



Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich



ZNZ HS16 Introduction to Neuroscience I

Fall 2016

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The Summary of the lectures in 2016

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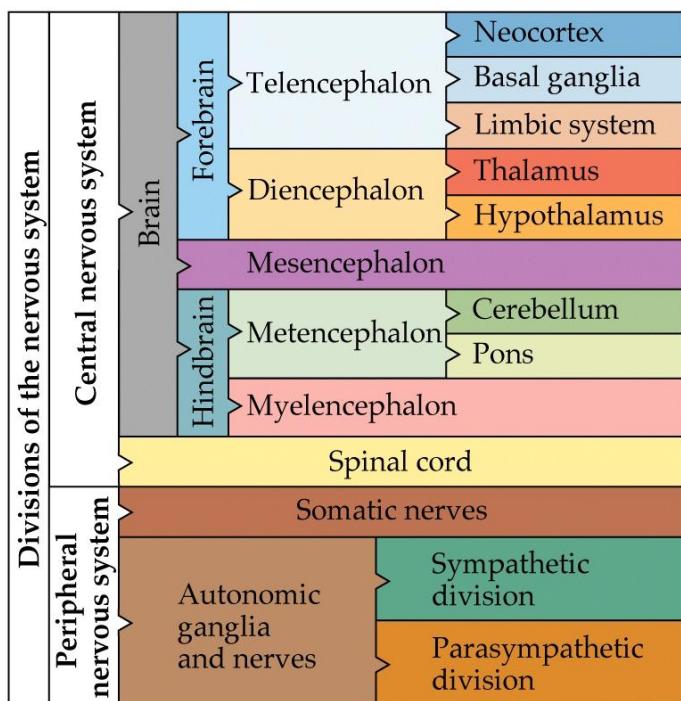
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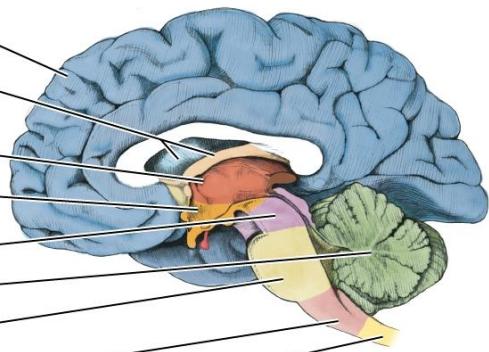
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(b) Organization of the adult human brain



(c) Adult brain



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Figure 1: Division of the Nervous System

Human & Comparative Neuroanatomy

Human Neuroanatomy

Why do we need to know the brain

The famous case of the HM patient: Henry Gustav Molaison went through a surgery on brain to cure his epilepsy. However, during the surgery two holes were drilled in the front of his skull and a portion of his brain, the front half of the hippocampus on both sides, and most of the almond-shaped amygdala, was sucked out. The procedure went badly wrong and Henry, then aged 27, was left with no ability to store or retrieve new experiences. He lived the subsequent 55 years of his life, until his death in 2008, in the permanent present moment.

Nervous system

The nervous system is divided in two parts: the Central Nervous System (CNS) and the Peripheral Nervous System (PNS). Each part has its own divisions as we can see in Figure 1.

- CNS
 - Brain
 - Spinal Cord
- PNS
 - Somatic and autonomic nervous system

Both system contains gray and white matter. In the PNS the gray matter contains **ganglia**: collection of neuron cell bodies -, the white matter contains **nerves**: bundles of axons. In the CNS the gray matter is divided in:

- Neural cortex - gray matter on the surface of the brain
- Nuclei - collection of neuron cell bodies in the interior of CNS
- Centers - collection of neuron cell bodies in CNS, each center has specific processing functions
- High centers - the most complex centers in brain.

The white matter in CNS is divided in two parts: the **tracts or fasciculus**: bundle of CNS axons that share a common origin and destination -, and the **columns or funiculus**: several tracts (fasciculi) that form an anatomically distinct mass

The centers and tracts that connect the brain with other organs and system in the body are called **pathways**. The ascending (sensory) pathway is called afferent. The descending (motor) pathway is called efferent.

Figure 2 shows the macro division of the brain: Telencephalon, Diencephalon, Brain stem (Mid-brain or Mesencephalon, Pons and Cerebellum and Medulla oblongata) and Medulla spinallis), in 3 we can see some views of the brain. Also part of the anatomy of the brain: cranial nerves, meninges, ventricles / cerebrospinal fluid and cerebral circulation.

Telencephalon - or Forebrain

The telencephalon (the biggest part of the brain) is divided in lobes, functional cortical areas, basal ganglia and limbic system.

The four lobes (frontal, occipital, temporal and parietal) are presented in Figure 4.

Gray matter The macroscopic boundaries of the gray matter are Gyri, Sulci and Commissural fiber tracts. Each one is divided as follows:

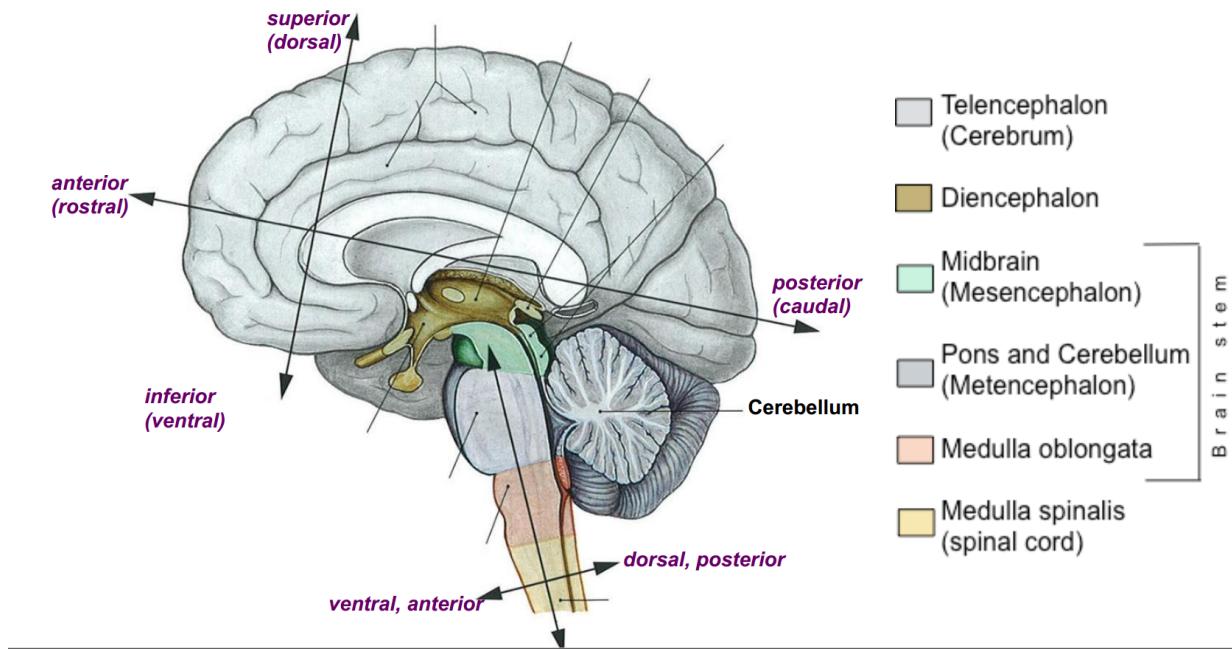


Figure 2: Division of the brain

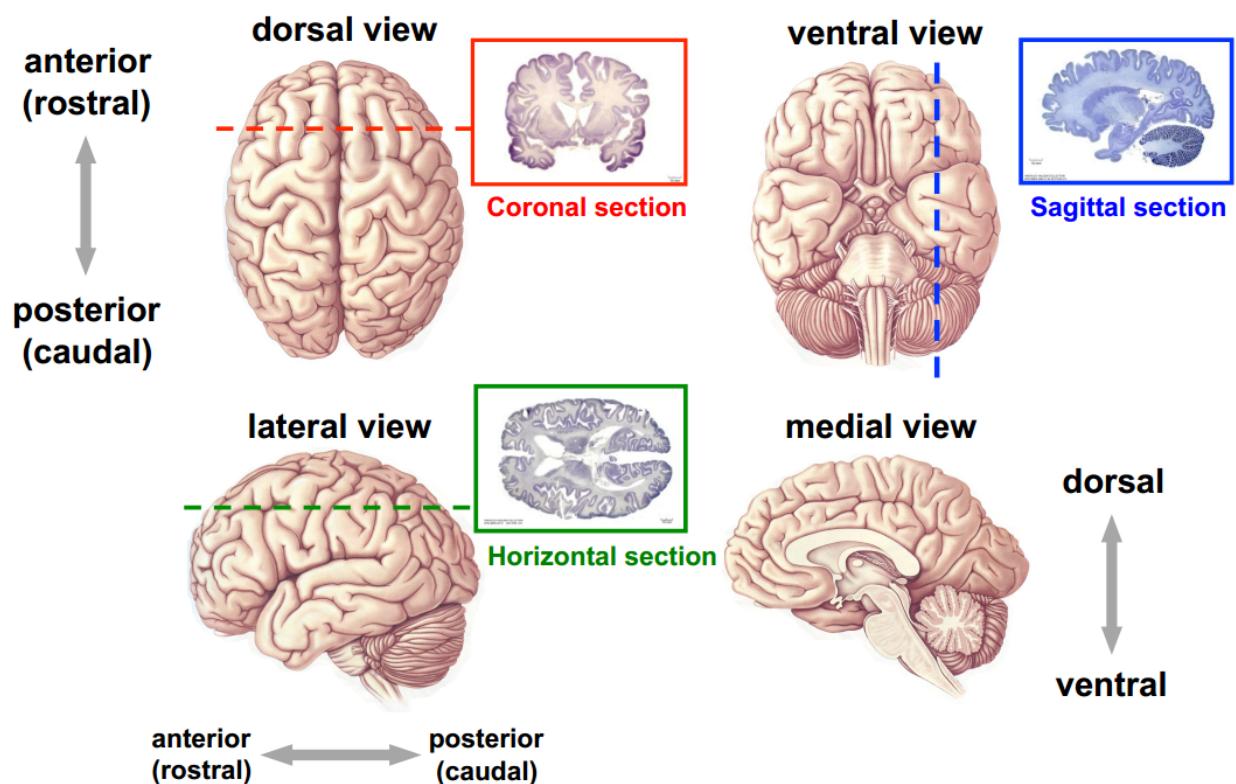


Figure 3: Views of the Brain

- Gyri

- precentral gyrus
- postcentral gyrus
- pars triangularis
- angular gyrus
- cingulate gyrus
- parahippocampal gyrus

- Sulci

- central sulcus
- lateral fissure
- parieto-occipital sulcus
- calcarine sulcus

- Commissural fiber tracts

- corpus callosum
 - Rostrum
 - Genu
 - Truncus
 - Splenium
- anterior commissure

Figure 4 shows the macroscopic boundaries of the gray matter. Besides the anatomical division, there is a functional division of the brain, where each area in the cerebral cortex has specific functional activities. The Wernicke's (language comprehension) and Broca's (speech production) areas are highlighted in Figure 5.

In 1909 Korbinian Brodmann described areas of the cerebral cortex on the basis of cytoarchitectural criteria. Areas differ in celltypes, layering and cell distribution, resulting in 52 Brodmann Areas.

The human brain is gyrencephalic, i.e., is formed by gyri, as the elephant brain. However other species can be lissencephalic (the brain is smooth, without gyri) as the domestic rabbit and the house mouse. Defects in the neuronal migration during early to mid gestation (12th to 24th weeks) leading to impaired development of gyri and sulci.

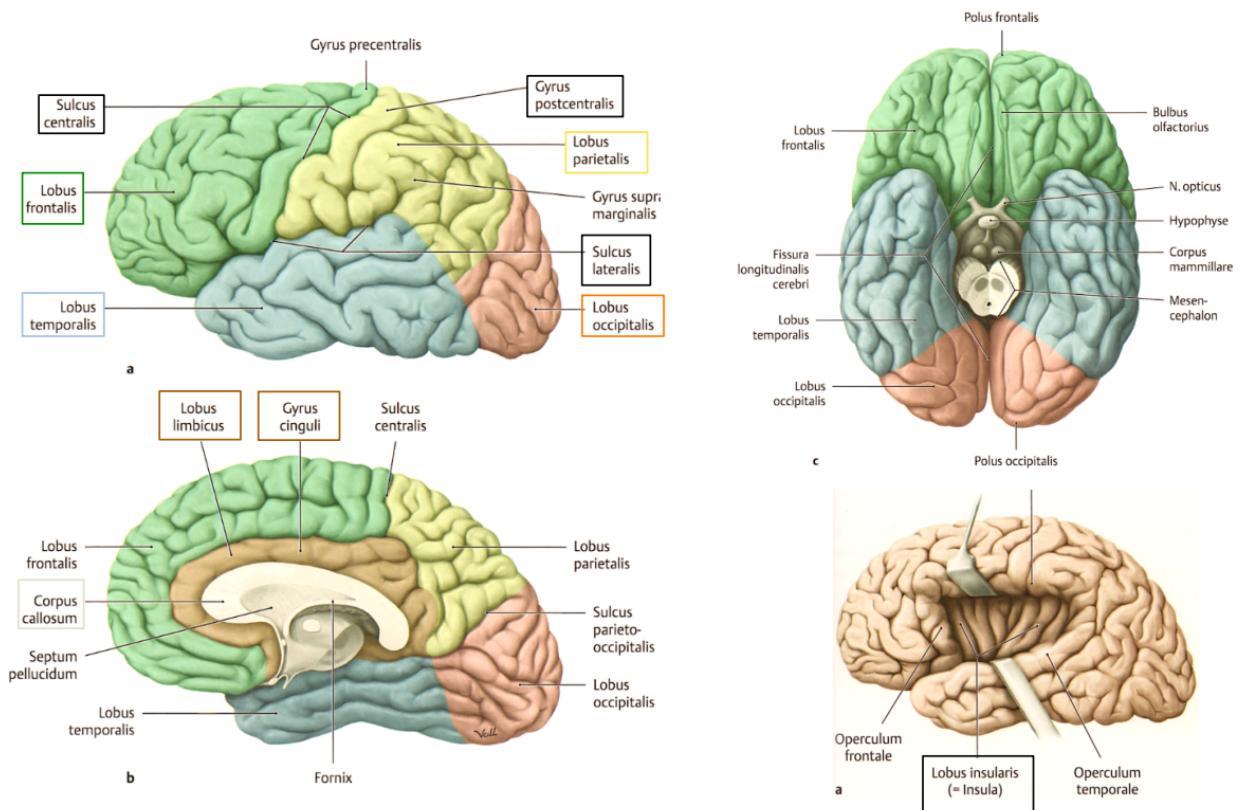


Figure 4: Macroscopic Boundaries - gray matter of the cortex

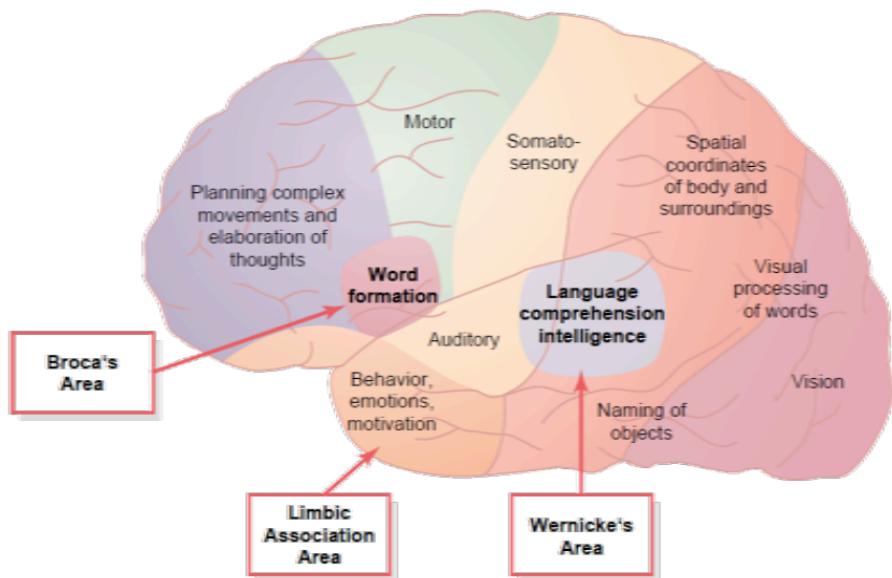


Figure 5: Functional Division - gray matter of the cortex

White matter The white matter can be divided macroscopically and microscopically. Macroscopically we talk about fibers and microscopically we talk about cells. Figure 6 exemplify the macroscopic division and Figure 7 exemplify the microscopic division, where we can see microglia, astrocyte and oligodendrocytes cells.

- Comissural fibers (red): link areas between the two hemispheres (corpus callosum, anterior commissure, posterior commissure)
- Association fibers (green): link cortical areas of the same hemisphere.
- Projecting fibers (blue): link the cortex with subcortical areas of the brain and the spinal cord.

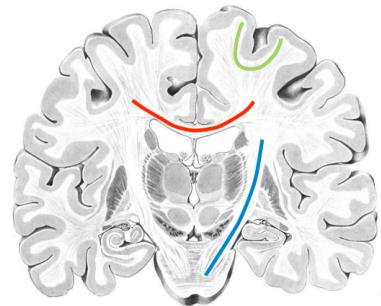


Figure 6: White matter - macroscopic fibers

Basal Ganglia The basal ganglia are the principal subcortical components of a family of neuronal circuits which link the thalamus and cerebral cortex. It is crucial for the initiation and modulation of voluntary movement by sending their output to the motor cortex via the thalamus. In addition, the basal ganglia also contribute to a variety of behavioral and cognitive functions other than voluntary movement.

The basal ganglia is divided in:

- Striatum: is the major recipient of inputs from the substantia nigra, cerebral cortex, thalamus, and brain stem. In humans (and most primates) consist of the caudate nucleus, the putamen, and the nucleus accumbens. In rats and mice consist of caudate putamen (human caudate nucleus + putamen) and nucleus accumbens.
- Globus Palidus: is divided into external and internal segments.

The internal segment (GPI) sends projections to the thalamus and pedunculopontine nucleus (a group of cells located in the brain stem).

The external segment (GPe) sends projections to the internal segment of the globus pallidus and to the subthalamic nucleus.

- Substantia Nigra: is a midbrain (mesencephalon) structure and contains a dense population of dopamine cells. The substantia nigra can be subdivided into substantia nigra pars compacta and pars reticulata.

