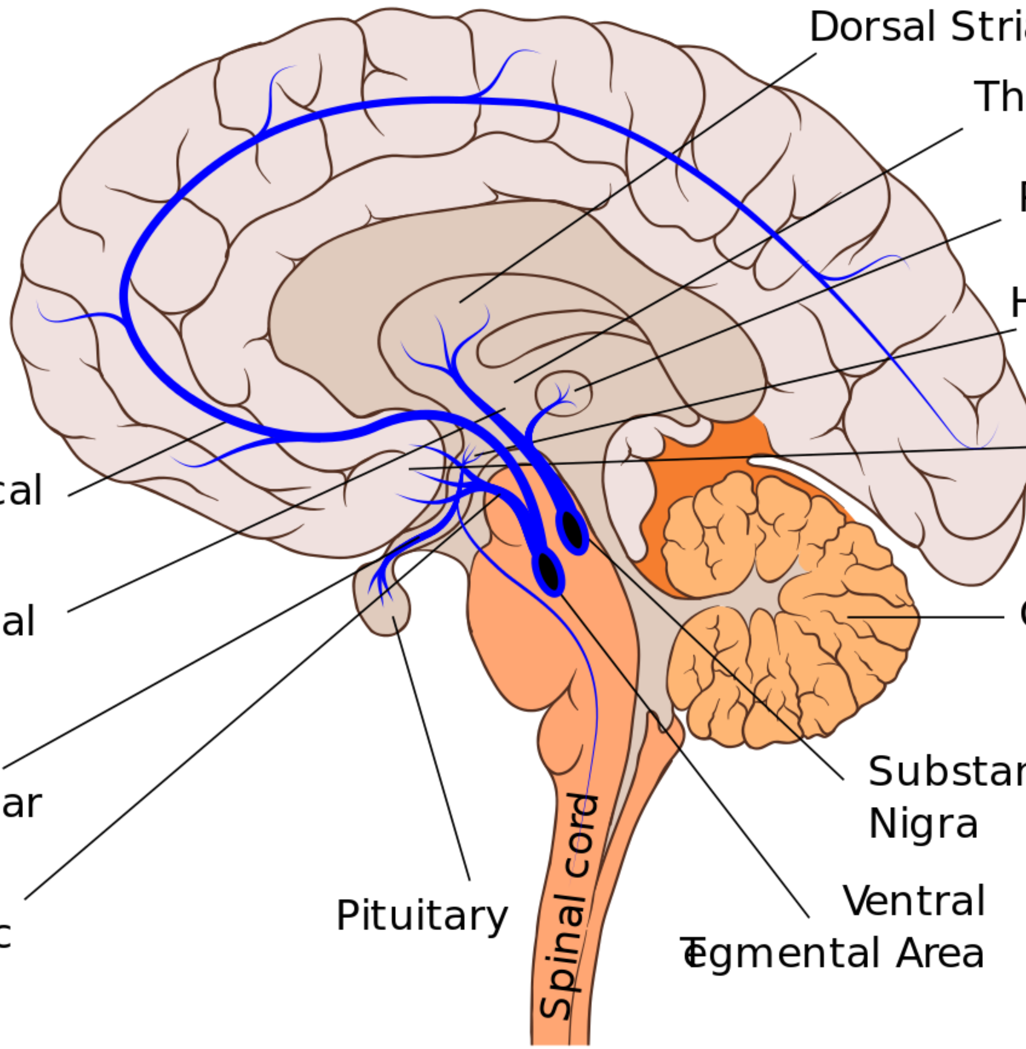
Neurotransmitters and neuromodulators



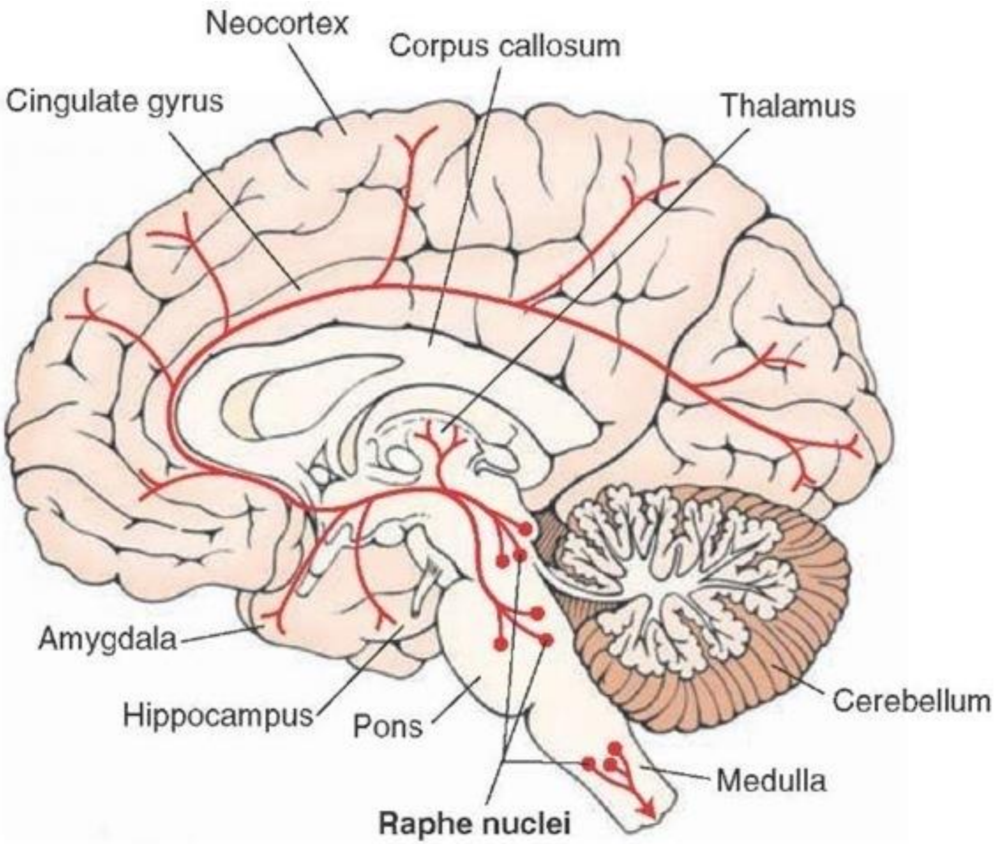
- There are around 50 neurotransmitters (NT) in the brain.
  - Excitatory and inhibitory
  - Neuromodulatory
- Glutamate is the major excitatory NT and GABA is the major inhibitory NT in the cortex.
- In addition, there are 4 major neuromodulatory NTs:
  - Dopamine
  - Serotonin
  - Norepinephrine (= noradrenalin)
  - Acetylcholine

Dopamine (DA)

Executive functions, reward, addiction, Schizophrenia	{	Mesocortical pathway
Reinforcement, motor functions	{	Nigrostriatal pathway
Hormone secretion control	{	Tubero-infundibular pathway
Reward, pleasure, reinforcement	{	Mesolimbic pathway

