

A few questions on the content of the
previous lecture

slido



The spatial arrangement of where sounds of different frequency are processed in the brain is called...

ⓘ Start presenting to display the poll results on this slide.

slido



Sound localisation is enabled by specialized neurons in the....

ⓘ Start presenting to display the poll results on this slide.

slido



Auditory receptors located alongside the basilar membrane in the cochlea are called...

ⓘ Start presenting to display the poll results on this slide.

Any questions/remarks before we begin
today's lecture?



Movement, motor control and motor learning

Dr. Lavinia Carmen Uscătescu

December 11th 2023

Outline

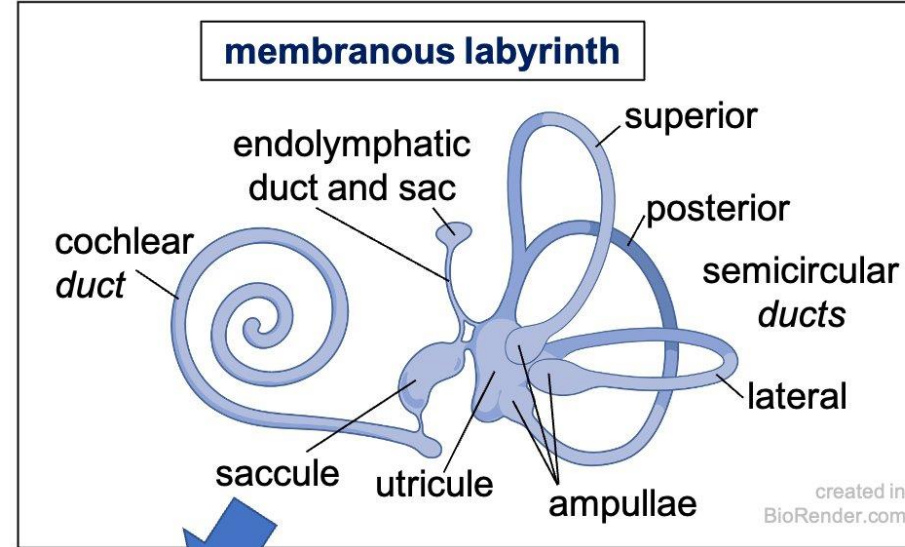
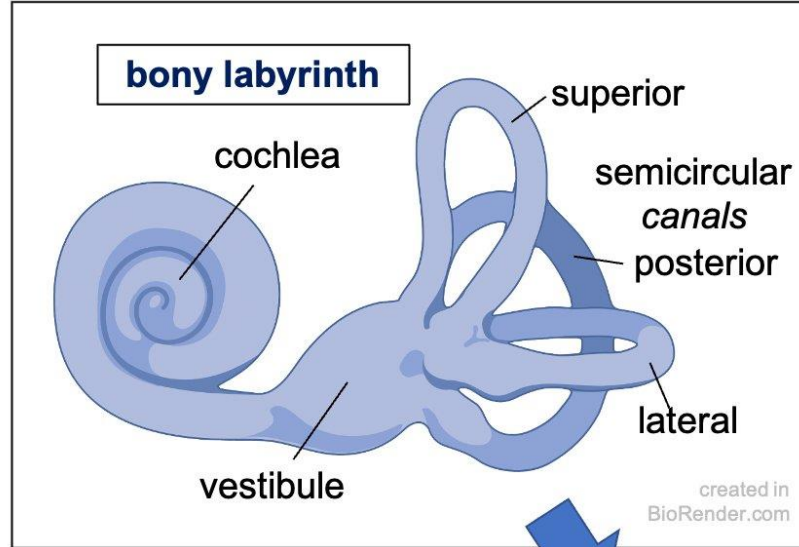
1. The vestibular system
2. The motor system
3. Motor system disorders

The vestibular system

Remember...

also called “**otic capsule**”; surrounds and houses the membranous labyrinth, separated by a layer of **perilymph**

contains **endolymph** & **sensory epithelium**



perilymph

extracellular fluid located in the **scala tympani** and **scala vestibuli** of the cochlea; major cation is **sodium**