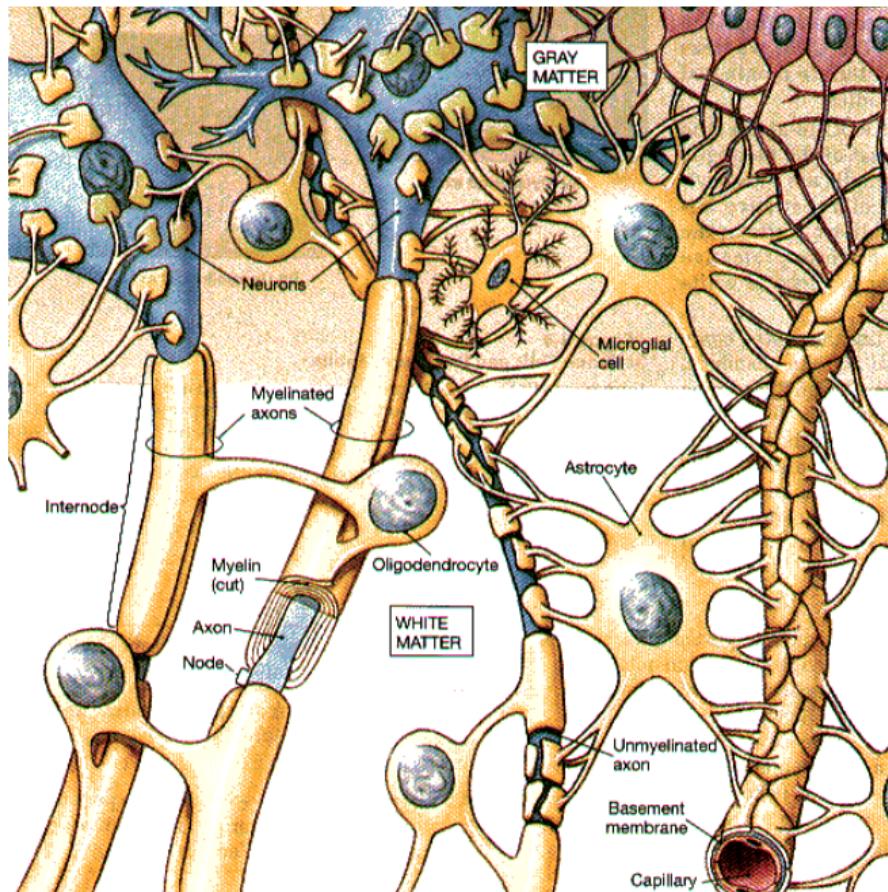


Figure 7: White Matter - microscopic structures

One of the disorders of the basal ganglia is the parkinson's disease, where the dopaminergic cells in the substantia nigra pars compacta are lost, it impairs motor skills, speech and other functions.

Limbic system Divided in cingulate gyrus (superior portion of limbic lobe), parahippocampal gyrus (inferior portion of limbic lobe), hippocampus and amigdalar complex. In Alzheimer's disease, the hippocampus is one of the first regions of the brain to suffer damage. memory problems (especially spatial memories) and disorientation appear among the first symptoms. People with extensive, bilateral hippocampal damage (such as in patients with progressed AD) may experience anterograde amnesia (the inability to form or retain new memories). The amigdala is envolved in emotions.

Diencephalon

The diencephalon is divided in thalamus, hypothalamus, epithalamus, subthalamus

Thalamus The thalamus is the gatekeeper of the brain: it is important for the transfer of information from the periphery to sensory processing regions in the telencephalon. It has important gating (filtering) functions: it determines whether sensory information reaches conscious awareness in the neocortex and participates in the integration of motor information from the cerebellum and basal ganglia and transmits this information to cerebral areas concerned with movement.

Hypothalamus The hypothalamus regulates several behaviors that are essential for homeostasis and reproduction: growth, eating, drinking and maternal behavior, by regulating hormonal secretions from the pituitary gland. It is an important control center for the autonomic nervous system and for the hypothalamus-pituitary-adrenal (HPA) stress-response system.

Neuroendocrinology of Hypothalamus

1. Hypothalamus produces releasing hormones (rh) and inhibiting hormones (ih) that directly influence anterior pituitary hormone secretion.
2. Hypothalamus produces two hormones (oxytocin and antidiuretic hormone) that are stored in the posterior pituitary.
3. Hypothalamus oversees the ANS (autonomic nervous system) thereby helping to stimulate the adrenal medulla via sympathetic innervation.

Epithalamus epithelial roof of the third ventricle, habenula, pineal body and afferent/efferent connections. It is responsible for the secretion of melatonin, regulation of day-night cycles, information processing related to olfaction.

Subthalamus It is the continuation of the tegmentum. Functionally part of the basal ganglia (motor control).

Mesencephalon - or Midbrain

The midbrain is a portion of the CNS associated with vision, hearing, motor control, sleep/wake, arousal (alertness), and temperature regulation. It comprises the tectum (or corpora quadrigemina), tegmentum, the cerebral aqueduct (or ventricular mesocoelia or "iter"), and the cerebral peduncles, as well as several nuclei and fasciculi. Caudally the midbrain adjoins the metencephalon (afterbrain) (pons and cerebellum), while rostrally it adjoins the diencephalon (thalamus, hypothalamus, etc). In Figure 9 the parts of the midbrain are listed.

1. Tectum (roof)
 - superior colliculus: visual and oculomotor reflexes
 - inferior colliculus: relay auditory tract
2. Tegmentum (floor)
3. Reticular formation: automatic processing of incoming sensation and outgoing motor commands, helps to maintain consciousness, can initiate motor response to stimuli (see also medulla oblongata!)
4. Red nucleus: involuntary control of background muscle tone and limb posture
5. Substantia nigra: regulates activity in the basal nuclei, degeneration of dopaminergic cells causes Parkinson's disease
6. Cerebral peduncles: connect primary motor cortex with motor neurons in brain and spinal cord, carry ascending sensory information to thalamus
7. Ventral tegmental area (VTA): part of the limbic system, projects e.g. to nucleus accumbens and amygdala, emotional reinforcement.

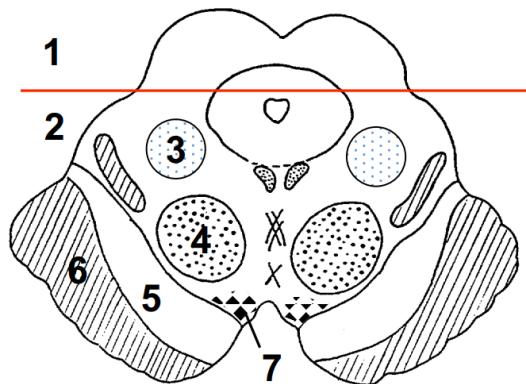


Figure 8: Mesencephalon - Functional units

Pons

Divded in two parts: locus coeruleus and pontine nuclei. The locus coeruleus (or blue spot) contains noradrenergic cells innervating large portions of the brain, mediating physiological response to panic and stress. The pontine nuclei receive fibers from all cortical areas and relay to the contralateral cerebellum.

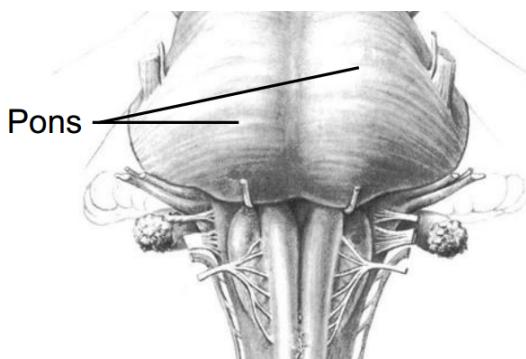
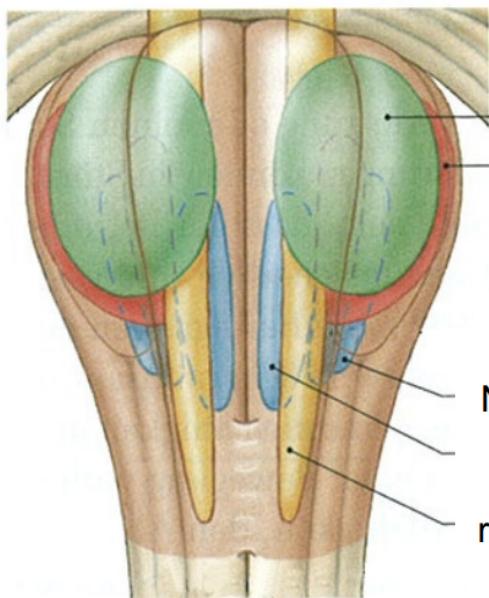


Figure 9: Pons

ventral/anterior



dorso-lateral

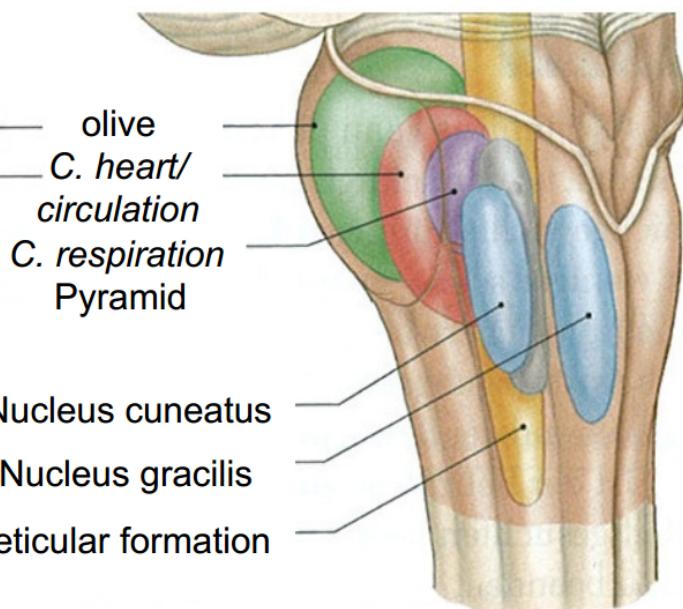


Figure 10: Medulla Oblongata

Medulla oblongata

It contains four main parts: olives, pyramid, reticular formation and reflex centers.

olive relay nucleus for afferent connection from motor cortex and red nucleus, efferent to contralateral cerebellum.

pyramid contains descending cortico-spinal fibers.

reticular formation (entire brain stem!) containing the raphe nuclei and magno/parvocellular nuclei, which regulate respiration, circulation, vomiting, swallowing, and pain control.

reflex centers for heart and circulation (vasomotor/cardiac) and respiratory rhythmicity.

Cerebellum

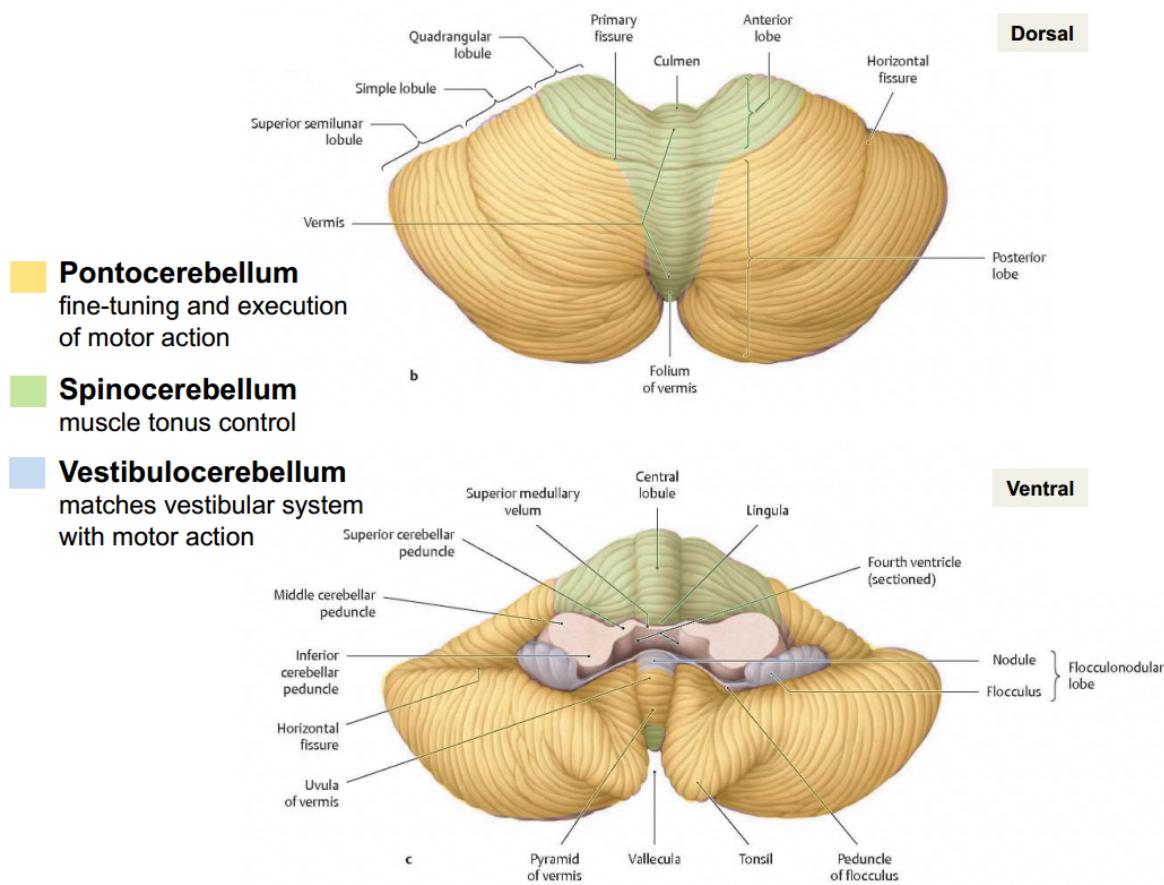


Figure 11: Cerebellum

Spinal Cord

The segmental organization of the spinal cord is illustrated in Figure 12. The spinal cord contains gray and white matter. The gray matter (inside part) of the spinal cord consists of cell bodies of interneurons, motor neurons, and synaptic connections. Fibers of the motor neurons in the ventral horn leave the spinal cord to muscles (efferent/motor commands). Afferent/sensory axons enter through the dorsal horn and either synapse on sensory interneurons in the dorsal horn, or join the ascending tracts in the white matter. The white matter of the spinal cord mostly consists of myelinated axons of motor and sensory neurons organized in columns (containing several fiber tracts) carrying information to (afferent/ascending) and from (efferent/descending) the brain.

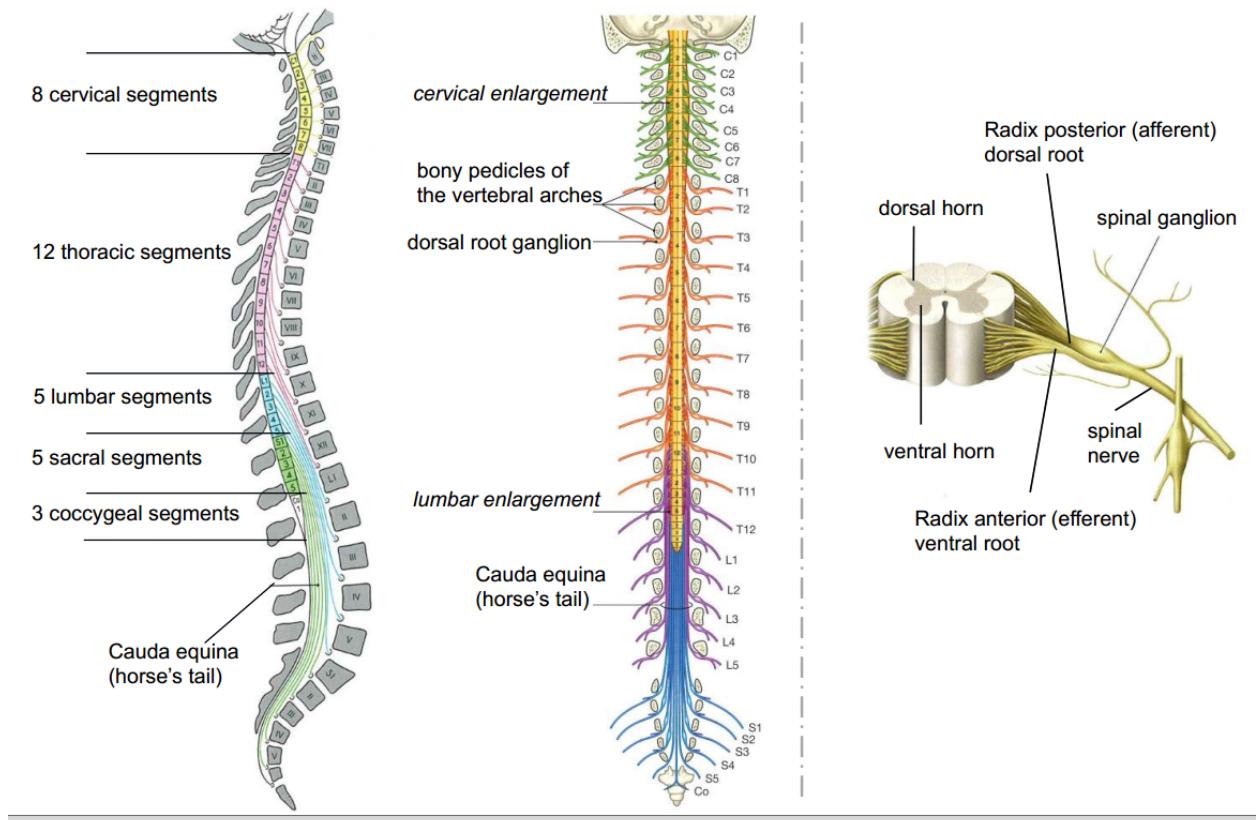


Figure 12: Spinal Cord

Cranial Nerves

Cranial nerves are the nerves that emerge directly from the brain (mostly from the brainstem), in contrast to spinal nerves (which emerge from segments of the spinal cord). Cranial nerves are generally named according to their structure or function. We have 12 cranial nerves: (i) olfactory, (ii) optical, (iii) oculomotor, (iv) trochlear, (v) trigeminal, (vi) abducens, (vii) facial, (viii) vestibulocochlear, (ix) glossopharyngeal, (x) vagus, (xi) accessory and (xii) hypoglossal nerve as we can see in Figure 14.

The cranial nerves provide motor and sensory innervation mainly to the structures within the head and neck. The sensory innervation includes sensation such as temperature and touch, and innervation such as taste, vision, smell, balance and hearing. The vagus nerve (x) provides sensory and autonomic (parasympathetic) innervation to most of the organs in the chest and abdomen.

Meninges

The meninges are the three membranes that envelop the brain and spinal cord. In mammals, the meninges are the **dura mater**, the **arachnoid mater**, and the **pia mater**. The inflammation of

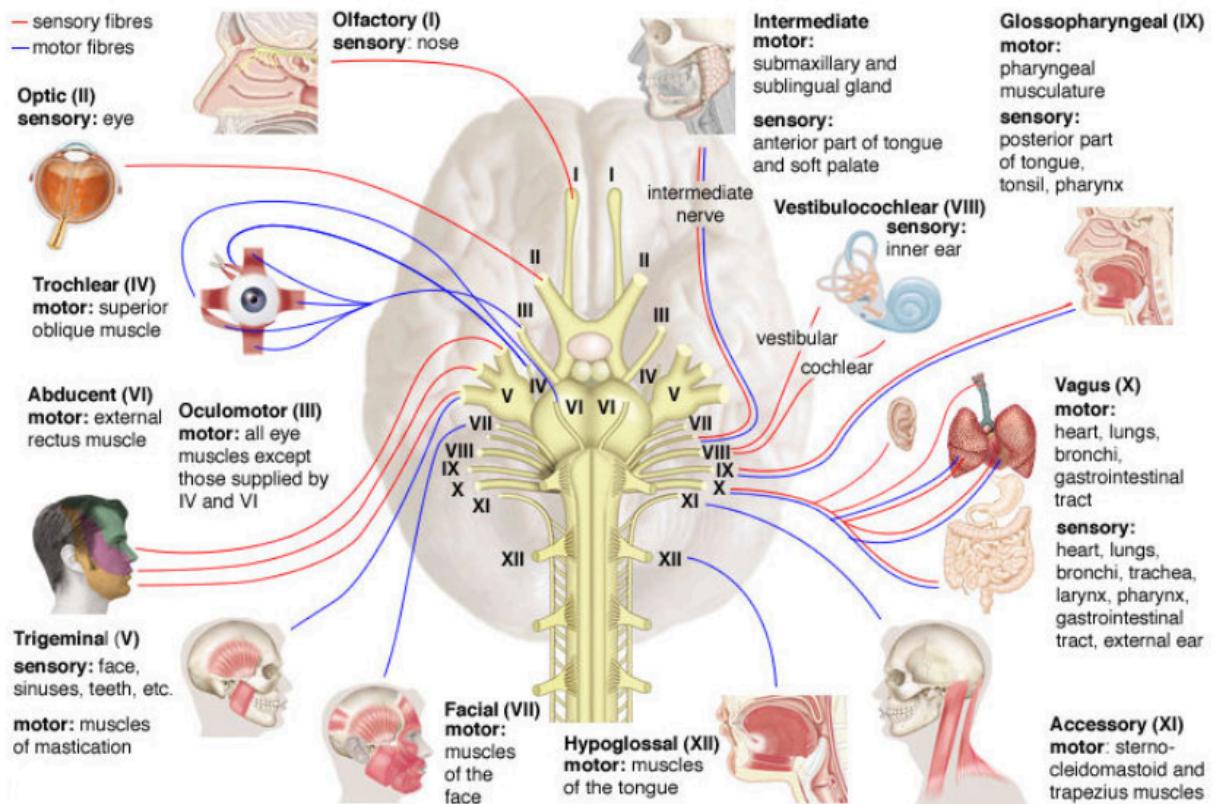


Figure 13: Cranial Nerves

the meninges is called Meningitis.