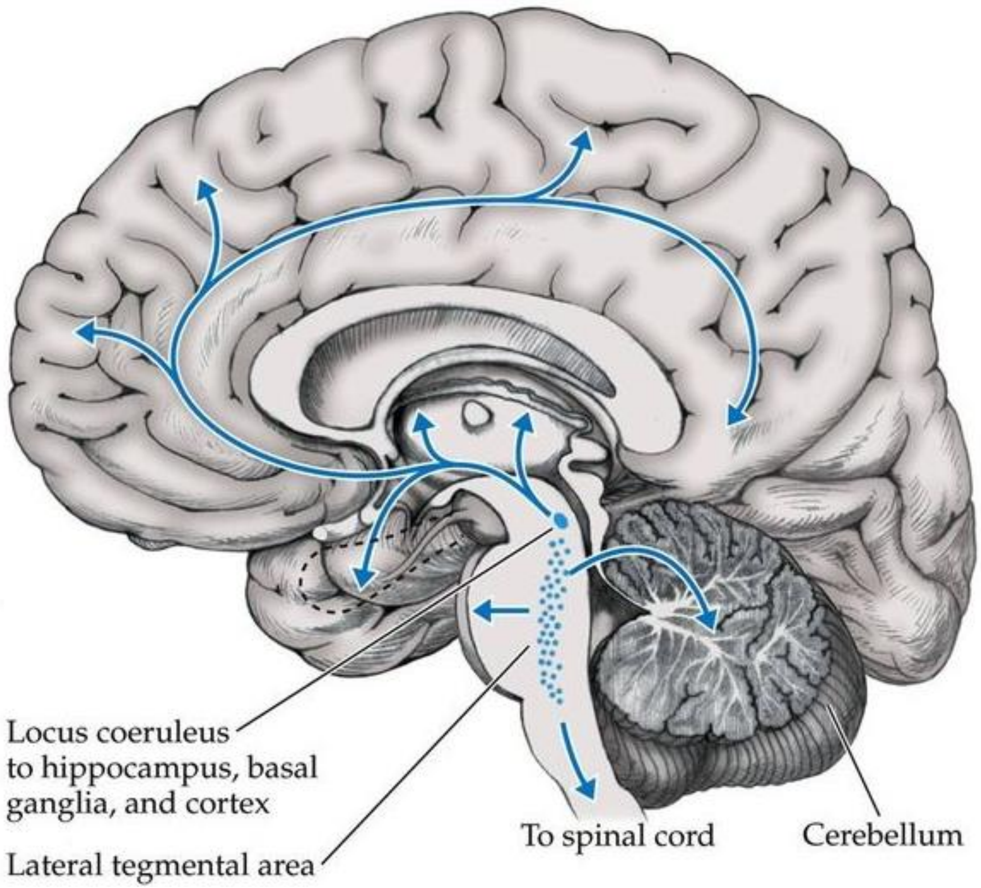


Serotonin - 5-hydroxytryptamine (5-HT)



- In general, it mediates gut movements and the animal's perceptions of resource availability.
- In more complex animals, resources can be related also to social and personal well-being.
- In response to the perceived abundance or scarcity of resources, mood may be elevated or lowered. Mood depends on how much serotonin the brain has at its disposal.

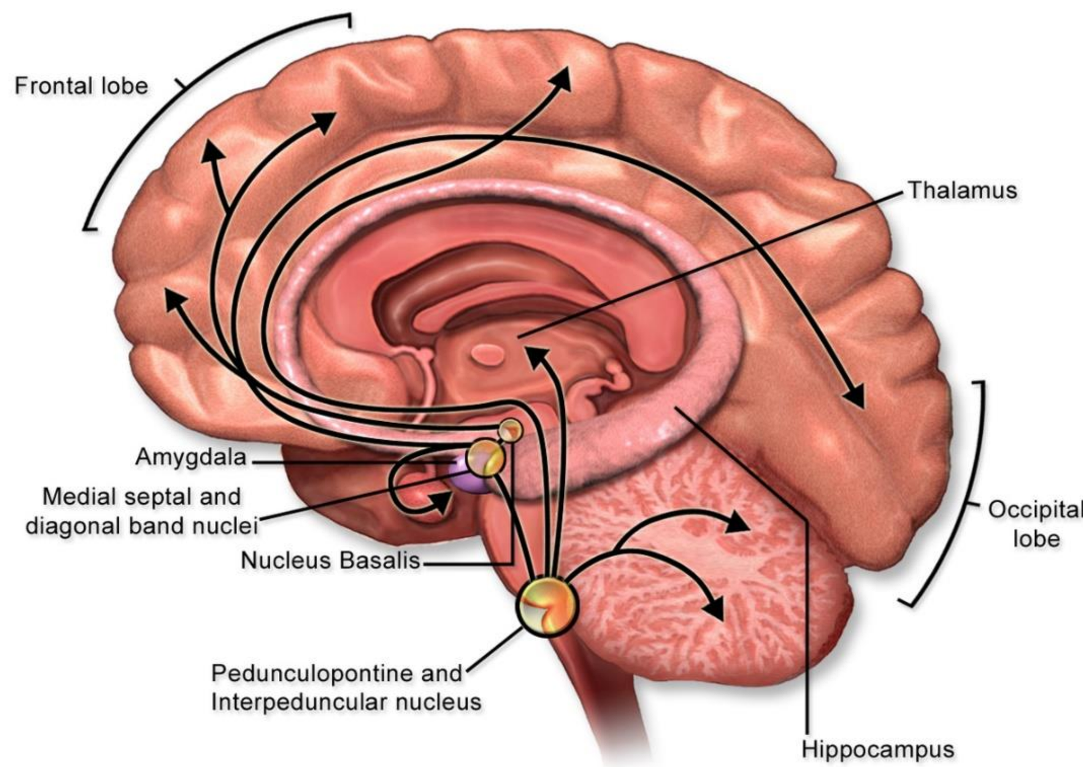
Noradrenaline (NA) / Norepinephrine (NE)



- The general function of NA is to mobilize the brain and body for action.
- In the brain, NA increases arousal and alertness, promotes vigilance, enhances formation and retrieval of memory, it also increases restlessness and anxiety
- The noradrenergic neurons in the brain form a system, that, when activated, exerts effects on large areas of the brain. The effects are manifested in **alertness, arousal, and readiness for action**.