- Dura mater: leather-like, inflexible layer surrounding the CNS and spinal cord. Inner and outer layers, containing large venous sinuses (e.g. superior sagittal sinus).
- Arachnoid mater: loose connective tissue bridging the liquor-filled space (subarachnoidal space) between dura mater and pia mater. Contains all larger blood vessels.
- Pia mater: translucent, thin membrane directly covering the entire surface of the brain, follows all sulci and gyri.

Ventricles and cerebrospinal fluid

The ventricles of the brain are a communicating network of cavities filled with cerebrospinal fluid (CSF) and located within the brain parenchyma. The ventricular system is composed of 2 lateral ventricles, the third ventricle, the cerebral aqueduct, and the fourth ventricle. Some disorders on the ventricles cause diseases: neurodevelopmental (schizophrenia), neurodegenerative (alzheimer).

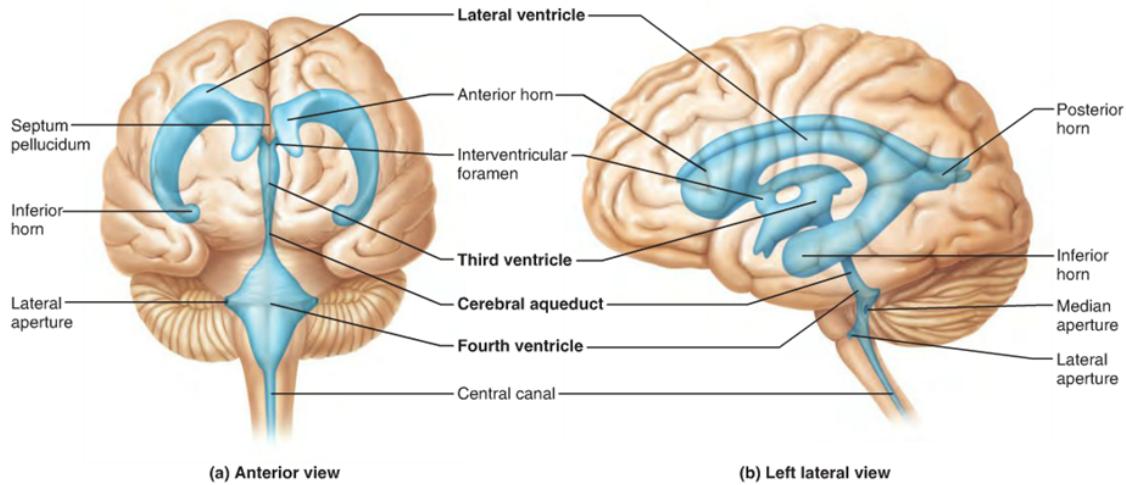


Figure 14: Ventricles

CSF is clear fluid, high content of NaCl, contains glucose and K+, low in proteins, very few cells (lymphocytes). It turnover three times a day. It flows throughout the ventricular system and is absorbed back into the bloodstream (via bloodbrain-barrier). Cerebrospinal fluid is located in the subarachnoid space between the arachnoid mater and the pia mater.

Functions of CSF Buoyancy, Protection and Homeostasis.

Buoyancy: The actual mass of the human brain is approx. 1500 grams; however, the net weight of the brain suspended in the CSF is equivalent to a mass of 25 grams. The brain therefore exists in neutral buoyancy, which allows the brain to maintain its density without being impaired by its own weight, which would cut off blood supply.

Protection: CSF protects the brain tissue from injury when jolted or hit. In addition, it helps regulating intracranial pressure (lowering CSF production can help preventing brain ischemia).

Homeostasis: Through absorption back into the blood stream, CSF can rinse “metabolic waste” from the CNS, allowing for a homeostatic regulation of the brain.

Common related pathology: hydrocephalus - abnormal accumulation of CSF within the brain. Can be congenital or acquired postnatally. Most common cause is aqueductal stenosis (passage between the 3rd and 4th ventricle is blocked or too narrow), so fluid accumulates in the upper ventricles.

Cerebral circulation

The brain is one of the most metabolically active organs in the body! Uses approximately 20-25% of the body's total energy requirements (despite accounting for only 2% of the body's mass). The brain stores little energy as glycogen and relies mostly on circulating glucose. The rate of the

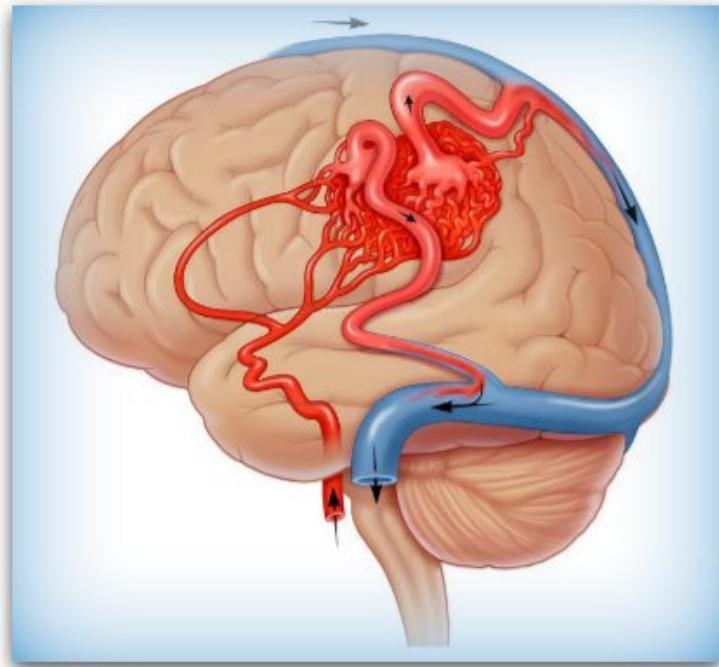


Figure 15: Arteries and Veins of the Brain

cerebral blood flow in the adult is typically 750 milliliters per minute, representing 15% of the cardiac output.

Arteries Supply oxygen-rich blood from heart to brain. Main branches of the internal carotids: anterior cerebral artery and middle cerebral artery. Main branches of the vertebral / basilar arteries: 3 arteries supplying the cerebellum and posterior cerebral artery.

Veins Carry oxygen-depleted blood away from brain

Comparative Neuroanatomy

Does brain size matter?

Is there a relationship between the size of an animal's brain and some kind of "behavioural complexity"? Not really. Elephants and whales have brains 4 to 5 times the size of a human being's, yet their behaviour is generally agreed to be less complex than ours.

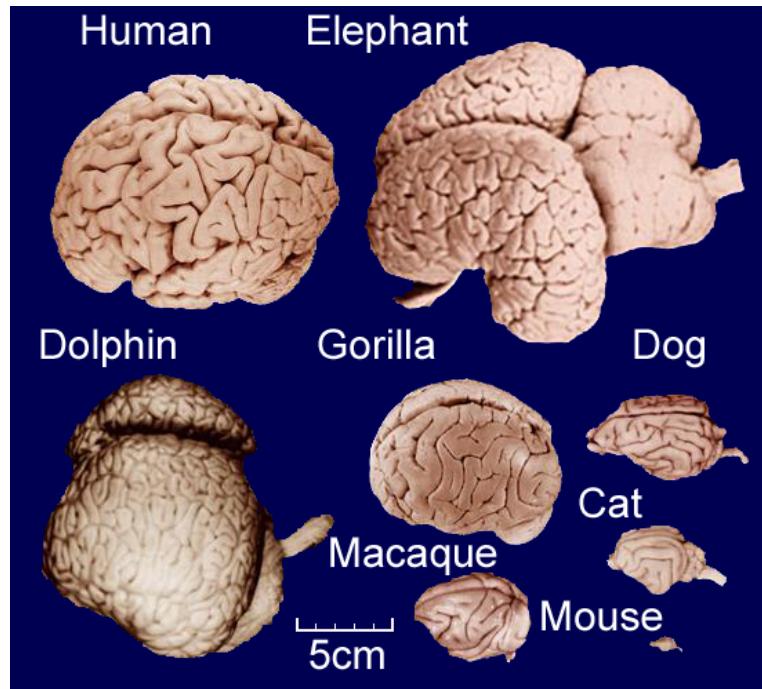


Figure 16: Brain size of different species

Encephalization Quotient (EQ)

describes brain size as a ratio of the expected average brain size relative to the actual body weight.
 EQ of humans: ≈ 7.5 (Human brains are 7.5x bigger than what one would expect for species of this size.)
 EQ of sq. monkeys: ≈ 1.1 .

Body mass and number of neurons

A capybara has 1,600,000,000 neurons and a common squirrel monkey (much smaller than a capybara) has 3,246,000,000 neurons.

Brain evolution in view of cortical expansion

Cortical expansion is often equated with "brain evolution", whereby the relative size of the cerebral cortex increases while the relative size of the cerebellum remains fairly constant. We can see in Figure 17 the human cortical expansion is relative but does not affect each region similarly.

Cross-species comparison of cortical areas

The human prefrontal cortex is responsible for planning, attention, working memory, cognitive flexibility and impulsivity. The human PFC is divided in dorsolateral PFC, anterior cingulate cortex

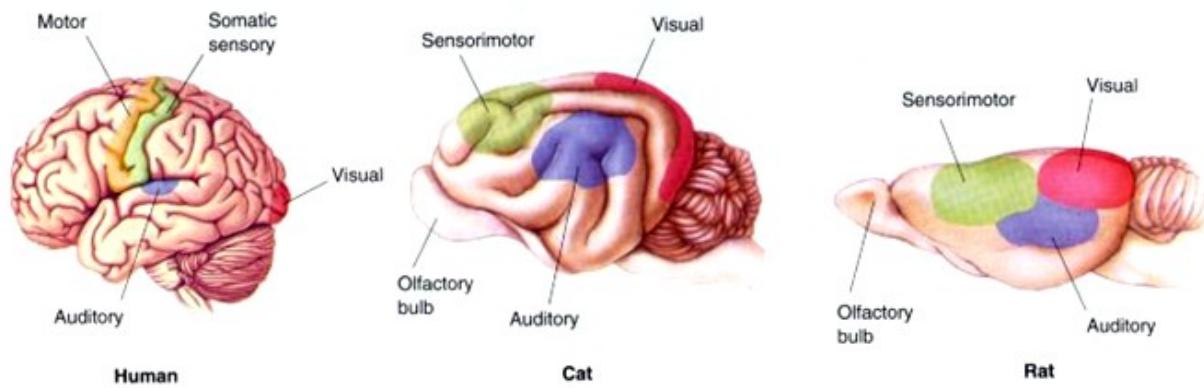


Figure 17: Cortical expansion

and anterior PFC (or medial PFC). Rats (and mice) also have PFC, with similar responsibilities: lesions to the medial part of PFC (mPfc) lead to working memory impairments as evident by the **increased number of working memory errors in the 8-arm radial arm maze**.

The rodent prefrontal cortex (PFC) is not as anatomically complex as the primate; however, many of the critical neuroanatomical and functional characteristics are preserved in rodents, which allow meaningful cross species comparisons relevant to study of the neurocognitive and neurobiological mechanisms that underlie changes in executive functioning across the lifespan. The medial portion of rodent PFC [which includes anterior cingulate (aCg), prelimbic (PL), and infralimbic (IL) cortices] shares strong anatomical homology with primate dorsolateral PFC

Cross-species comparison of subcortical areas

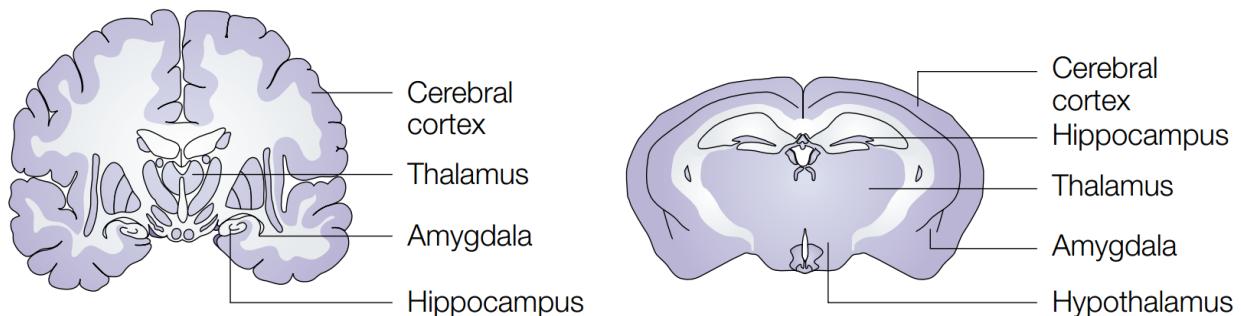
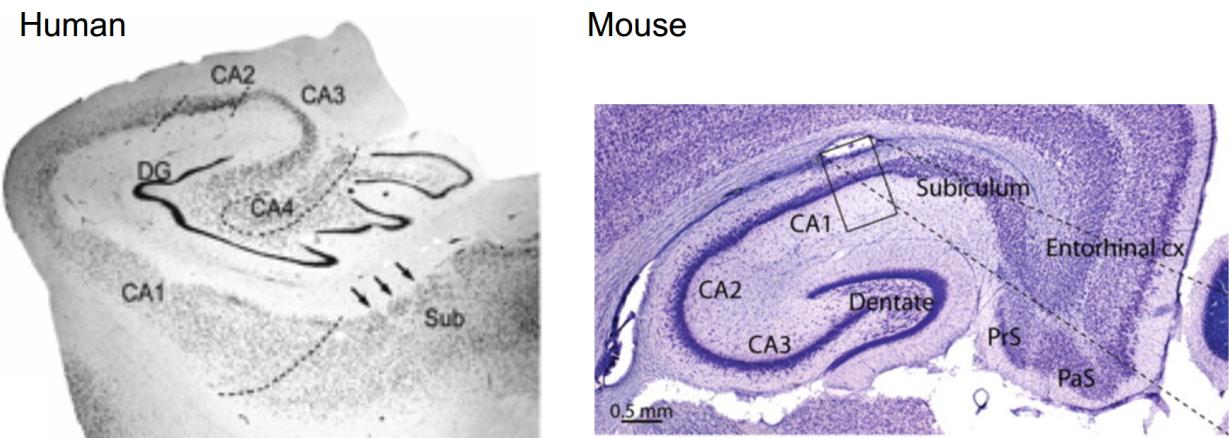


Figure 18: Cross-species comparison of subcortical areas

Hippocampus

Hippocampal anatomy The longitudinal axis of the hippocampus is described as ventrodorsal in rodents and as anteroposterior in primates. A rotation of 90-degree is required for

the rat hippocampus to have the same orientation as that of primates, as you can see on Figure 19.



Arellano et al, 2003, *Brain* 127, 45-64.

CA = Cornu ammonis
DG = Dentate Gyrus
Sub = Subiculum

Figure 19: Cross-species hippocampus anatomy

Hippocampal Functions In London taxi drivers were observed an increased brain activity associated with spatial navigation in the **right hippocampus** and left tail of the caudate. In rats the effect of hippocampal lesions on reference learning and memory was tested using the Morris water maze experiment. As bigger is the lesion on dorsal hippocampall, as bigger the deficit in the acquisition of spatial reference. Not so big deficit if the lesion were in the ventral hippocampal.

Experiment: The position of a submerged platform is constant from trial to trial at a given test day as well as form test day to test day. Animals are repeatedly placed into the tank with varying starting positions; with the help of spatial distal cues as reference points, they are required to find the invisible platform. Following completion of the acquisition phase, the platform is removed from the tank. The animals are once again placed in the tank; the critical measure here is whether the animals would “remember” the position of the platform and therefore would spent more time in quadrant where the platform was positioned before.

Amygdala

Amygdalar Anatomy Primary amygdalar nuclei and basic circuit connections and function are conserved across species. An enlarged image of the basolateral complex of the amygdala (BLA) and central nucleus of the amygdala (CeA) or analogues are shown next to a coronal section from the brains of a lizard, rat, cat, monkey, and human, in Figure 20.

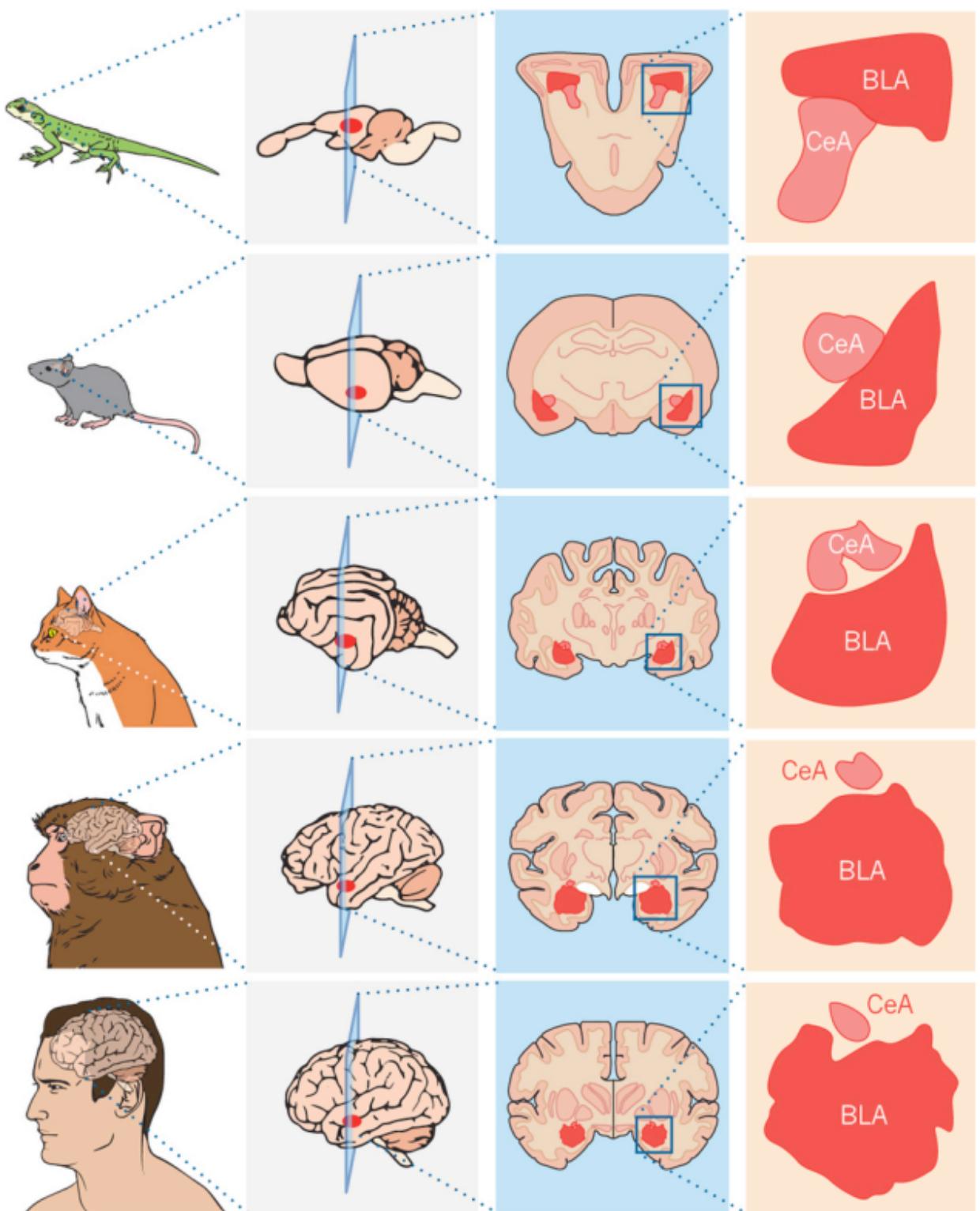


Figure 20: Cross-species amygdalar anatomy

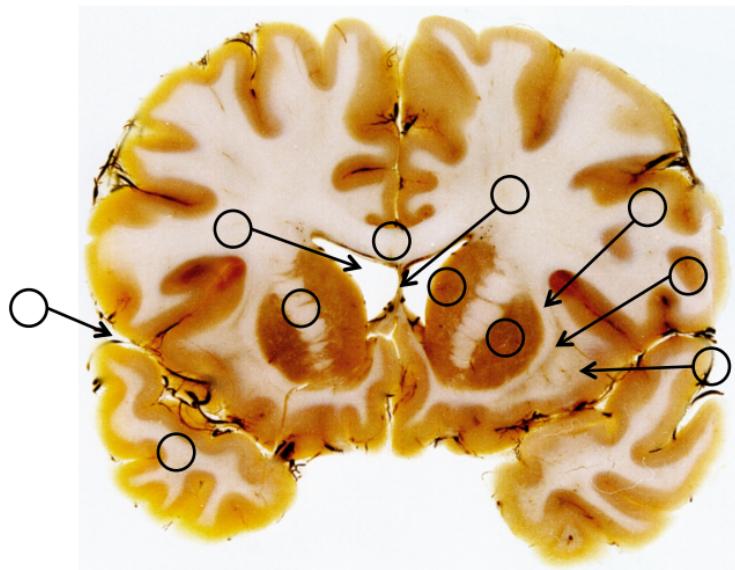
Amygdalar Functions In post-traumatic stress disorders (PTSD), the amygdala is hyperactive in response to negative emotional stimuli vs. neutral and positive stimuli. In rodents the investigation of amygdalar function is tested using the **classical (pavlovian) fear conditioning**. In rats with amygdala lesions, the response to the non-threatening doesn't happen anymore.

Experiment: present a non-threatening stimulus (like a sound) with a noxious stimulus (like a middle shock) until the animal shows a fear response not just to the shock but also to the sound alone.

Basal ganglia

Exercises

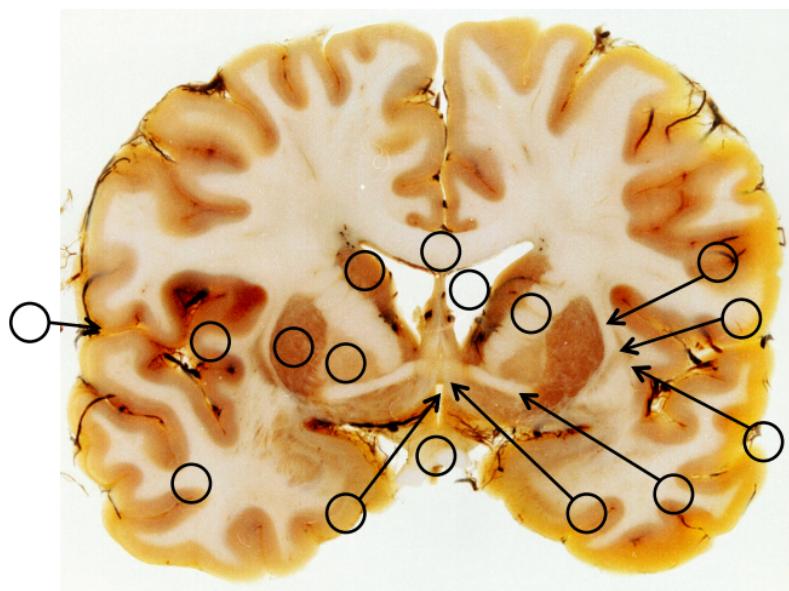
Coronal section - I



- 1 caudate nucleus
- 2 claustrum
- 3 corpus callosum
- 4 external capsule
- 5 extreme capsule
- 6 internal capsule
- 7 lateral fissure
- 8 lateral ventricle
- 9 putamen
- 10 septum pellucidum
- 11 temporal lobe

Figure 21: Coronal section I

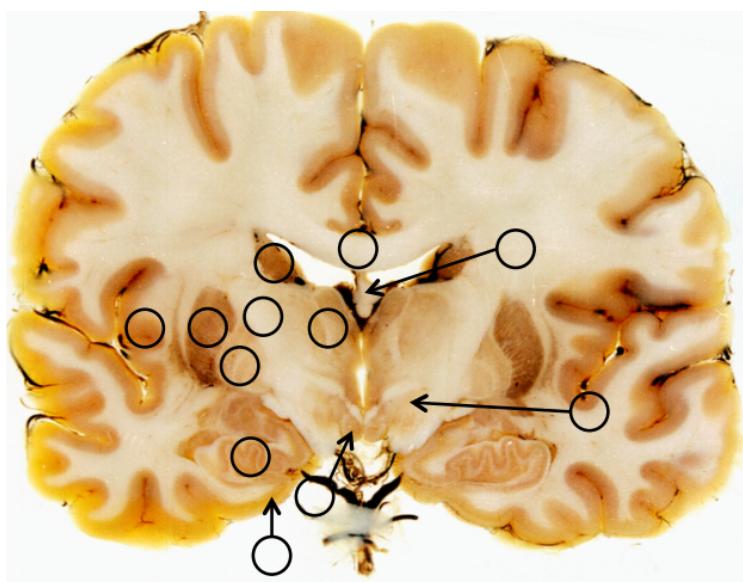
Coronal section - II



- 1 anterior commissure
- 2 caudate nucleus
- 3 claustrum
- 4 corpus callosum
- 5 external capsule
- 6 extreme capsule
- 7 fornix
- 8 globus pallidus
- 9 insula
- 10 internal capsule
- 11 lateral fissure
- 12 lateral ventricle
- 13 optic chiasm
- 14 putamen
- 15 temporal lobe
- 16 3. ventricle

Figure 22: Coronal section II

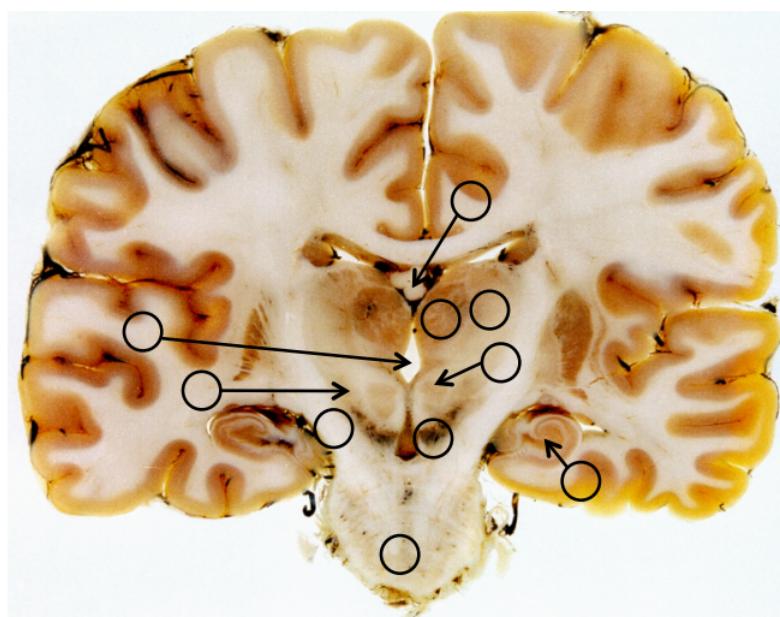
Coronal section - III



- 1 caudate nucleus
- 2 corpus callosum
- 3 fornix
- 4 globus pallidus (GPe, GPi)
- 5 hippocampus
- 6 insula
- 7 internal capsule
- 8 mammillary body
- 9 putamen
- 10 parahippocampal gyrus
- 11 subthalamic nucleus
- 12 thalamus

Figure 23: Coronal section III

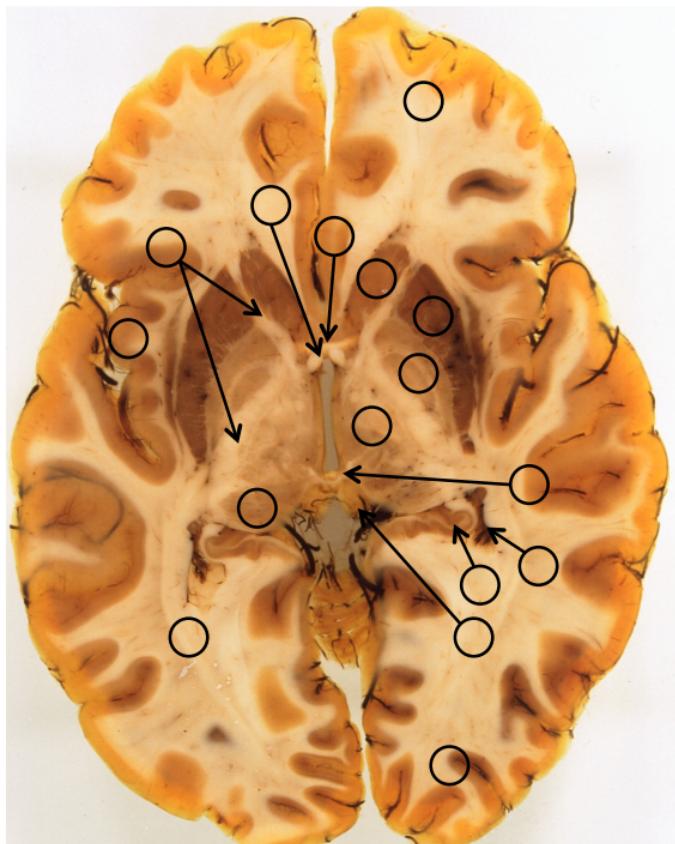
Coronal section - IV



- 1 cerebral peduncle
- 2 fornix
- 3 hippocampus
- 4 red nucleus
- 5 pons
- 6 subthalamic nucleus
- 7 substantia nigra
- 8 thalamus, medial nuclei
- 9 thalamus, lateral nuclei
- 10 3. ventricle

Figure 24: Coronal section IV

Horizontal section



- 1 anterior commissure
- 2 caudate nucleus
- 3 fornix
- 4 frontal lobe
- 5 globus pallidus
- 6 habenula
- 7 hippocampus
- 8 insula
- 9 internal capsule
- 10 lateral ventricle, inferior horn
- 11 occipital lobe
- 12 optic radiation
- 13 pulvinar nuclei (thalamus)
- 14 putamen
- 15 superior colliculus
- 16 thalamus

Figure 25: Horizontal section

Molecular & Cellular Neuroscience

Building a central nervous system

Human brain: 86 billions neurons and about equal number of glia cells.

Neural Induction and Pattern Formation

Embryonic Origins of the Nervous System

Figure 26: the ectoderm (blue/red in image) covers the outside of the embryo during *gastrulation*.¹ Ectodermal cells give rise to different derivatives depending on position along the

¹Gastrulation is a phase early in the embryonic development of most animals, during which the single-layered *blastula* is reorganized into a trilaminar ("three-layered") structure known as the *gastrula*. These three germ

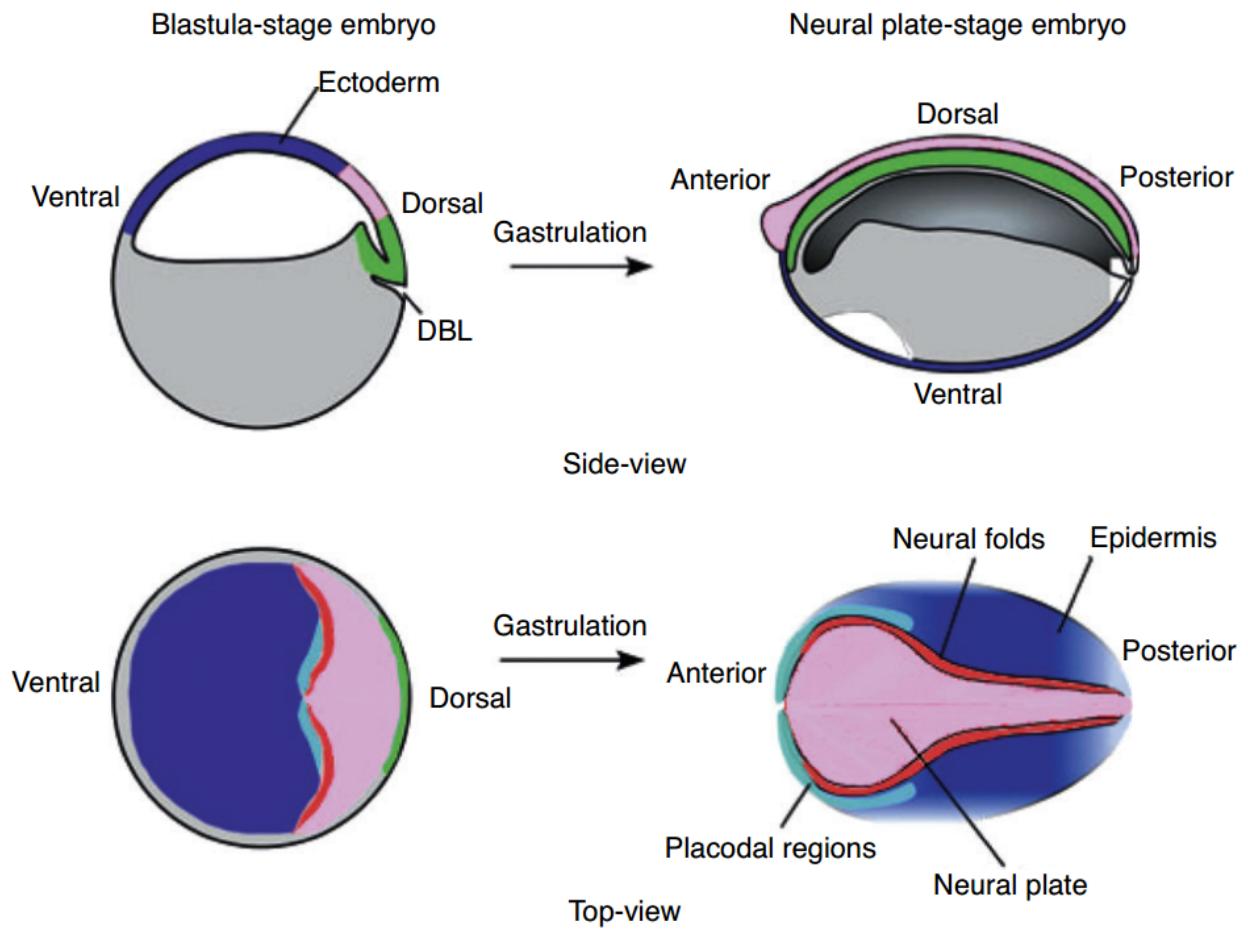


Figure 26: Embryonic origin of the neural system

dorsoventral (DV) axis of the embryo. The dorsal-most ectoderm (red) thickens to form the **neural plate**, a structure shaped like a tennis racquet with the head lying anteriorly. During a complex morphogenetic process called **neurulation**, the flat neural plate rolls up into a tube that sinks into the interior of the embryo and becomes overlain by epidermal ectoderm. This neural tube is the anlage of the central nervous system (CNS). As the neural plate folds and closes, neural crest cells detach from its lateral margins and migrate away, later condensing to form the major part of the peripheral nervous system (PNS).

The famous Spemann Organizer

Figure 27: Tissue around the DBL² was removed from one embryo (black) and placed into the ventral side of another (white). The transplanted DBL, if large enough, will cause a complete layers are known as the ectoderm, mesoderm, and endoderm.

²dorsal blastopore lip, where mesodermal cells start to involute during gastrulation

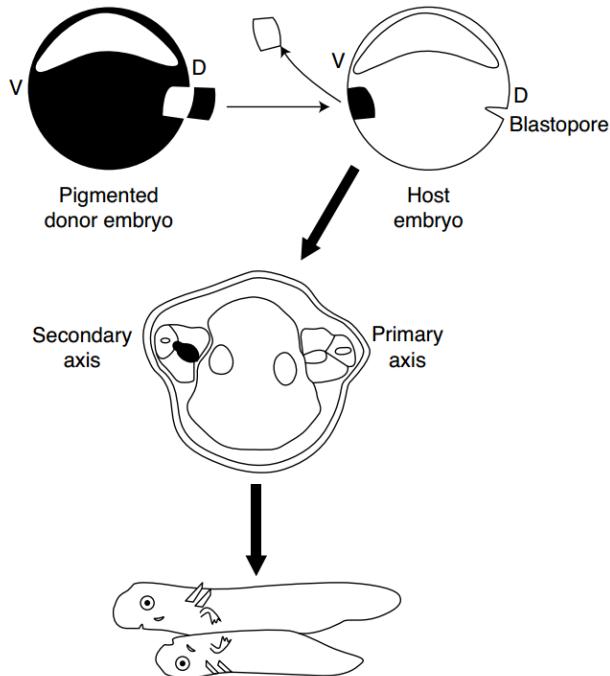


Figure 27: Spemann Organizer Experiment

second dorsal axis to form on the host embryo, resulting in twinning. Cross section through the tadpoles shows that the second dorsal axis contains a complete nervous system. By using differently pigmented embryos, one can show that the majority of the nervous system in this new dorsal axis is not derived from the transplanted tissue, but rather from host tissue, fated to give rise to ventral tissues in the absence of a graft.

The default model for Neural Induction

An important aspect of the default model for neural induction is that ectoderm will inherently (by default) form neural tissue unless it is exposed to antineurializing signals.

Figure 28: Experiments in Xenopus embryos that led to the default model: culture of animal cap explant results in epidermis differentiation; dissociation for several hours followed by reaggregation of animal cap tissue results in neural induction; the presence of BMPs during dissociation prevents neural induction and promotes epidermis formation; the expression of a dominant-negative Activin receptor results in neural induction even without dissociation. BMPs induce epidermal fate and inhibit neural induction via Smad1 activity; BMP inhibitors act as neural inducers by blocking BMPs; FGFs act as neural inducers by counteracting Smad1 and via BMP-independent mechanisms; Wnt/ β -catenin signaling predisposes ectoderm for neural induction by both preventing the transcription of Bmp genes and inducing the expression of BMP inhibitors.