Acetylcholine (ACh)

- ACh is used at the neuromuscular junction—i.e. the motor neurons in the spinal chord release ACh in order to activate muscles.
  - Curare blocks transmission of signals from nerves to muscles
- In the cortex and hippocampus, ACh modulate learning and memory. Low levels of ACh lead to anterograde amnesia.
  - Nicotinic receptors
  - Muscarinic receptors



Learning rules across the "plastic" areas of the brain

	Learning Signal			*Dynamics*		
Area	**Reward**	**Error**	**Self Org**	**Separator**	**Integrator**	**Attractor**
Basal Ganglia	+++	---	---	++	-	---
Cerebellum	---	+++	---	+++	---	---
Hippocampus	+	+	+++	+++	---	+++
Neocortex	++	+++	++	---	+++	+++

- Comparison of learning mechanisms and activity/representational dynamics across four primary areas of the brain. +++ means that the area definitely has given property, with fewer +'s indicating less confidence in and/or importance of this feature. --- means that the area definitely does not have the given property, again with fewer -'s indicating lower confidence or importance.

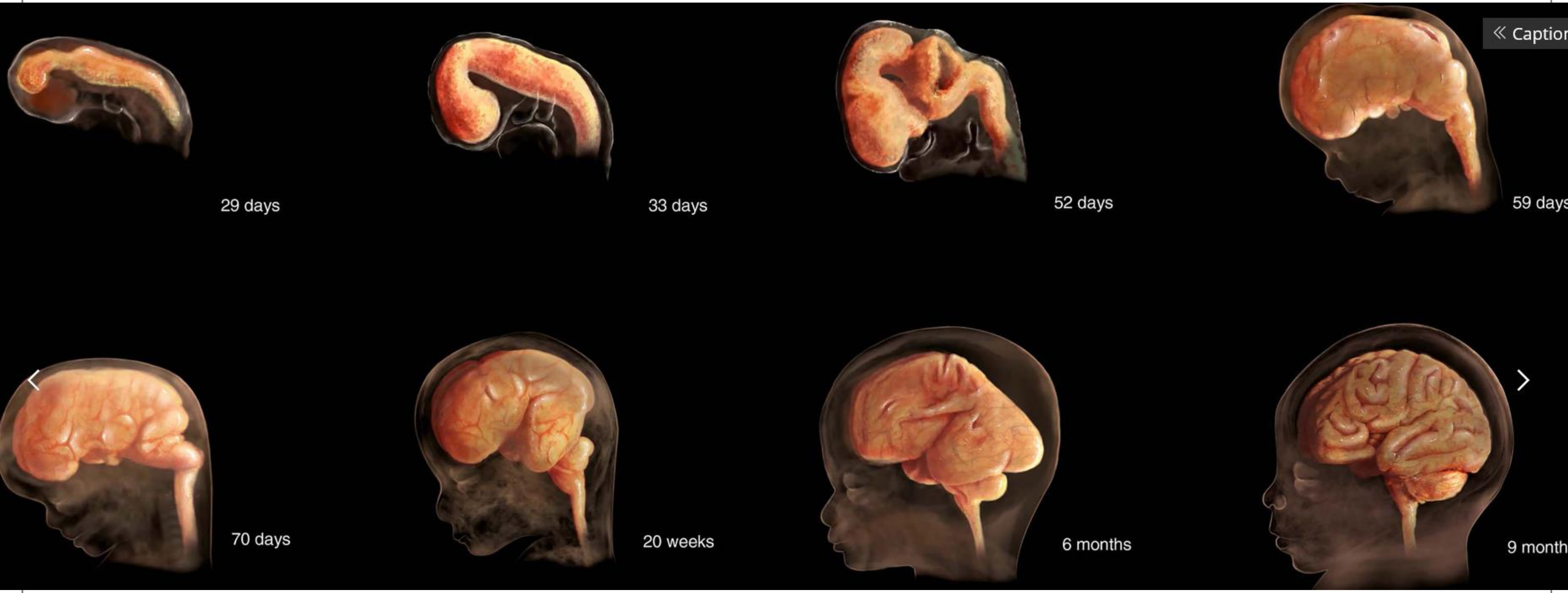
Comparing and contrasting major areas (O'Reilly)

- The evolutionarily older areas like the basal **ganglia, cerebellum, and hippocampus**, employ a separating form of activation dynamics, meaning that they tend to make even somewhat similar inputs map onto more separated patterns of neural activity – i.e. the major way of dynamics is **separation**.

- **The neocortex** represents an important innovation. In terms of activation dynamics, it builds upon the **attractor dynamics**. This means a strong ability to develop representations that integrate across experiences to extract generalities, instead of always keeping everything separate all the time.