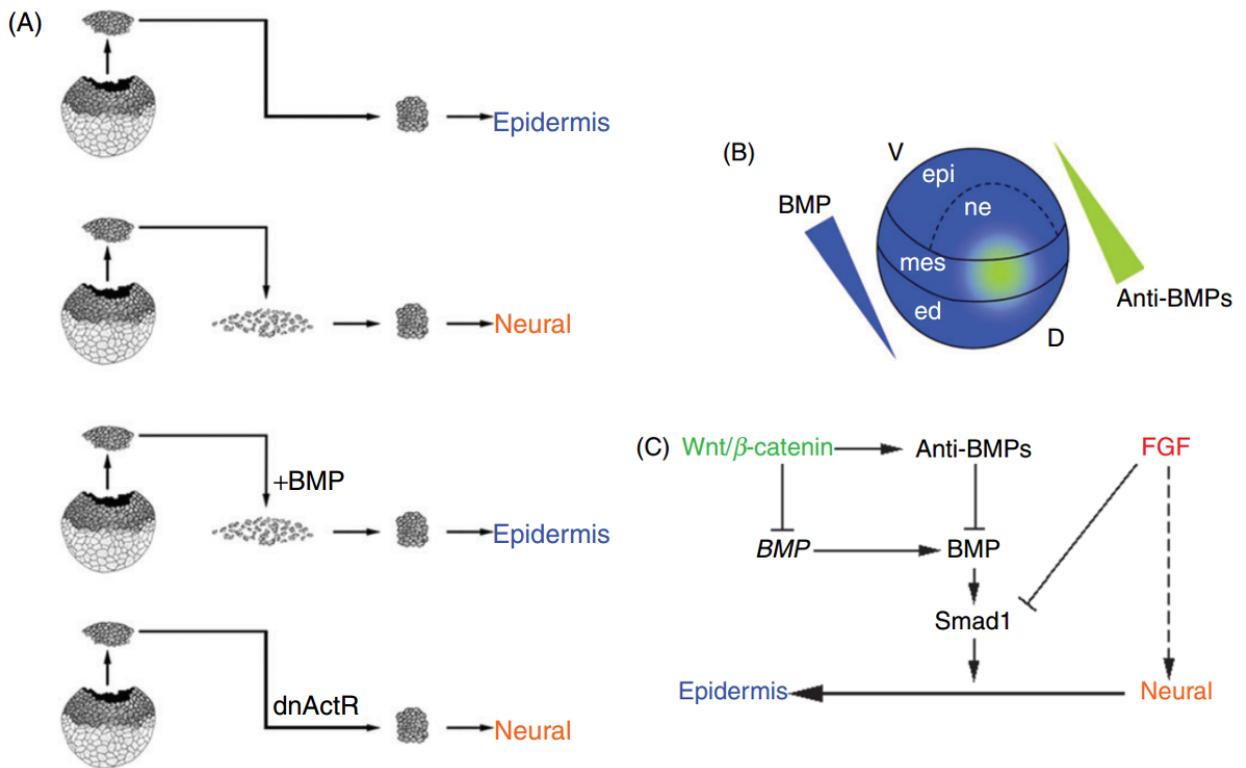


Figure 28: Default model for neural induction

Early Neural Patterning

The neural plate is parcellated into subdivisions along the anterior-posterior (AP) and dorsalventral (DV) axes. This subdivision give rise to a multitude of different cell types in a spatially organized manner; these then become wired up in a stereotyped fashion and subserve distinct tasks in functional neural networks.

Growth Cones and Axon Pathfinding

Cellular Determination

Neurogenesis and Migration

Excitability

Glia and more

Glial cells: non-neuronal cells that maintain homeostasis, form myelin and provide support and protection for neurons in CNS and PNS. They are divided in *macrogli* and *microglia* cells.

- microglia destroy infectious agents and work as immune defense system of the brain through phagocytosis.
- macroglia divided in two groups: astrocytes and oligodendrocytes.

Astrocytes

Five functions:

- Energy metabolism: provide O₂ to neurons from blood
- Waste recycling: remove CO₂ from neurons to blood
- Neurotransmission: convert glutamate in glutamine to neurons
- Biosynthesis: produce glutamine
- blood flow regulation: regulates contraction and dilatation of blood vessels

Oligodendrocytes

In CNS they are called oligodendrocytes, in PNS Schwann cells. Responsible for myelin formation.
Myelin is responsible for:

- critical in increase action potential conduction
- provide metabolic support
- affect signal processing and long distance communication by modulating the degree of myelination

Plasticity: the myelination changes throughout adult life based on experience and neuronal activity.

Synapses

Most flow information is chemical: a single pre action potential can generate a large postsynaptic potential.

Neurotransmitters

Interneuronal communication is chemical in nature but neurons also use other process to communicate (as electrical, ephaptic iteration etc). **Neurotransmitters** are substances that are released from neurons, act on receptors of postsynaptic cells and produce a functional change in the target cell.

Mainly communication types:

electrical and chemical. Each type of communication has specific channels. The chemical communication occurs by synapses and the electrical communication occurs by gap junctions. **synapse**: gap between two neurons (synapse cleft). The transmission is not all or none, but it is graded. **gap junction**: two neurons are connected by gap junctions. When one fires, the other fires simultaneously and with the same intensity.

There are diverse types of neurotransmitters. However, there is a classical structure of a neurotransmitter:

- neuron must produce and release the substance
- substance must be released from nerve terminals
- substance should reproduce at postsynaptic the event seen on the presynaptic
- should have mechanisms to terminate the action of the substance

These rules are related with the five steps of the chemical neurotransmission (communication):

1. Synthesis of neurotransmitter in the presynaptic neuron
2. Storage of the neurotransmitter (or its precursor) in the presynaptic nerve terminal
3. Release of neurotransmitter into the synaptic cleft
4. Binding and recognition of neurotransmitters by target receptors
5. Termination of the action of the released neurotransmitter

There are two types of receptors: ionotropic and metabotropic.

- ionotropic: are made from proteins to form an ion channel. The transmitter binds with the receptor and opens the channels for the ions going through. Ionotropic receptors have rapid changes with short duration.
- metabotropic: are made of a single peptide and the transmitter binds with the receptor and then, the G-protein is activated. The activation of G-protein will open the ion channel. Usually is necessary a second messenger to do this. Metabotropic receptors have slower response but with long duration.

There are two main types of release of neurotransmitters: kiss and run and endocytosis.

- kiss and run: a fusion pore opens to allow transmitter release and then closes rapidly to reform the vesicle, this way, the vesicle is available immediately to reuse.

- endocytosis: vesicle fuses with the membrane completely to release transmitters. The reformation of the vesicle requires that appropriate proteins be reassembled
 - the vesicle can return directly to the release pool
 - the vesicle first fuses with endosome and then a new vesicle is generated

There are two ways to finalize the action of a neurotransmitter: active and passive.

- active: glia cells cleanse the neurotransmitters or by enzymatic degradation
- passive: diffusion of the transmitter in the environment.

Why so many types of neurotransmitters?

There are many terminal synapses onto a single neuron. This way to distinguish different information they need different chemical codes.

Systems Neuroscience

Somatosensory and Motor Systems

Three groups of receptors: **mechanoreceptor**, **nociceptor** and **thermoceptors**. The nociceptors and thermoceptors are free nerve endings: unmyelinated terminal on dermis/epidermis. The myelinated type (mechanoreceptor) is divided into four major types with two subcategories. The subcategories are slow and fast adaptation. The **slow adaptation** means the neuron fires while the stimulus occurs, the **rapid adaptation** fires in the beginning then adapts and stops.

- Meissner's corpuscles: rapid adaptation, closest to epidermis
- Pacinian corpuscles: rapid adaptation, high vibrations
- Merkel's disks: slow adaptation, located in epidermis, identification of shapes, edges and textures
- Ruffini's corpuscles: slow adaptation, deep in the skin (ligaments, tendons), sensitive to stretching.

The CNS plays an active role in determining perception, one interesting case is the phantom limb. The phantom limb occurs when people lose their limbs and still have the sensation of pain or other stimuli from the missing limb.

Somatosensory Pathway

Sensory pathway: receptors receives the stimulus and transduce it to pass the information to the first order neurons (neurons that have cell body on dorsal root ganglion or in the trigeminal ganglion). After the axon of the first order neurons enter the spinal cord they branch into ascending and descending pathways. The major branch ascend ipsilaterally through the dorsal column to medulla.

Motor pathway

Definitions:

- motor neurons: body along the spinal cord and brainstem. Send axons to one muscle and innervate some muscle fibers.
- motor unit: motor neuron + muscle fibers.

An individual muscle is controlled by a pool of motor units. This pool contains varying portion of motor unit types. The pool of motor neurons forms an elongated column that extends for two or three segments of the spinal cord.

Three types of muscle fibers formed by contraction and metabolic properties:

- Type I: slow twitch and aerobic (oxidative) metabolism
- Type IIA: fast twitch and aerobic and anaerobic metabolism
- Type IIB: fast twitch and anaerobic (glucolysis) metabolism

Each motor neuron must link with fibers of the same type. This way, also the motor neurons are divided in three types:

- Type S: slow twitch, lower production of force and resistant to fatigue. Linked with type I fibers. They have small cell bodies, responsible for postural and tonic movements.
- Type FR: fast twitch, relative high amount of force produced and relative resistance to fatigue. Linked with Type IIA fibers. They have large cell bodies and faster firing rates, responsible for fast and powerful movements.
- Type FF: fast twitch, higher amount of force produced, fatigue quickly. Linked with Type IIB fibers. They have large cell bodies and fast firing rates, responsible for brief bursts of muscle strength.

Motor pattern reflex:

- Withdrawal of a part of the body to avoid pain or tissue damage

- Coughing or sneezing to remove an irritant from nasal or tracheal mucosa
- Swallowing reflex to propel the food down the esophagus to stomach

Diencephalon and subcortical areas of telencephalon controls the goal-direct behavior (hypothalamus and basal ganglia). The hypothalamus controls autonomic functions (temperature regulation, intake fluid or food). The basal ganglia has critical importance for normal initiation of motor behavior (thalamus: input, pallidum: output). The frontal lobe contains minor neurons that give us capacity to imitate movements.

Corticospinal neurons: large pyramidal cells in the motor cortex that send their axons to the contralateral side of the spinal cord. They are able to activate they target motor neurons directly.

Cortical influence on movements by direct projections to the input of basal ganglia or to the spinal cord (corticospinal projections). Responsible for conscious decision about initiate and maintain movement and to adaptation using visually information.

Two main system in motor:

- Medial system - axons descend through brainstem and spinal cord close to the midline: postural control.
- Lateral system - axons descend in the lateral column of spinal cord: fine control of voluntary movements.

Convergence and divergent on primary motor cortex:

- convergence: any given muscle is controlled by a large territory in M1.
- divergence: single M1 neurons have output connections that diverge to innervate the spinal motor neuron pools of multiple muscles.

Basal Ganglia Loops

There is a parallel organization on basal ganglia: cortex → striatum → pallidum → thalamus → cortex

Motor loop: primary motor cortex → putamen → lateral globus pallidus → ventral lateral and ventral lateral anterior nuclei.

Oculomotor loop: posterior parietal pfc → caudate → globus pallidus internal → mediodorsal and ventral anterior nuclei.

Prefrontal loop: dorsolateral pfc → anterior caudate → globus pallidus internal → mediodorsal and ventral anterior nuclei.

limbic loop: amygdala, hippocampus → ventral striatum → ventral pallidum → mediodorsal nucleus

Visual System

Auditory & Vestibular System

Circuits underlying Emotion

Learning in artificial and biological neural networks

Answers

Human & Comparative neuroanatomy

Coronal section - I

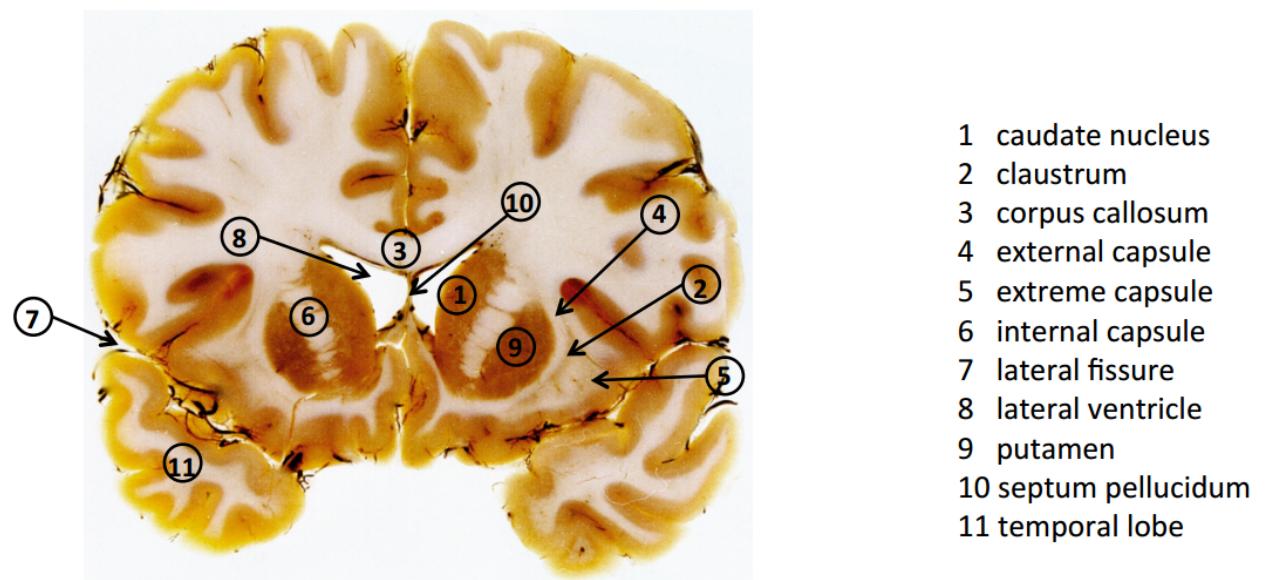
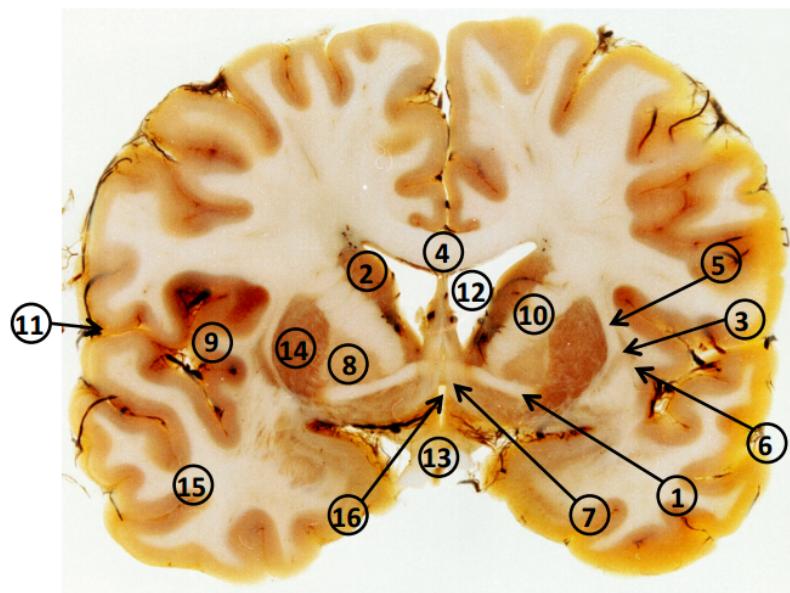


Figure 29: Coronal section I

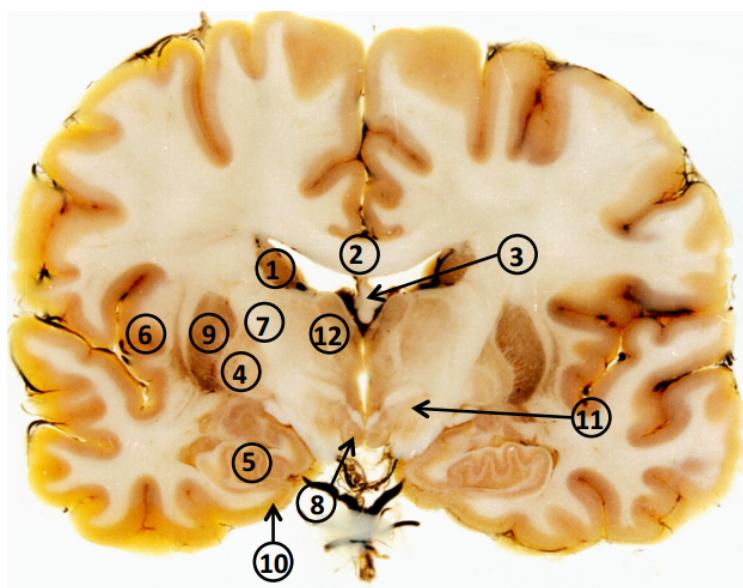
Coronal section - II



- 1 anterior commissure
- 2 caudate nucleus
- 3 claustrum
- 4 corpus callosum
- 5 external capsule
- 6 extreme capsule
- 7 fornix
- 8 globus pallidus
- 9 insula
- 10 internal capsule
- 11 lateral fissure
- 12 lateral ventricle
- 13 optic chiasm
- 14 putamen
- 15 temporal lobe
- 16 3. ventricle

Figure 30: Coronal section II

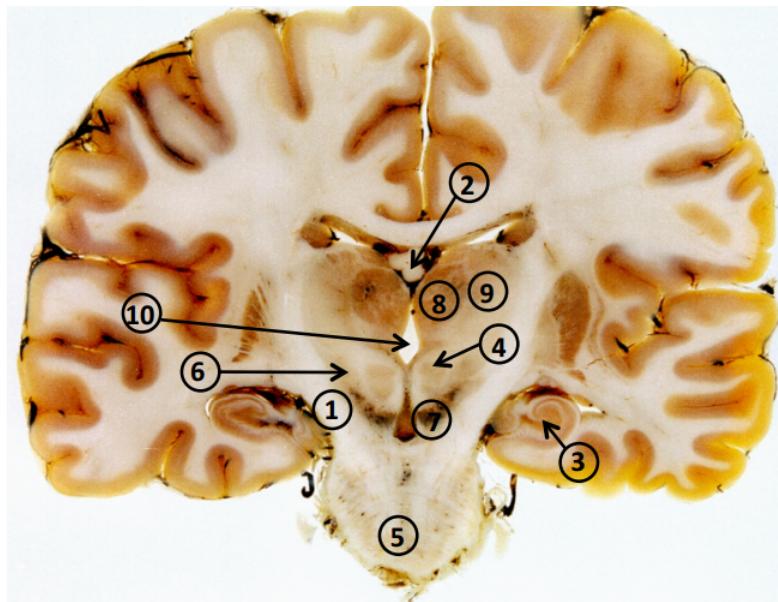
Coronal section - III



- 1 caudate nucleus
- 2 corpus callosum
- 3 fornix
- 4 globus pallidus (GPe, GPi)
- 5 hippocampus
- 6 insula
- 7 internal capsule
- 8 mammillary body
- 9 putamen
- 10 parahippocampal gyrus
- 11 subthalamic nucleus
- 12 thalamus

Figure 31: Coronal section III

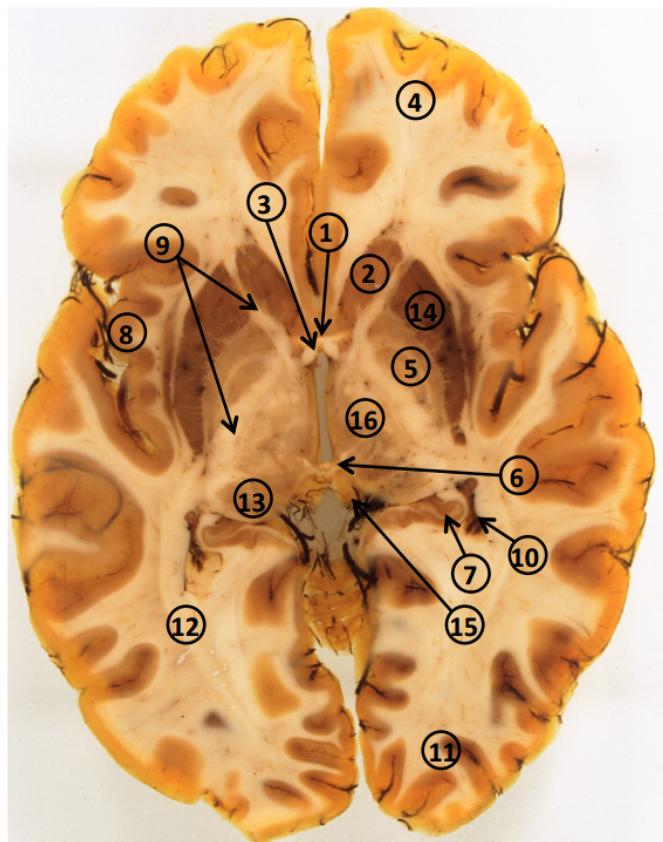
Coronal section - IV



- 1 cerebral peduncle
- 2 fornix
- 3 hippocampus
- 4 red nucleus
- 5 pons
- 6 subthalamic nucleus
- 7 substantia nigra
- 8 thalamus, medial nuclei
- 9 thalamus, lateral nuclei
- 10 3. ventricle

Figure 32: Coronal section IV

Horizontal section



- 1 anterior commissure
- 2 caudate nucleus
- 3 fornix
- 4 frontal lobe
- 5 globus pallidus
- 6 habenula
- 7 hippocampus
- 8 insula
- 9 internal capsule
- 10 lateral ventricle, inferior horn
- 11 occipital lobe
- 12 optic radiation
- 13 pulvinar nuclei (thalamus)
- 14 putamen
- 15 superior colliculus
- 16 thalamus

Figure 33: Horizontal section

Previous Exams

Note this answers were provided by students and were not verified by a teacher. Use them at your own risk.