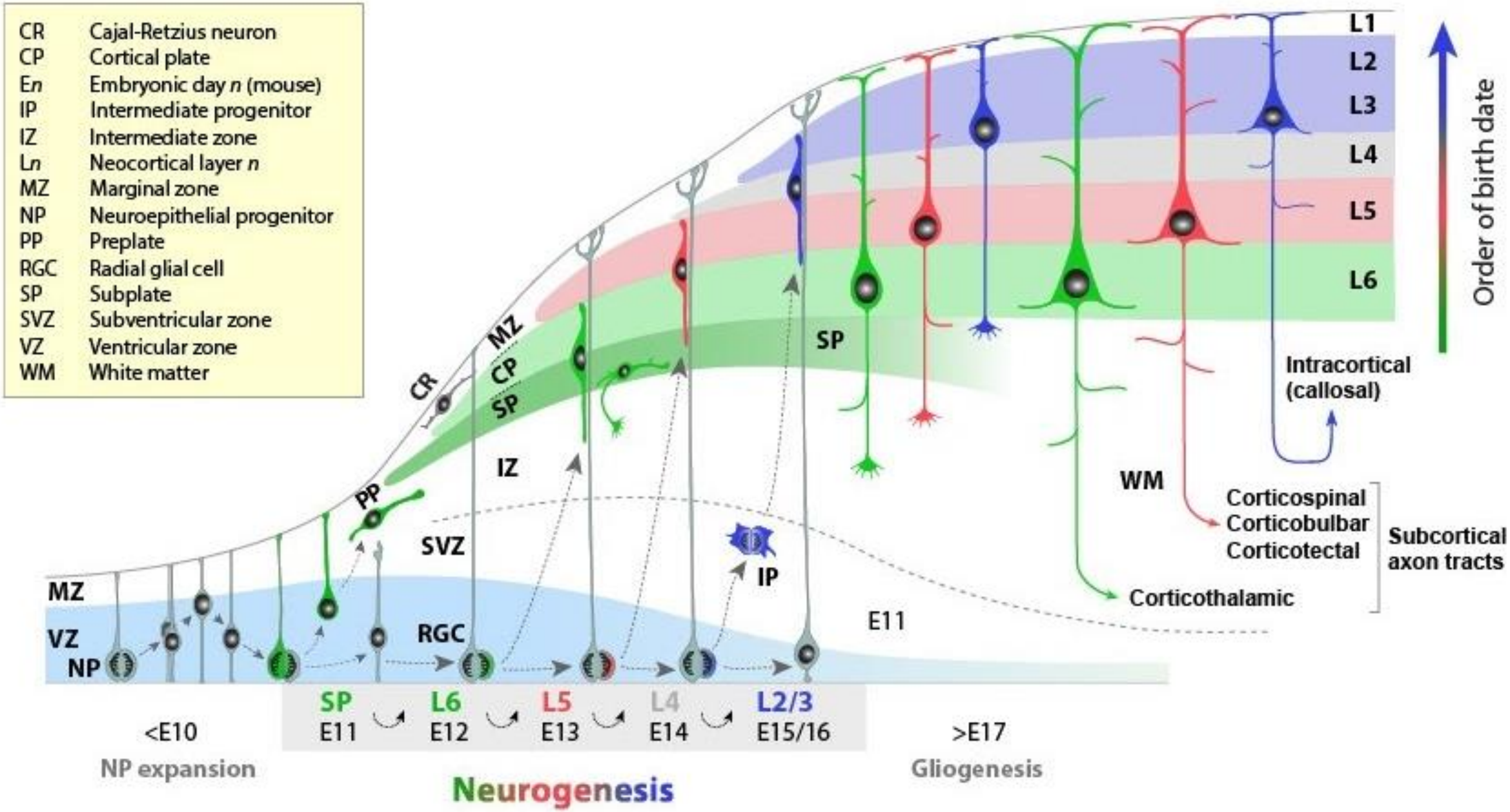
- The **cost** for this integration ability is that the system can now form the wrong kinds of generalizations, which might lead to bad overall behaviour. But the advantages apparently outweigh the risks, by giving the system a strong ability to apply previous learning to novel situations.