2016

Q1. Anatomy

Label Coronal section III as in Fig:23.

Another image of the brain to labeling as the first one (top-left) of Fig:4.

Define the parts of the prefrontalcortex in human ans in rats, also describe how they impact in working memory.

Q2. Neurogenesis

Define gradient

Choose an example where gradient are important in neurogenesis. Define how this gradient is read out, ...

Q3. Synapses

Define at least five experiments about the importance of Ca^{2+} for neurotransmission?

What is the flow of the Ca^{2+} in the synapse membrane? How the Ca^{2+} is transported?

more question involving Ca^{2+}

Q4. Excitability

Consider the voltage-clamp experiment of a single channel. The following graph was obtained: image of a linear current-voltage graph. Why the current change when the voltage change?

What is E_{rev} ?

What is single channel conductance (g)?

Why some ion channels allows an specific type of ion going through, for instance, why potassium channel allow only potassium ions to go through?

What is channel inactivity?

You analyse a ALS patient with gPI (?). What do you observe?

Q5. Auditory and Vestibular pathway

Define the cortical and the subcortical areas involved in the ascending auditory pathway, namely the parts where the information cross the midline

How the horizontal spatial localization is calculated in the SOC?

What are the five organs of the vestibular pathway? How they are involved in rotation and linear movements of the head?

Q6. Biological and artificial learning

Consider the experiment: a sound is played before an air puff in the subject eye. In response to the air puff, the subject blinks. After a while, when the sound is played, the subject blinks. In this example, define: CS, US, CR, UR.

Rescola-Wagner: what is the aim of RW rule? What is the formula? In the previous example, what are the weights before and after learning? What are the weights if the air puff occurs only in 50% of the times that the sound is played?

What is the Hebb's postulate? Is the RW rule related with the Hebb's postulate? If yes, explain how.

2013

Q1. 5 methods (advantages + limitations) to label CNS neurons in rodent.

Q2. Label 15 parts on a coronal slice (slice in which you see pons)

Describe how your project is related to some brain parts OR talk about the midbrain and its functional parts (+labelling a drawing of it).

Q3. Chemical + electrical synapses

Q4. A man with the “man who lost his body” documentary problem, how to test for his condition.

Q5. Neurogenesis areas, labelling techniques, positive regulators and diseases associated with problems in neurogenesis.

Q6. Bird auditory neuron behaviors, setup of the experiment with the bird and why is it important that the bird does not hear any external sounds.

2012

Q1. Neuroanatomy

Q2. Somatosensory

Q3. Vision system

Q4. Neural computation

Q5. Brain development: neurogenesis

Q6. Ion channel or synaptic transmission

2011

Q1. Discuss the functions and structures of the hypothalamus as discussed in the lecture material.

Label 18 structures in 2 different coronal slices see exercises.

Q2. Describe how DRG (dorsal root ganglion) sensory neurons development in comparison to motor neurons. How are cell boundaries formed in general and among the specific motor/sensory nerves

Q3. Axon Guidance: what were sperry's findings that support the chemoaffinity hypothesis. What molecules are involved in this and how do they function.

Q4. Describe from how sound is encoded neurally (from entering the ear to being perceived as sound in brain - complete pathway)

Q5. Draw a flowchart for a typical neuroproteomics experiment

Q6. Fill in the blank and multiple choice questions from Tobi's lecture: Who invented the term Neuro Engeneering? What is CMOS? Power consumption of brain. Synchronous logic is ubiquitous slide know physiologists friend photodiodes - how they are similar to retina CARVER MEAD

2010

Q1. Auditory pathway

Q2. Development of CNS and PNS

Q3. Boundary building (one slide, different cell type)

????

Q4. Pathfinding (Chemoaffinity, give 2 examples)

Q5. Anatomy (hypothalamus, position and function)

Q6. Neuromorphic engineering

2009

Q1. Neuroanatomy: which of the 12 cranial nerves origin and/or end in the brainstem? What are their respective sensory, motor and /or vegetative functions ?(please describe in detail) Which nuclei of the cranial nerves are located in the mesencephalon?

Q2. Auditory system: Describe differences between "conductive hearing loss" and "sensorineural hearing loss". Describe the classical test which is often used to determine between both forms of hearing loss. Describe biological causes and current treatments aids for such hearing impairments.

Q3. Proteomics in neuroscience:

a. explain the term "proteome"

b. what are the benefits of measuring the proteome in addition to the genome?

c. Describe what a mass spectrometry is doing in principle.

d. How would you quantify proteins in a proteomic experiment? Please name and describe at least 2 proteomics technologies

e. Why is the proteome more complex compared to genome? Name and describe 3 reasons.

Q4. Ion channels: What are the principal functions of dendrites, axon and nerves endings in the transcription of signals through the nervous system? Which types of ion channels are critical for the function of each of these 3 structures? Provide specific examples.

Q5. Neural network: Explain the temporal and spatial network definition. Give an example for each network definition and describe how you can detect these networks in the brain.

Q6. Neuromorphic engineering: Considering organizing principles used in biological retina explain (...)

2008?

Q1. Describe the diencephalon and its major components according to the text "the brain in a nutshell"

Q2. Compare structure and development of the cerebellum and the cortex

Q3. What evidence did Sperry find that supports his chemoaffinity hypothesis? Have Sperrys proposed "recognition molecules" been found? If yes name one example and describe what properties of this molecules support its role as a recognition molecule

Q4. Describe the structure of a voltage potassium channel. Explain the mechanisms that make the channel selective for only potassium ions.

Q5. Describe three functional properties of neurons in v1 that are absent in the LGN. For each property describe in detail an experiment that illustrates it including the type of stimulus and the observed neural responses. Finally, choose one of these three properties and explain as precisely as possible how it can emerge at the cortical level.

Q6. Which dynamic processes occur in single neuron and the local neural circuit during signal flow through a neural network? Name critical structural and functional aspects and discuss how they can be measured experimentally

2007

Q1. Label each part of the brain, two coronal section, 18 areas.

see exercises.

Describe the lobes of cortex, according to the handout.

Q2. Compare the cell migration to form the cortex and the migration in the peripheral neural system forming...

answer

Q3. About neurotrophic factor. What's the experiment led to the finding of neurotrophic factor? Compare trophic and tropic factor.

answer 1

Q4. What's the difference between ionotropic and metabotropic receptors?

Ionotropic receptors are made from proteins combined to form an ion channel. The neurotransmitter binds the receptor and open the channel for the ions going through. Ionotropic receptor have rapid changes with short duration. Metabotropic receptors are made of a single peptide and the neurotransmitter binds with a g-protein instead of the ion channel directly. It is need a second messenger to open the ion channel. Metabotropic receptors have slower response but with long duration.

Q5. Serotonin

Q6. Insect eye

2006

Q1. Label each part of the brain.

see exercises.

Describe the components of midbrain according to the description in the shells of the brain

Q2. Why the ion channel is selective to a ion with particular polarity, e.g. why the positive channel allows cations going through? List different ion channels in different part of the neuron: (1) axon, (2) axon terminal and (3) postsynaptic membrane

Q3. How does cells differentiate in neural tube? How does cells differentiate in peripheral nervous system?

Q4. What is the structure and function of myelinated nerve in PNS?

Q5. Describe the structure and function of dopaminergic systems, the relation between the systems and psychology and neuropharmacology

Q6. Visual system: describe the two columns in V1, and give out the definitions of them. What is the relation between this two columns and also between them and other part of visual system. Give out one experiment for testing of each column.

2005

Q1. Draw the connectivity between motor cortex, thalamus, basal ganglia and cerebellum for motor control and show which connections are excitatory or inhibitory

Coronal view to fill with 16 names see exercises.

Q2. Model organisms for understanding human brain development and function. Give three general advantages of these models. Compare in a table with advantages and disadvantages the models: Drosophila, C. Elegans, Zebrafish, Mouse. Give an example for each of how it helped understand the brain

Q3. Two main route for cell death, detail differences

Q4. Myelin: structure and function

Q5. What are the two main modes of electrophysiological communication between neurons? Describe structure.

Q6. Vision:

A. cites six roles for vision in insects

B. 1. what structural/functional differences between insect and human eyes 2. in what experiments are insects eyes worse or better than human eyes? 3. five share important features of insect and human eyes

C. 1. what is flow field? 2. draw the flow field perceived by a fly flying straight in a long corridor 3. what is ... field? (i forgot the name oops) 4. draw pure rotation force field and its matched field filter

2004

Some questions (especially number 6) are about subject not taught anymore during the first ZNZ introduction semester, so don't worry about them.

Q1. Describe the major formations involving the hippocampus in the associative cortex.

Coronal slices, 16 areas to be labelled see exercises.

Q2. Structure and role of myelinating cells in the adult nervous system.

Q3. Name some crucial functions of Neurotrophic factors.

Q4. How is information transported in the nervous system? Explain features and function.

Q5. In vertebrates the vision system has some special wiring pattern. What's special about it (as in, how is it different to olfaction)? Explain biological/physiological means in the development of vision.

Q6. Imagine year 2020. Human genomics has advanced to the point where you not only can choose the gender and hair color of your child, but also apply specific changes to the visual system. Name 6 changes to the human visual system you would apply to your kid. Explain why you chose them and what physiological implications they would have.

See Visual System, question 4.

All Question - topics

Here you can find a pull with question of previous exams and questions from self-study (PQ³), that is, questions marked as PQ are not question listed in previous exams.

Cytology

1. What is the structure and function of a myelinated peripheral nerve?

Structure: ???

The myelin in the peripherical nervous system is generated from Schwann cells. Myelin is a fatty substance (composed about 75% of lipids, 20% of proteins and 5% of carbohydrates) that surrounds the axon of some nerve cells, in the PNS, the myelin is formed by many layers of schwann cells membrane. The mainly function of a myelinated nerve is increase action potential conduction, that is, the message is delivered faster when compared with an unmyelinated nerve. The myelin in peripheral nerve also provides a track along with a severed nerve can regrowth. This regeneration do not happens in unmyelinated nerver or in myelinated nerves in CNS.

2. Myelin : structure and function

Structure?

Myelin is a fatty substance (about 75% of lipids, 20% of proteins and 5% of carbohydrates) that surround the axon of some nerve cells. The maily function of the myelin is increase the action potencial conductancy, that is, to make the signal be propagated faster. In CNS the myelin is generated by olygodendrocytes and in the PNS by Schwann cells. In the PNS the myelin helps severed nerves to regrow, and unmyelinated and myelinated from CNS can't regenerate.

3. Structure and role of myelinating cells in the adult nervous system.

Structure? Adult nervous system... this differ anything from previous answers?

4. Serotonin

Serotonin (or 5-HT) is a neurotransmitter. It is popularly thought to be a contributor to feelings of well-being and happiness. The serotonin receptors are metabotropic receptors (that is, they bind with a receptor that will activate a g-protein) but 5-HT3 is a ionotropic receptor. The alteration on serotonin levels can cause some disorders: the decay of serotonin

³PQ stands for personal question

can cause depression, anxiety and even social phobia. However, higher levels of serotonin can cause serotonin syndrome (with confusion, loss of balance, fever etc).

5. Two main route for cell death, detail differences

There are two main ways to programmed cell death: autonomous specification and conditional specification.

- autonomous specification: involves the segregation of cytoplasmic molecules by asymmetric division. This way, cell death is programmed into the lineages that generate somatic cells.
- conditional specification: involves external signals. One example is when the axons do not find the cues to grow or do not make connection with their target. The absence of this connection generates a programmed cell death.

6. Proteomics in neuroscience:

- a. explain the term "proteome"
- b. what are the benefits of measuring the proteome in addition to the genome?
- c. Describe what a mass spectrometry is doing in principle.
- d. How would you quantify proteins in a proteomic experiment? Please name and describe at least 2 proteomics technologies
- e. Why is the proteome more complex compared to genome? Name and describe 3 reasons. ?

Anatomy

1. Label 2 coronal slices, 16/18 areas to be labelled

See exercises: Figures 30 and 33.

2. Label 15 parts on a coronal slice (slice in which you see pons)

See exercises: Figure 32.

3. Describe the major formations involving the hippocampus in the associative cortex.

The hippocampus is located at the medial temporal lobe and it is a structure that resembles a seahorse. The hippocampus is divided in three major parts: the dentate gyrus, the subiculum and the cornu ammonis. The hippocampus is associated with learning and memory. The consolidation of short term memories in long term memories involves the hippocampus. The associative cortex is the cortex part outside the primary areas. It is essential for mental functions that are more complex than basic detection of sensory stimulation. Each sensory (primary) system has its own associative cortex areas. The hippocampus receives input from all the association areas and sends signals back to them as well as other, this way, the hippocampus creates new associations (or learning). The hippocampus associates the current features of the perceived object with other older memories related with the same object. This creates a rich multi modal memory. For instance, the memory of a bird is associated with its sound.

4. Mesencephalon: components & nuclei (brain in a nutshell)

The mesencephalon, also known as midbrain is divided in two major parts: the tectum (roof) and the tegmentum (floor). These two parts are separated by the cerebral aqueduct (a tiny canal that connects the third and fourth ventricle). The tectum is made of the colliculi, which are divided in superior colliculus and inferior colliculus.

- the superior colliculus is responsible for visual and oculomotor reflex
- the inferior colliculus is responsible for sound reflex (relay the auditory tract).

The tegmentum is divided in five structures: reticular formation, red nucleus, substantia nigra, cerebral peduncles and ventral tegmental area.

- reticular formation: is involved in automatic processing of incoming sensations and outgoing motor commands, and helps to maintain consciousness
- red nucleus: is involved in motor coordination (involuntary control of muscle tone and limb posture)
- substantia nigra: is the only part of the brain that contains melanin. Also contains dopaminergic neurons. It is involved in regulation of the basal nuclei activities. It is divided in two parts:

substantia nigra pars compacta: formed by dopaminergic neurons. The degeneration of these neurons cause Parkinson's disease.

substantia nigra pars reticulata: contains most of neurons as inhibitory, that release GABA.

- cerebral peduncles: connect primary motor cortex with motor neurons in brain and spinal cord. Contains the large ascending (sensory) and descending (motor) nerve tracts.

- ventral tegmental area: part of the limbic system, involved in emotional reinforcement, projects to nucleus accumbens and amygdala.

5. Motor activity structures and fibers

Motor neuron: neurons with the nucleus along the spinal cord and brainstem, they send their axons to one muscle and innervate some muscle fibers. All the muscle fibers must be of the same type. Muscle fibers are classified according to contract properties (slow or fast) and metabolic properties (aerobic or anaerobic). There are three types of muscle fibers:

- Type I - fibers with slow twitch and good oxidative (aerobic) metabolism
- Type IIA - fibers with fast twitch and oxidative and both aerobic and anaerobic metabolism: with good resistance to fatigue)
- Type IIB - fibers with fast twitch and anaerobic (glycolysis) metabolism.

An individual muscle is controlled by a pool of motor neurons (varying in portion of motor units). A motor unit is formed by one motor neuron and all related muscle fibers, as the muscle fibers, motor units also are classified in three types:

- Type S - slow twitch, small amount of force produced and high resistance to fatigue
- Type FR - fast twitch, moderate force produced and relative resistance to fatigue
- Type FF - fast twitch, higher force produced and fatigue quickly

Each type of motor unit is related with a muscle fiber type, so, Type S motor unit is associated with Type I muscle fibers, the Type FR with Type IIA and Type FF with Type IIB.

The pool of motor neurons forms an elongated column that extends over two or three segments, and they can be of three types: α , β and γ . α motor neuron innervates skeletal muscle fibers, γ motor neuron innervates muscle spindles and β motor neuron innervates both types.

6. Output structures and structures modulating output

???

7. Draw the connectivity between motor cortex, thalamus, basal ganglia and cerebellum for motor control and show which connections are excitatory or inhibitory
8. Describe the diencephalon and its major components according to the text "the brain in a nutshell"

The diencephalon is divided in four major parts:

- thalamus: is the gatekeeper of the brain, that is, is important for the transfer of information from the periphery to sensory processing regions in the telencephalon. It determines whether sensory information reaches conscious awareness in the neocortex. It participates in the integration of motor information from the cerebellum and basal ganglia to cerebral areas concerned with movement.

TODO: explain thalamus

- hypothalamus: regulates behaviors essential for homeostasis and reproduction: growth, eating, drinking and maternal behaviour by regulating hormonal secretions from pituitary gland. It is an important control center for the autonomic nervous and stress-response system.
- epithalamus: epithelial roof of the third ventricle. It is responsible for regulation of day-night cycles and information processing related to olfaction.
- subthalamus: it is continuation of the tegmentum, functionally part of the basal ganglia.

9. Discuss the functions and structures of the hypothalamus as discussed in the lecture material.

The hypothalamus is located under the thalamus and above the pituitary gland and the brain stem. It contains important collection of nuclei and is about the size of an almond and it is part of the limbic system. The hypothalamus is mainly responsible for homeostasis of the body and for production of many essential hormones. The hypothalamus produces releasing and inhibitory hormones that influence anterior pituitary hormone secretion. It produces oxytocin and antidiuretic hormones that are stored in the posterior pituitary. Besides that, the hypothalamus oversees the autonomic neural system, helping to stimulate the adrenal medulla via sympathetic innervation.

10. Anatomy (hypothalamus, position and function)

see question 9

11. Which of the 12 cranial nerves origin and/or end in the brainstem? What are their respective sensory, motor and /or vegetative⁴ functions? (please describe in detail). Which nuclei of the cranial nerves are located in the mesencephalon?

The Autonomic Nervous System (ANS) is comprised of both sensory and motor components, which involuntarily tend to homeostasis. Autonomic sensory neurons transmit information to the CNS, via autonomic sensory receptors which are primarily situated, in the visceral organs (smooth muscle organs in the thorax, abdomen, and pelvis). The Sensory Nervous

⁴out-of-date term for the autonomic nervous system

System (SNS) consists of somatic sensory neurons, which transmit stimuli from the sensory receptors in the skin, skeletal muscles, joints, and the special senses, to the CNS. In parallel, SNS motor neurons, called somatic motor neurons, voluntarily convey information from the CNS to the skeletal muscles.