Development of the brain *in utero*



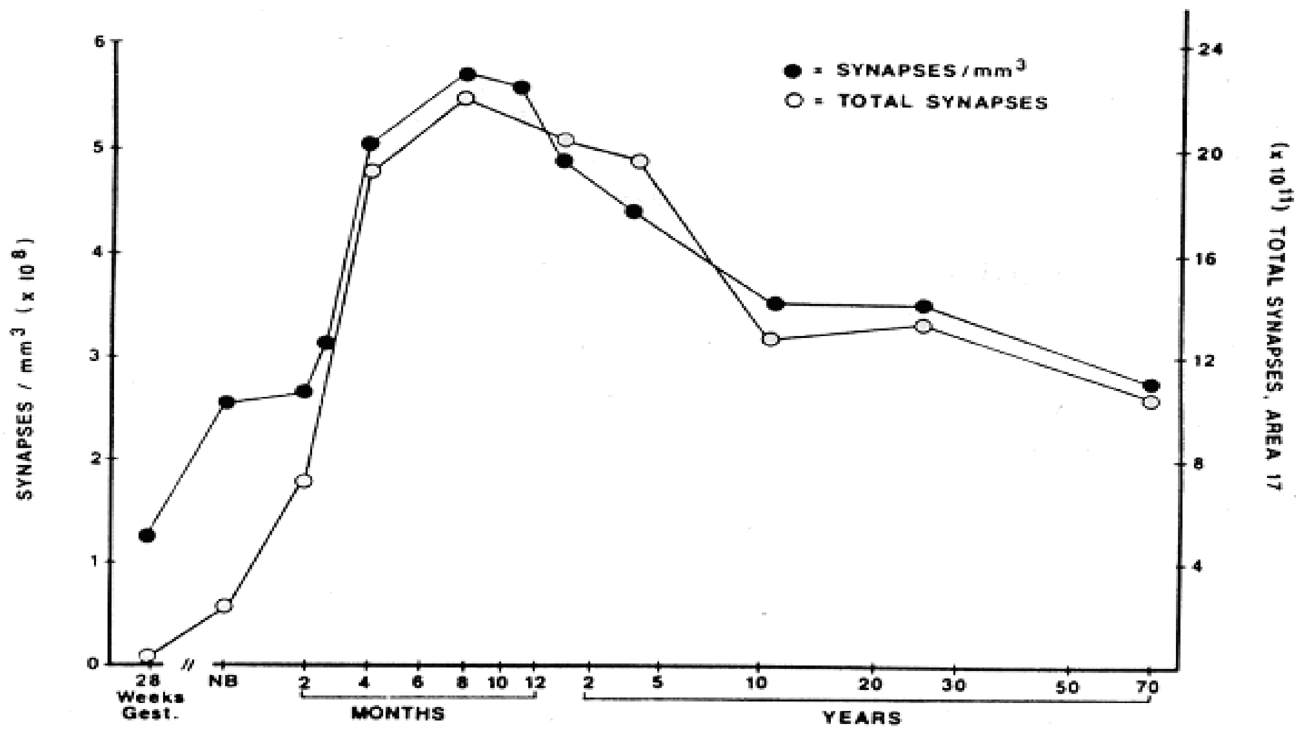
- Konkel, 2018, https://doi.org/10.1289/EHP2268

Neurogenesis



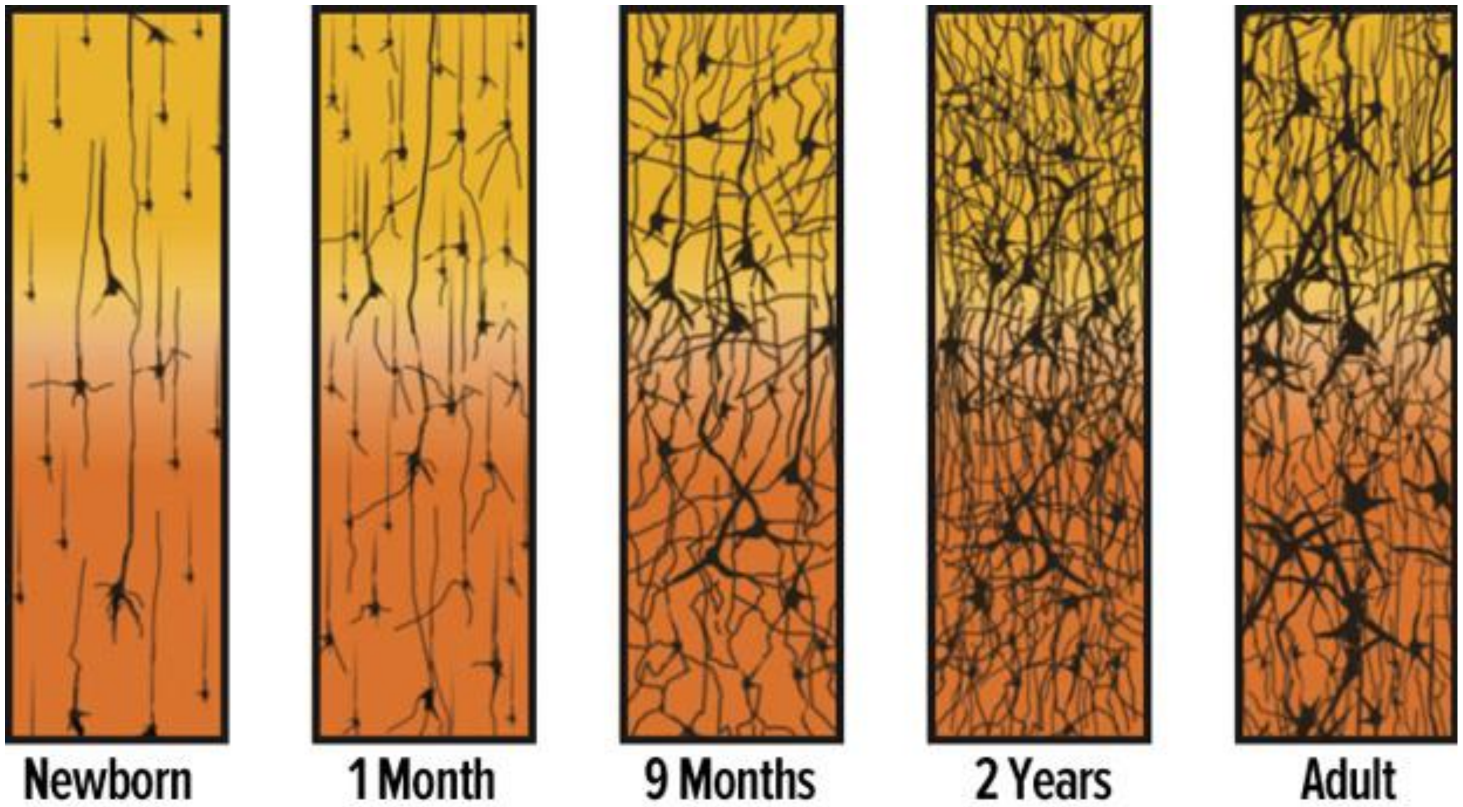
- First, the neurons have to assume their position, then they can form connections. Position of neurons as well as their connectivity is determined genetically during early development.

Development of brain synaptic connectivity



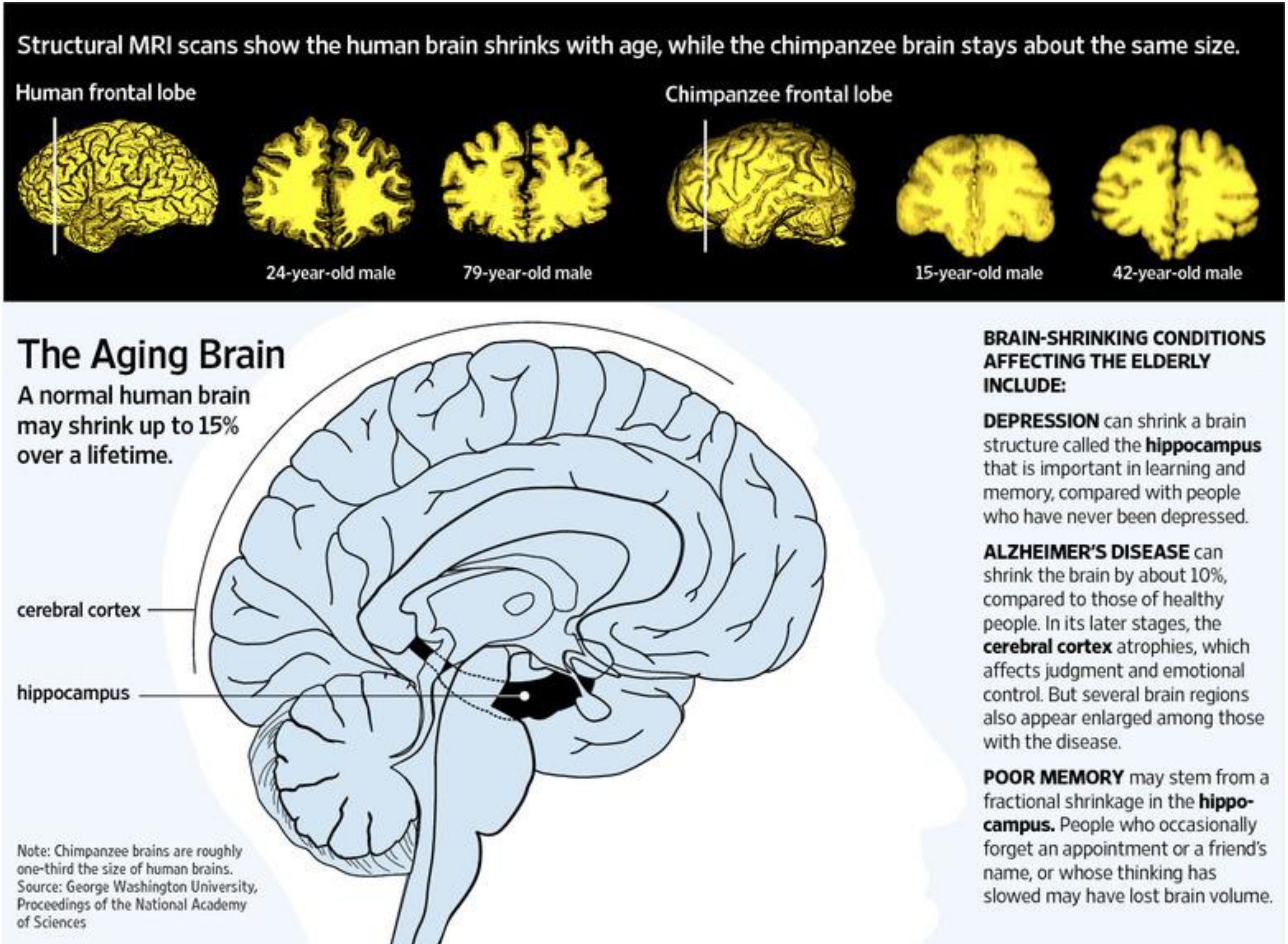
- Peter Huttenlocher discovered that synapses are created after about 28 weeks = 6 months of gestation. Then their number increases within 1 year after birth and then they are "pruned“.
- Examined the brains of about 50 people, mostly infants and young children who had died unexpectedly, but also a few adults, one of them age 90.