Autonomic motor neurons can be subcategorized to sympathetic and parasympathetic classes, which typically induce opposing effects. The two neurons types convey information from the CNS to smooth muscle, cardiac muscle, and glands, leading to muscle contraction and inducing glandular activity. The sympathetic autonomic motor neurons support exercise or emergency responses, "fight-or-flight" responses, while the parasympathetic division regulates "rest-and-digest" activities. The Enteric Nervous System spans the entire length of the gastrointestinal tract (GIT) and is comprised of over 100 million neurons, which include both sensory and motor components, whose function is involuntary and CNS-independent. The ENS sensory neurons monitor both chemical and mechanical modifications within the GIT, while the motor neurons control GIT smooth muscle contraction, underlying passage of food through the GIT. These neurons are also responsible for regulating gastric acid secretion and secretion of endocrine cell-derived hormones.

12. **Describe the lobes of cortex, according to the handout.**

There are five lobes in the cortex: frontal lobe, parietal lobe, occipital lobe, temporal lobe and limbic lobe.

- frontal lobe: it is located in the frontal part of the brain, before the parietal lobe and above temporal lobe. The frontal lobe is separated from the parietal lobe by central sulcus and from temporal lobe by lateral fissure. The frontal lobe contains the primary motor cortex responsible for movements of the body parts, also the frontal lobe is responsible for thinking, planning, etc.
- parietal lobe: it is located above the temporal lobe and between frontal and occipital lobes. The parietal lobe contains the somatic area, responsible for sensations and perception.
- occipital lobe: is the visual processing center of the brain, contains the primary visual cortex.
- temporal lobe: receive and interprets auditory information. It is responsible for memory and understanding/comprehension of language.
- limbic lobe: is localized in the medial surface of each hemisphere (parts with the frontal, parietal and temporal lobes). Initially, its localization consider the cingulate gyrus and the parahippocampal gyrus. However, the limbic lobe can include more or less structures (it is not totally defined yet). It is a higher neural center that coordinate emotions.

- 13. Describe the structure and function of dopaminergic systems, the relation between the systems and psychology and neuropharmacology**
- 14. Describe how your project is related to some brain parts OR talk about the midbrain and its functional parts (+labelling a drawing of it).**

Midbrains is also called mesencephalon. Please, check question 4

15. PQ - Hindbrain: components

The hindbrain is also called rhombencephalon. It can be divided in two major parts: myelencephalon and metencephalon. The myelencephalon forms the medulla oblongata, and the metencephalon forms the pons and cerebellum.

- cerebellum: the human cerebellum does not initiate motor functions but it is related to coordination, precision and accurate timing. The cerebellum receives sensory information and integrates these input to fine tuning of the motor activity.

16. PQ - Brainstem: components

The brainstem is located at the base of the brain superior to the spinal cord. In the human brain includes the midbrain (see parts in question 4), pons and medulla. The brainstem provides the main motor and sensory innervation to the face and neck: of the twelve cranial nerves, ten originates at the brainstem

- pons: located between the medulla oblongata and the midbrain. It contains tracts that carry signals from the cerebrum to medulla and to the cerebellum.
- medulla (or medulla oblongata): is located in the lowest part of the brainstem. It transmits signals between the spinal cord and the higher parts of the brain.

Development

1. Name some crucial functions of Neurotrophic factors.

Neurotrophic factors are a family of biomolecules that support the growth, survival and differentiation of developing and mature cells.

2. How do different types of neurons differentiate in the neural tube?

See question 10

3. How do different types of neurons differentiate in the periphery?

TODO

4. Example for migration

TODO

5. Compare in a table with advantages and disadvantages the models: Drosophila, C. Elegans, Zebrafish, Mouse. Give an example for each of how it helped understand the brain

TODO

6. Compare structure and development of the cerebellum and the cortex

TODO

7. What evidence did Sperry find that supports his chemoaffinity hypothesis?

The chemoaffinity hypothesis suggests that neurons make connections with their targets based on interactions with specific molecular markers. Sperry did the follow experiment: detached a frog eye, rotated it by 180 degrees, and then putted it back. When the axons rewired, the vision was rotated by 180 degrees. So, he create a hypothesis that there is a molecular tagging the axon grow.

8. Have Sperry's proposed recognition molecules been found? If yes, name one example and describe what properties of this molecule supports it's role as a recognition molecule.

Yes, one example of the molecule is the Ephrin. To find this, one experiment was organized: posterior or anterior retinal explants were presented with alternating lanes, or stripes, of membrane derived from the anterior and posterior tectum. They found that posterior axons avoided membranes form the posterior tectum, while anterior axons showed no preference for either. So, they conclude this behaviour should be related with a high concentration of repulsive substance in the posterior of the tectum. The EphrinA is found in a high concentration in posterior and low concentration in anterior of the tectum while EphA is found in a high concentration in anterior and low concentration in posterior of the retina.

9. What were Sperry's findings that support the chemoaffinity hypothesis. What molecules are involved in this and how do they function.

See question 8

10. Development of CNS and PNS

Neural induction is the earliest step in the determination of ectodermal fates. The BMP (bone morphogenic protein) act as a signal of epidermal induction, and this give rise to the default model of neural induction. The default model of neural induction says that ectodermal cells will become neural as long as they are not exposed to antineurulating signals. The formation of the brain starts with a process called neurulation. The neurulation is a formation of a hollow tube (neural tube) from a flat sheet of cells (neural plate). The neural tube will form the CNS, and some neural crest cells detach during the neurulation to form the PNS.

After the neural tube is formed, the developing nervous system cells rapidly increase in number and three bulges appear at the anterior end of the neural tube and become the forebrain, midbrain, and hindbrain. Cell division occurs in the ventricular zone of the neural tube (the zone next to the ventricle); when they leave the cell division cycle, cells migrate into other layers. The cells of the neocortex migrate in an inside-out pattern; the deepest layers form first so that the cells of the superficial layers must migrate through them. Migration of the cells of the neural crest is of particular interest because these cells ultimately form the PNS, and thus many have a long way to migrate. Neural crest cells transplanted to a new part of the neural crest migrate to the destination that is appropriate for cells in the new location; thus the migration routes must be encoded in the medium rather than in the cells; differential adhesion to routes through the medium is hypothesized to guide the migration of future PNS neurons. Once migration is complete, cells must aggregate correctly to form various neural structures; this is hypothesized to be mediated by specialized neural cell adhesion molecules in the cell membranes.

In the neural tube, the differentiation in diverse parts of the brain is guided by hox genes. The type and concentration of hox genes will become a specific part of the CNS. The change in this concentration or hox genes type, for instance, to have two equal concentrations and types in different places will give origin for the same part in different locations. The notochord in the floor plate give origin to the motor neuron cells. Additional notochord will create new motor neuron cells and the removal of the notochord will generate no motor neurons.

From roof to plate the concentration of BMP decreases. From plate to roof the concentration of SHH decreases, and this gradient of concentrations will determine the cell fate.

11. Pathfinding (Chemoaffinity, give 2 examples)

TODO

12. Compare the cell migration to form the cortex and the migration in the peripheral neural system forming... .

TODO

13. What's the experiment led to the finding of neurotrophic factor? Compare trophic and tropic factor.

Experiment: TODO

Tropic molecules guide growing axons toward a source and trophic molecules support the survival and growth of neurons and their processes once an appropriate target has been contacted.

14. How does cells differentiate in neural tube? How does cells differentiate in peripheral nervous system?

TODO

15. Neurogenesis areas, labelling techniques, positive regulators and diseases associated with problems in neurogenesis.

In adults, neurogenesis occurs in two areas: SVZ (subventricular zone - olfactory bulb) and SGZ (subgranular zone - dentate gyrus - hippocampus). To map the neurogenesis we can use labelling techniques as retroviruses labeling and BrdU labeling. Both techniques can be used to cell lineage mapping and counting. The major advantage of the BrdU labeling is its sensitivity to detecting proliferating cells, however some conditions like inflammation may lead to a different number of counting cells. The major advantage of retroviruses labeling is its infect the entire cell, allowing to picture morphological characteristics, however, the injection of the retroviruses causes brain injuries. In adults, there are some factors that regulates the neurogenesis. Some of positive regulators (that is, increasing the neurogenesis) are running (exercises in free will) and rich environment. In the other hand, negative regulators (decreasing the neurogenesis) are stress, depression, drugs, aging etc. The decreasing on neurogenesis cause spatial-memory and pattern-separation problems. Some diseases associated with problems in neurogenesis are Parkinson, Alzheimer and Huntington.

16. 5 methods (advantages + limitations) to label CNS neurons in rodent.

TODO

17. PQ - What are neural stem cells?

Neural stem cells are cells that can selfrenew (maintenance and expansion). They can give rise to neurons and glia cells.

18. PQ - How can adult neural stem cells be studied?

We can study adult neural stem cells to observe how the cell divide and labelling them, with retroviruses labelling for instance. Another way is promote the ablation of the neurogenesis. There are some ways to ablate neurogenesis: irradiation, transgenic mice or local cell ablation.

19. PQ - What influences Adult Neural Stem cells / Neurogenesis?

In adults, the neurogenesis can be regulated by factors such as voluntary exercise (running), enriched environment that increases neurogenesis or aging, stress, depression, drugs that decrease neurogenesis.

20. PQ - What is the functional contribution of adult neural stem cells?

There are some controversial results about the reason of neurogenesis in adults. The main (probably) functions are learning (hippocampus and olfactory bulb), working memory and pattern separation (where two similar inputs are transformed into less similar inputs).

21. PQ - Does adult neurogenesis occur in humans?

Yes. However, there are just two areas where the adult neurogenesis occurs: SVZ (sub ventricular zone - olfactory bulb) and SGZ (sub granular zone - part of dentate gyrus of the hippocampus).

22. PQ - What is a hope for degenerative diseases?

Therapy with neural stem cell transplantation. Neural stem cells can generate other type of cell and maybe regenerate some degenerated cells.

23. PQ - How do axons move (mechanically)? Reorganization of microtubules in the growth cone how do axons navigate?

The axons move using the growth cone, that "looks" in the external environment for signals indicating the direction to grow. These signals are cues that can be attractive or repellent (and range in short or long length). The growth cones contain receptors that recognize

these cues and interpret the signal as a chemotropic response. Some relation between receptor and cues (ligand) are:

DCC and UNC → Netrins → attractive for DCC and repulsive for UNC

Plexins → Semaphorins → repulsive

Robo → Slits → repulsive

Eph → Ephrin → repulsive

24. PQ - How to study basic principles of axonal pathfinding?

One way to study the axon pathfinding is direct manipulation of growth axons exposing them to purified guided cues to see if they will cause the axon to turn or not. One experiment used to check the axonal pathfinding is the stripe choice experiment, where we can see axons growing to specific regions instead of others.

25. PQ - Define the terms: sleep homeostasis, circadian rhythm. Explain the physiological markers of each of these processes and describe their relevance and meaning.

- sleep homeostasis: Homeostasis refers to regulatory mechanisms that maintain the constancy of the physiology of organisms. Sleep has a regulatory system enabling organisms to compensate for the loss of sleep (e.g. due to sleep deprivation) or surplus sleep (e.g by prolonging sleep in the morning or by napping). Physiological markers is the sleep intensity. The homeostatic mechanism regulates sleep intensity (that increases according to how long it is awake), while the circadian clock regulates the timing of sleep.
- circadian rhythm: Repetitive event with a period length of about one day. the physiological markers (in humans): melatonin secretion by the pineal gland.

Ion Channel

1. Why is the ion channel selective to an ion with particular polarity, e.g. why the positive channel allows cations going through? List different ion channels in different part of the neuron: (1) axon, (2) axon terminal and (3) postsynaptic membrane

Why: ???

Ion channels are selectively permeable, that is, allow some types of ions going through. The selectivity usually uses the size and the charge of the ions.

- Axon ion channels: ion channels on axon are used to propagate the action potential. In unmyelinated axons, the action potential is propagated smoothly, however, in

myelinated axon, there are ion channels only at nodes of ranvier, this way the action potential "jump" between nodes, and then is propagated faster.

- Axon terminal ion channels: are the autoreceptors. Sometimes, the presynaptic cell release the neurotransmitters and they also bind with the ion channels on the presynaptic cell. This generates a feedback to the presynaptic cell.
 - Postsynaptic membrane ion channel: are the receptors. When the neurotransmitters are released on the synaptic cleft, they bind with the receptors (ion channels or g-proteins) and allow ions to cross the membrane.
- 2. Describe the structure of a voltage-gated potassium channel. Explain the mechanisms that make the channel selective for only potassium ions.**
- A voltage-gate channel is a channel sensitive to the voltage gradient across the membrane. The voltage-gate potassium channel are selective for ions with the same charge and size of K⁺. The pore of potassium channel is negatively charged, attracting positive potassium. The channel has a "filter" which is size-specific for potassium.
- 3. Draw a flowchart for a typical neuroproteomics experiment**

TODO

- 4. What are the principal functions of dendrites, axon and nerves endings in the transcription of signals through the nervous system? Which types of ion channels are critical for the function of each of these 3 structures? Provide specific examples.**
- dendrites: contains voltage-gated ion channels, dendritic spikes have great implications in learning, memory and neuronal communication. They are often major factors of LTP.
 - axon: also contains voltage-gated ion channels, axon spikes occurs when the EPSP or IPSP (that are summed up in axon hillock) exceeds the trigger threshold and then, the action potential propagates through the axon,
 - nerve endings: ??
- 5. What's the difference between ionotropic and metabotropic receptors?**

Both ionotropic and metabotropic receptors are transmembrane. Ionotropic receptors are made from proteins combined to form an ion channel. The neurotransmitter binds the receptor and opens the channel for the ions going through. Ionotropic receptor have rapid changes with short duration. Metabotropic receptors are made of a single peptide and the

neurotransmitter binds the receptor that activates a g-protein. It is need a second messenger to open the ion channel, one example of second messenger is calcium. Metabotropic receptors have slower response but with long duration.

6. Structural selectivity feature allowing cationic channel to conduct positive but not negative ions

TODO

Synaptic Transmission

1. How is information transported in the nervous system? Explain features and function.

The information is transported either along a single neuron or between neurons. Along a single neuron with an action potential and between two neurons through synapses (chemical or electrical). In chemical transmission, the presynaptic cell release vesicles that contains neurotransmitters in the synaptic cleft. Then, these neurotransmitters bind the receptors on the postsynaptic cell. The signal generated on the postsynaptic cell can be excitatory or inhibitory. If the signal is strong enough, the postsynaptic cell fires passing the information on.

2. Transmission of neuronal signals: list ion channels critical for i) Axons ii) Dendrites (difference excitatory, inhibitory) and iii) Nerve Terminals

- Axons: ion channels on axon are used to propagate the action potential. In unmyelinated axons, the action potential is propagated smoothly, however, in myelinated axon, there are ion channels only at nodes of ranvier, this way the action potential "jump" between nodes, and then is propagated faster.
- dendrites: ion channel on dendrites are the receptors. When the neurotransmitters are released on the synaptic cleft, they bind with the receptors (ion channels or g-proteins) and allow ions to cross the membrane. The signal generated on the receptor cell can be excitatory or inhibitory. If the signal is strong enough, the postsynaptic cell fires passing the information on.
- Nerve terminal ion channels: are the autoreceptors. Sometimes, the presynaptic cell release the neurotransmitters and they also bind with the ion channels on the presynaptic cell. This generates a feedback to the presynaptic cell.

3. Function of AP (action potential), resting potential, synaptic potential, channels for all these potentials

- action potential: electrical signal produced on axon to boost the information flow in the neuron. Main function is make the information going through the axon, once the neuron is not naturally a good electrical conductor.
- resting potential: is the point of equilibrium wrt the ions to which the membrane is permeable. If the membrane is permeable just to one ion, then the resting potential will be equal to equilibrium potential for this ion. If the membrane is permeable to more than one ion, the resting potential is a value between all the individual equilibrium potential. The main function of the resting potential is to be a threshold who indicates when a neuron fires or not.
- synaptic potential: electrical signal associated with communication between neurons. The main function of the synaptic potential is to allow transmission of information from one neuron to another.

4. What are the two main modes of electrophysiological communication between neurons? Describe structure.

The two main modes of communication between neurons are chemical and electrical.

- chemical: this kind of communication occurs through synaptic clefts. This communication is a sequential communication: when the information arrives at the axon terminals, the vesicles merge with the membrane and release neurotransmitters. These neurotransmitters will bind the receptors on the postsynaptic cell to allow the information to flow. The action potential is generated because of the ion movement. The membrane usually has a resting potential around -70mV (it is said polarized). When the membrane is polarized, the ion channels are closed and there is no ion movement. When the receptor binds, the channels open and the ions move, depolarizing the cell. If the depolarization reaches a threshold, the action potential is initiated by complete depolarization. After the spike, the ion channels close and the membrane initiates the repolarization. The output of a chemical communication is the release of neurotransmitters.
- electrical: electrical communication occurs through gap junctions. In the gap junctions, neurons fire together. Electrical communication is faster than chemical communication (usually found on the need of really fast responses, as on defensive reflexes), however, electrical communication lacks gain, that is, the action potential of the post-synaptic cell is equal or less than the action potential of the pre-synaptic cell. One difference between the chemical and electrical communication is that electrical does not need a receptor to recognize chemical messages. The output of an electrical communication is the electrical signal itself.

A good material to better understand the communication between neurons is this [site](#).

5. Chemical + electrical synapses

see question 4

Auditory System

1. Describe how sound is encoded neurally (from entering the ear to being perceived as sound in brain - complete pathway)

The sound generates variation in air pressure that enter the external and the middle ear. Then, the middle ear amplifies the vibration to send to the inner ear because the inner ear is filled with fluid. After that, the hair cells in the cochlea transduce the sound waves in neural signals. In the cochlea the complex sounds are also decomposed into simple elements. After that, the signal reaches the auditory nerve fibers that branches and enters the CNS through the cochlear nucleus. After the cochlear nucleus, the signal enters the superior olivary complex. In the superior olivary complex (medial superior complex, lateral superior complex and medial nucleus trapezoid body) the signal from both ears meet together, this way, in the MSO it is computed the interaural time difference (the MSO cells work as a coincident detector, responding when the signal from both ears arrive together) and in the LSO it is computed the interaural level difference (intensity). The medial nucleus trapezoid body send inhibitory signals to the LSO, this way, the input from LSO are excitatory ipsilateral signals and inhibitory contralateral signals. After that, the signals enter the inferior colliculus, where the input is the ITD and ILD together with the tonotopic map, tuning the spatial location, then goes to the medial geniculate body (thalamus) where the tonotopic map is preserved in the ventral nucleus of MGB and finally, arrive in the auditory cortex. The auditory cortex is divided in core(primary), belt (secondary) and parabelt (higher level). In the primary, we can find a tonotopic map. This pathway is shown in Figure 34.

When the hair cells bend in direction of the tallest cilium transduction open K⁺ channels and depolarization occurs, so, Ca²⁺ voltage-gate channels open and the transmitters are released onto the auditory nerve.

The primary auditory cortex is located in the superior temporal gyrus and has a precise tonotopic map (representation of the sound frequency). The dorsal stream is responsible for spatial sound processing (where) and the ventral stream for sound identification (what).

The descending pathway for the auditory system is used to minimize damage to loud sounds, setting cochlear gain and as a negative feedback, inhibiting some signals, reducing noise.

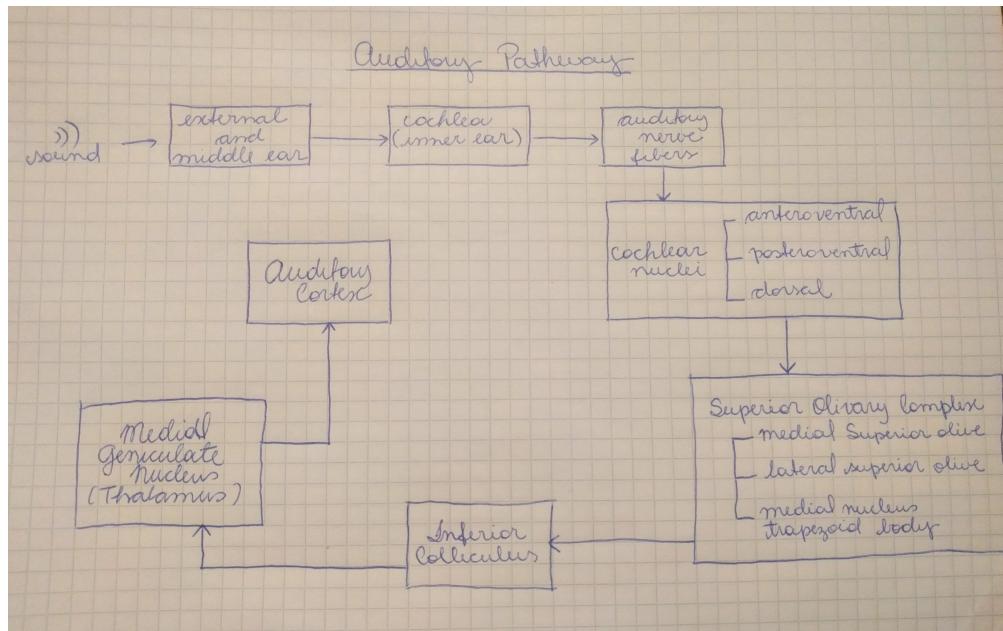


Figure 34: Auditory pathway

2. Auditory pathway

see question 1

3. **Describe differences between "conductive hearing loss" and "sensorineural hearing loss". Describe the classical test which is often used to determine between both forms of hearing loss. Describe biological causes and current treatments aids for such hearing impairments.**

- Conductive hearing loss: involve damage to the external or middle ear, can be caused, for example, by occlusion of the ear canal by wax or external objects, rupture of tympanic membrane. The effect of this loss is the sound seems faint.
- Sensorineural hearing loss: involve damage to the inner ear, mostly typically the hair cells or the 8th nerve itself. Usually, this damage is caused by a congenital factor or environmental insults that leads to cell death.

A classical test to distinguish between these two forms of hearing loss is the Weber test. This test can be conducted if we previously know which ear has a injury. With a vibrating fork localized in the middle of the both ears, the patient is asked to say which ear the sound is louder. In a patient without loss, the sound will be identified as the same level in both sides. If the patient report the sound louder in the damaged ear, it is the conductive hearing loss case. However if the patient reports the sound is better in the good ear, than it is the sensorineural hearing loss case. This happens because in the conductive loss, the sound do

not dissipate freely and then a great amount of sound is transmitted to the cochlea, while in the sensorineural hearing loss the vibration of the sound is not transduced into a neural signal.

4. **Bird auditory neuron behaviors, setup of the experiment with the bird and why is it important that the bird does not hear any external sounds.**

Sensory-Motor System

1. **Describe how DRG (dorsal root ganglion) sensory neurons development in comparison to motor neurons. How are cell boundaries formed in general and among the specific motor/sensory nerves**
2. **Sensory inputs contribute to the production of locomotor patterns in three important ways. Identify these functions and illustrate them by means of clear examples.**
3. **PQ - Motor pathway**
4. **PQ - Sensory pathway**
5. **PQ - Basal ganglia loops**
6. **PQ - Direct and indirect pathways of basal ganglia**

Visual System

1. **Describe the two columns in V1, and give out the definitions of them. What is the relation between this two columns and also between them and other parts of visual system. give out one experiment for testing of each column.**

In V1 we find two kind of columns: the orientation column and the ocular dominance column.

- orientation column: areas that selectively respond to specific orientation in the visual field. Experiment: present stimuli for an animal using different orientations, using a video camera record changes in light absorption. For each orientation stimuli use a color to combine all the recorded images. The combination will present a pattern as a pinwheel.

- ocular dominance column: (also called ocular preference), some areas that are selective for one eye only. Experiment: close only the right eye from the animal and present stimuli to the left eye. Using a sensitive video camera record changes in light absorption that occur as the animal views the stimuli. After, close only the left eye of the animal and repeat the process. The difference between the two recorded images will appear with a stripped-shape, showing the ocular dominance.

The relation between the two columns is determined by the organization of the visual cortex. If you move the electrode tangentially through the cortex, you will find the ocular dominance column. However, if you move the electrode tangentially in the orthogonal direction you will find the orientation dominance.

Relation with other areas: ???

2. **Describe three functional properties of neurons in area V1 that are absent in the Lateral Geniculate Nucleus. For each property describe in detail an experiment that illustrates it, including the type of stimulus and the observed neuronal responses. Finally, choose one these three properties and explain as precisely as possible how it can emerge at the cortical level.**

- binocular depth (stereopsis): in the V1 area, neurons have information about both eyes together, this way, they can be sensitive to the depth wrt the fixation point. Experiment: fix your finger in front of your eyes (with a distance about 10 centimeters). In an alternated way, open and close each eye (right eye closed and left open and vice-versa). You will see your finger in different positions. However, with both eyes open you see just one image.
- orientation: Some V1 neurons are orientation selective - they respond strongly to lines, bars, or edges of a particular orientation (e.g., vertical). Experiment: an animal is fitted to focus the eyes on a screen, where oriented images will be projected. An extracellular electrode records the neuronal responses. We will see that some neurons will respond strongly for lines/bar/edges in specific orientation and will respond weakly (or even not respond at all) to other orientations.
- direction (motion): Some V1 neurons are direction selective - they respond strongly to oriented lines/bars/edges moving in a preferred direction (e.g., vertical lines moving to the right). Experiment: the same experiment can be applied for direction. However, the oriented line/bar/edge will move for an specific direction this time. We will see that some neurons will respond strongly for lines/bar/edges moving in a specific direction and will respond weakly (or even not respond at all) to other directions.

How binocularity emerge at the cortical level: each eye see the world from a slightly different point of view, so, objects that are before or after the fixation point are projected to noncorresponding points on the retinas. There are some neurons in V1 area that are maximally activated when the stimulus fall on noncorresponding points on the retina. They

are the near cells and the far cells. The near cells discharge to disparities in front of the fixation point and the far cells discharge to disparities beyond the fixation point. The combination of these neurons contribute to the depth sensation.

3. **In vertebrates the vision system has some special wiring pattern. What's special about it (as in, how is it different to olfaction)? Explain biological/physiological means in the development of vision.**

In visual system, there is a topographic map on the cortex (the spatial arrangement in the retina is preserved in the primary visual cortex). This way, the image observed for the retina is mapped into the cortex in the same way. But the left hemisphere maps the image from the right retina and vice versa. In the visual cortex we have a map of location of the sensory stimulus as well as a quality of the stimulus. For the olfaction, a spatial map is not necessary, so, the map on olfactory system is regarding the quality of an odorant stimulus

4. **Imagine year 2020. Human genomics has advanced to the point where you not only can choose the gender and hair color of your child, but also apply specific changes to the visual system. Name 6 changes to the human visual system you would apply to your kid. Explain why you chose them and what physiological implications they would have.**

- add new subtype of cones to see other wavelength (much more colors and even infrared)
- change the way how the ganglion axons exits retina, to avoid a blind spot.
- add other subtypes of rod (to add color), this way, with low light the color will be still present.
-
-
-

5. **Insect eye**

6. **Vision:**

- A. cites six roles for vision in insects**

- B. 1. what structural/functional differences between insect and human eyes**
 - 2. in what experiments are insects eyes worse or better than human eyes? 3. five share important features of insect and human eyes**

C. 1. what is flow field? 2. draw the flow field perceived by a fly flying straight in a long corridor 3. what is ... field? (i forgot the name oops) 4. draw pure rotation force field and its matched field filter TODO

7. PQ - Visual System pathway

The image (visual field) is inverted and reversed in the retinal image. The retina is a neural portion of the eye, contains five type of neurons:

- photoreceptors: do not exhibit action potentials, light activation causes a graded change in membrane potential and a corresponding change in the rate of transmitter release. Action potential are not necessary to transmit information over so short distance. They do phototransduction.
 - rhods: scotopic vision, low light
 - cones: photopic vision, more light. Three types: Short (Blue), Medium (G) and Long (R) wavelets.
- bipolar cells
- ganglion cells
- horizontal cells
- amacrine cells

Phototransduction: the light in a photoreceptor causes hyperpolarization. Transmitter release from synaptic of photoreceptor is dependent on voltage-sensitive Ca^{2+} channels. When it is dark, the Ca^{2+} channels open and the Ca^{2+} enters the membrane, increasing the number of transmitters released. When there is light, the Ca^{2+} channels open but the Ca^{2+} exits the membrane, decreasing the number of transmitters released.

The axons of the retina ganglion cells form the optic nerve and go straight to the optic chiasm. In the optic chiasm, the nasal axons cross the midline and together with the temporal axons form the optical tract (with fibers of both eyes). Here, the fibers take different branches:

- to the lateral geniculate nucleus (thalamus), that is composed of six layers⁵.
- to superior colliculus: head and eye movements to visual targets
- to pretectum: pupillary light reflex

From the Lateral Geniculate Nucleus, the signal flows to the optic radiation (internal capsule) and then to the Primary Visual Cortex. Figure 35 represent this flow.

⁵2 layers are of magnocellular - large neurons, and 4 are of parvocellular - small neurons. The layers are in the following order: contralateral-nasal, ipsilateral-temporal, ipsilateral-temporal, contralateral-nasal, ipsilateral-temporal, contralateral-nasal

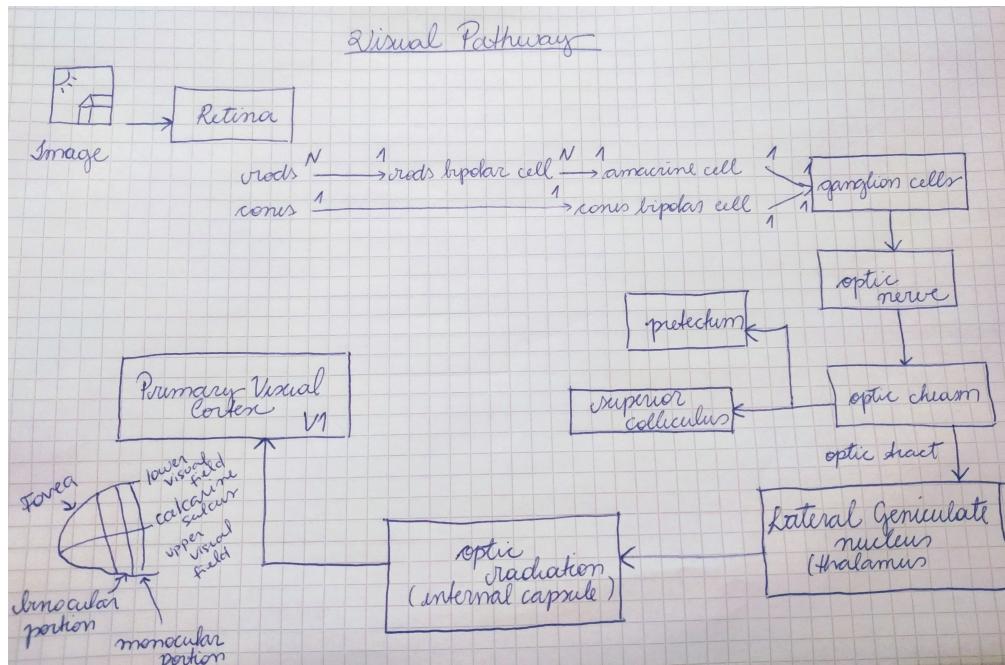


Figure 35: Visual pathway

Vestibular System

1. PQ - Vestibular System pathway

Four main functions of vestibular system:

- perception of self motion
- head position
- spatial orientation (relative to gravity)
- motor function: stabilization of eyes, head and posture.

Five organs:

- Semicircular organs: related with rotation and acceleration of the head
 - horizontal canal
 - anterior canal
 - posterior canal
- Otolith organs: related with linear acceleration of the head/static head positions
 - utricle: hair cells organized in different directions, but towards the striola
 - saccule: hair cells organized in different directions but outwards the striola

The pair of semicircular organs are organized as: the two horizontal canals and the anterior ipsilateral canal with the posterior contralateral canal and the anterior contralateral canal with the posterior ipsilateral canal.

The hair cells are located at utricle, saccule and ampulla (in the ampulla, the hair cells are all polarized to the same direction). When the head (or body) movements, the hair cells in the vestibular organs can be activated (depolarized), and then they send a signal to the vestibular nerve. The superior vestibular nerve receives input from horizontal canal, anterior canal and utricle. The inferior vestibular nerve receives input from posterior canal and saccule. So, the signal is sent to vestibular nuclei and then to the thalamus (vestibular posterior nuclei complex), where they can project to primary somatosensory cortex or to an area between somatic sensory cortex and motor cortex. Figure 36 shows a simplified flow.

There are three reflexes of the vestibular system:

- vestibulo-ocular reflex: maintain equilibrium and eye fixed during head movements.
 - head rotation: the movements of the eyes are in two phases: slow (until the limit of orbital range) and fast: jump movement for a new position.
 - head translation (linear movements): near objects move fast, far objects move slow
 - head movement in the vertical plane: orientation relative to the gravity
- vestibulo-cervical reflex: maintain posture
- vestibulo-spinal reflex: maintain muscle tone

balance is the product of vestibular, vision and proprioception inputs.

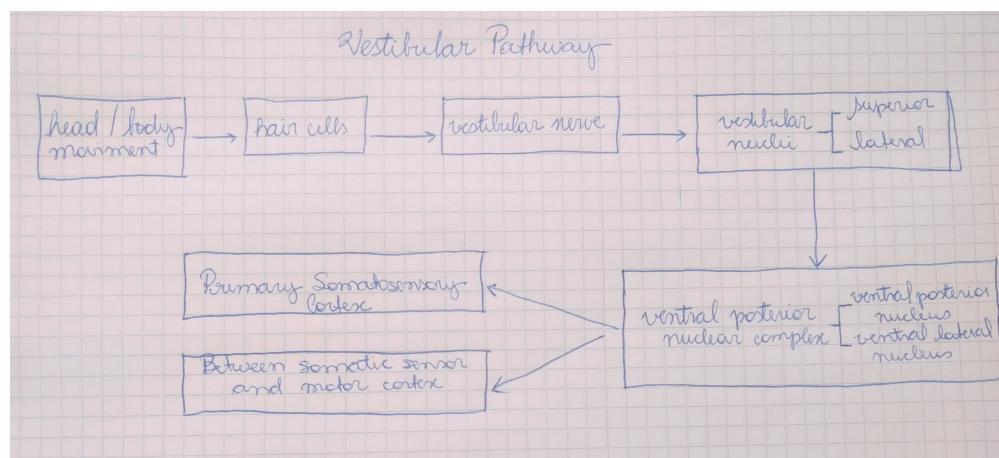


Figure 36: Vestibular pathway

Learning and Memory

1. Everything about declarative and nondeclarative memory:

A lot of behaviors come from learning. Learning is acquisition of knowledge or skills through experience. The long term memory is divided in two parts: declarative and non declarative memory.

a. short definitions

- declarative memory (or explicit memory): is the memory based in facts and events. Involves conscious recollection, like remember the time of an appointment.
- nondeclarative memory (or implicit memory): is used unconsciously and can affect thoughts and behaviors. It is divided in four major parts:
 - priming memory: is the memory of recent things (we tend to believe in recent acquisition more truthly).
 - procedural memory: is our skills and habits, we access everyday to make our way to work or to lace a shoe, for instance.
 - associative memory: is subdivided in endronal and skeletal.
 - endronal associative memory: related with remember the face of a friend when we hear his/her voice.
 - skeletal associative memory: related with an action, as when you salivate when you see your favorite food.
 - The nonassociative memory: is subdivided in habituation and sensitization
 - habituation: decrease of response to a repetitive stimulus, when you do not care anymore with a repetitive noise
 - sensitization: increase of response to various stimulus after a noxious one, when you do not have more courage to jump after break a leg once.

b. anatomical location

- declarative memory: medial temporal lobe
- nondeclarative memory
 - priming: neocortex
 - procedural: striatum
 - endronal associative: amygdala
 - skeletal associative: cerebellum
 - nonassociative (habituation and sensitization): reflex pathways

c. animal models ??

- 2. Please give a definition of "classical conditioning" and explain in the terms US, CS and CR. Give at least two examples for rodent procedures of classical conditioning and specify for each of them what the US, CS and CR are.**

Classical conditionin is a learning procedure in which a good or bad stimulus is paired with a neutral stimulus in order to produce a new behavior. The US (unconditioned stimulus) is the good or bad stimulus, CS (conditioning stimulus) is the neutral stimulus and CR (conditioned response) is the result of the learning.

- example one: the mouse has no reaction when a tone is played (play tone = unconditioned stimulus). When the rat receives a shock, it freezes (shock = conditioned stimulus). During training phase, we will play a tone and soon after we will give a shock in the rat. After the training phase, when we play the tone, the rat will freeze, even if no shock is given, this is the conditioned response.
- example two:

Circuits underlying emotions

- 1. Describe the potentiated startle reflex and underlying anatomical structures - fear**

?

Neuromorphic engineering

- 1. Differences in organizing principles between electronic and neural computation**
- 2. Illustrate neural computation principles by specific examples (e.g. retina), explain functional utility**
- 3. Neuromorphic engineering**
- 4. Considering organizing principles used in biological retina explain (...)**
- 5. Fill in the blank and multiple choice questions from Tobi's lecture: Who invented the term Neuro Engineering? What is CMOS? Power consumption of brain. Synchronous logic is ubiquitous slide know physiologists friend photodiodes - how they are similar to retina CARVER MEAD**

Neural networks

- 1. Which dynamic process occur in a single neuron and in the local neural circuit during signal flow through a neuronal network? Name critical structural and functional aspects and discuss how they can be measured experimentally.**
- 2. Explain the temporal and spatial network definition. Give an example for each network definition and describe how you can detect these networks in the brain.**
- 3. Model organisms for understanding human brain development and function. Give three general advantages of these models. Compare in a table with advantages and disadvantages the models: Drosophila, C. Elegans, Zebrafish, Mouse. Give an example for each of how it helped understand the brain**

Neural computation

- 1. Describe the perceptron learning rule and example where it can be applied**

Perceptron is a supervised learning, it can be applied to predict an output given the patterning input and the desired output. In the training, a output is generated for the given input pattern, then, the connection's weight are changed accordly with the product between:

- the difference between the desired output and the predicted output.
- the input pattern

- the learning rate

The learning rule of the perceptron is given by $\Delta w = \eta * (y' - y) * x$, where y' is the desired output, y is the predicted output, η is the learning rate, x is the input pattern and Δw is the weight variation.

One example where we can apply the perceptron is the prediction of handwriting digit recognition. Given examples of handwriting digits and the desired output (the correct number), a perceptron network can predict the desired number for a new pattern.

References

The pictures used in this summary are from the class slide sets or internet, and belong to their respective owners. In the context of the summary they are used for educational purposes only.

Molecular and Cellular Neuroscience

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- Excitability (Müller)
Principles of Neural Science Part II, Chapter 5-7
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