Postnatal development of neuron bodies and dendrites



- Corel, JL. The postnatal development of the human cerebral cortex. Cambridge, MA: Harvard University Press; 1975.
- http://www.urbanchildinstitute.org/why-0-3/baby-and-brain

The aging brain



Neuroscience of sex differences

- "You can be a scientist interested in the nature of sex differences while being a clear supporter of equal opportunities and a firm opponent of all forms of discrimination in society." (Simon Baron-Cohen)

- Findings include females having more grey matter volume in the right frontal pole, inferior and middle frontal gyrus, anterior cingulate gyrus, insular cortex, both thalami, left parahippocampal gyrus.

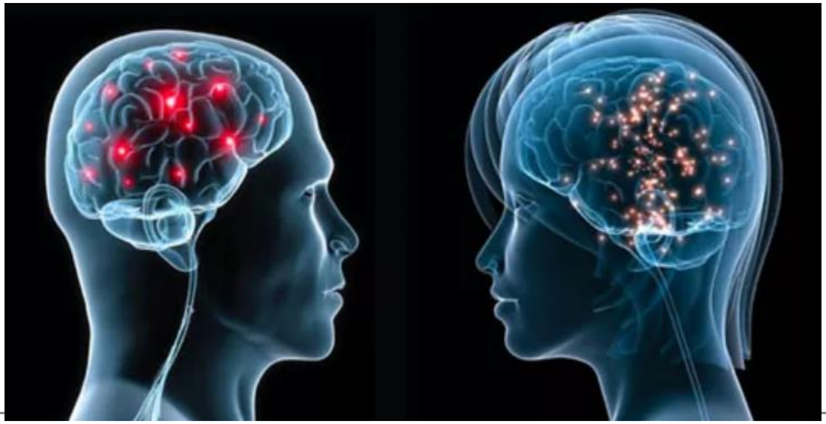
- Males have more grey matter volume in both amygdalae, hippocampi, anterior parahippocampal gyri, posterior cingulate gyri, putamen and temporal poles, areas in the left posterior and anterior cingulate gyri, and areas in the cerebellum bilaterally.

Neurochemical differences

- The hormonal theory of sexuality holds that, just as exposure to certain hormones plays a role in *in utero* sex differentiation, such exposure also influences the sexual orientation that emerges later in the individual.

- Prenatal hormones may be seen as the primary determinant of adult sexual orientation, or as a co-factor with genes and social conditions.

- This hypothesis originates from countless experimental studies in non-human mammals, yet the argument that similar effects can be seen in human neurobehavioral development is much debated.



Psychological differences and gender

- Sex differences in psychology are differences in mental functions and behaviours of the sexes and are due to a complex interplay of genetic, developmental, and social/cultural factors.

- Differences have been found in a variety of fields such as mental health, cognitive abilities, personality, emotion, sexuality, and tendency towards aggression. Such variation may be innate, learned, or both.

- Gender is traditionally conceived as a set of characteristics or traits that are associated with a certain biological sex (male or female). These gender characteristics are referred to as masculine or feminine.

- Researchers and theorists take different perspectives on how much of gender is due to genetic, neurochemical, and evolutionary factors (nature), or is the result of culture and socialization (nurture).