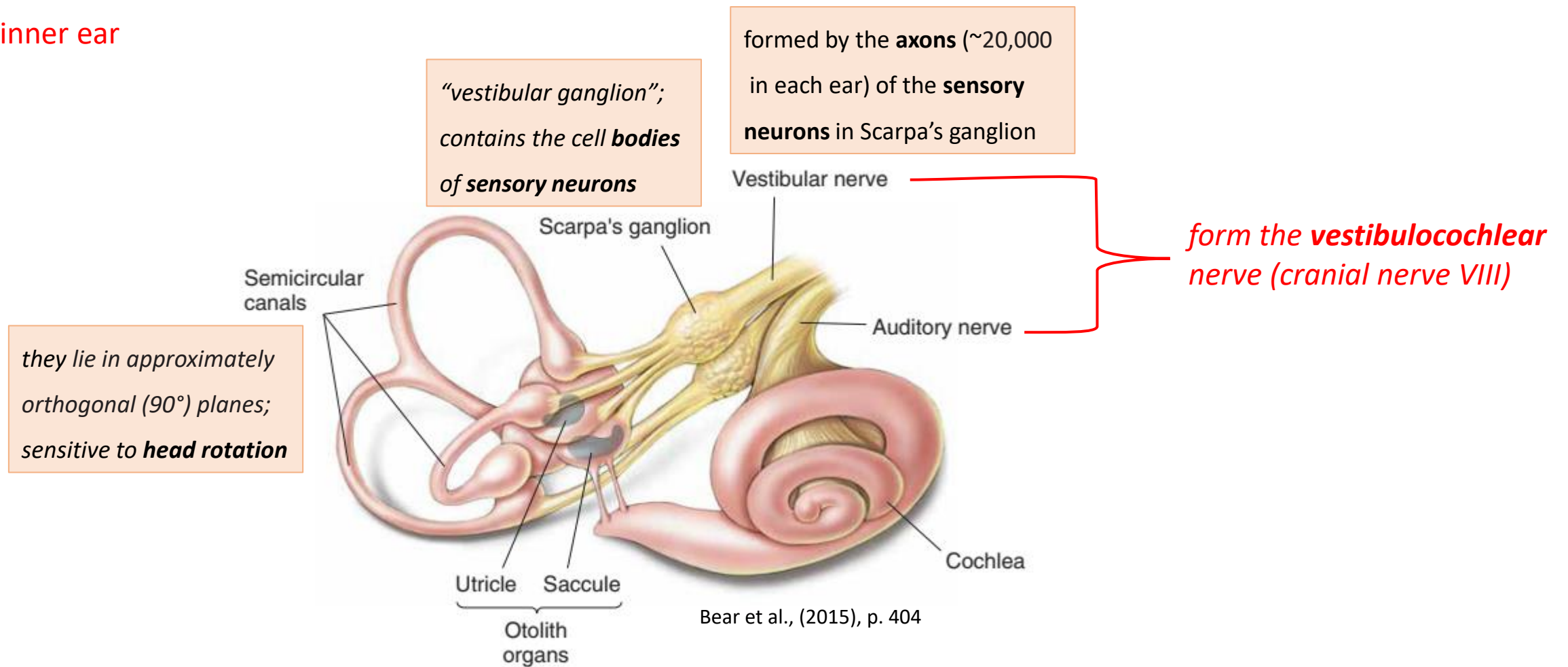
endolymph

fluid located in the **membranous labyrinth** of the inner ear; major cation is **potassium**



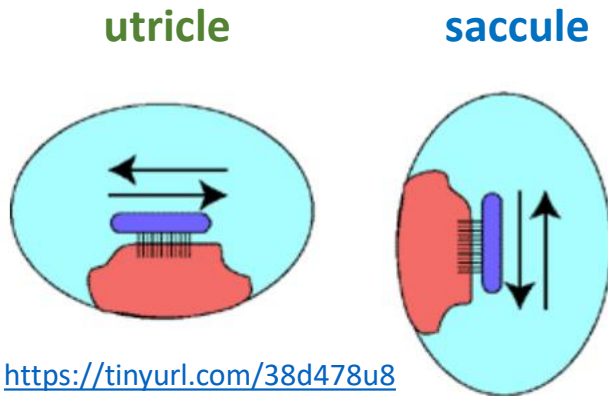
<https://tinyurl.com/b37rx6wt>

The inner ear

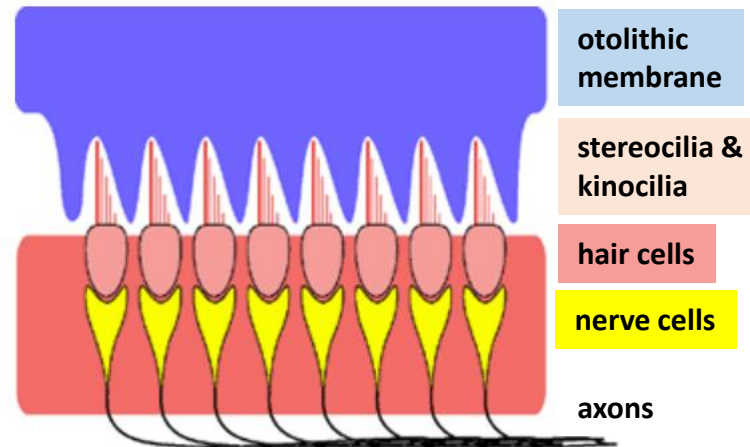


large **chambers** near the center of the labyrinth; detect the force of **gravity, tilt and acceleration** of the **head**; contain **hair cells** (similar to those in the cochlea)

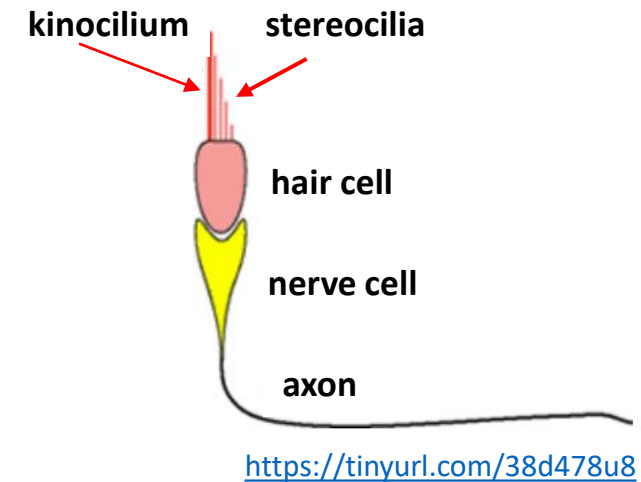
The otolith organs (utricle and saccule) enable the detection of linear acceleration (changes in the head angle)



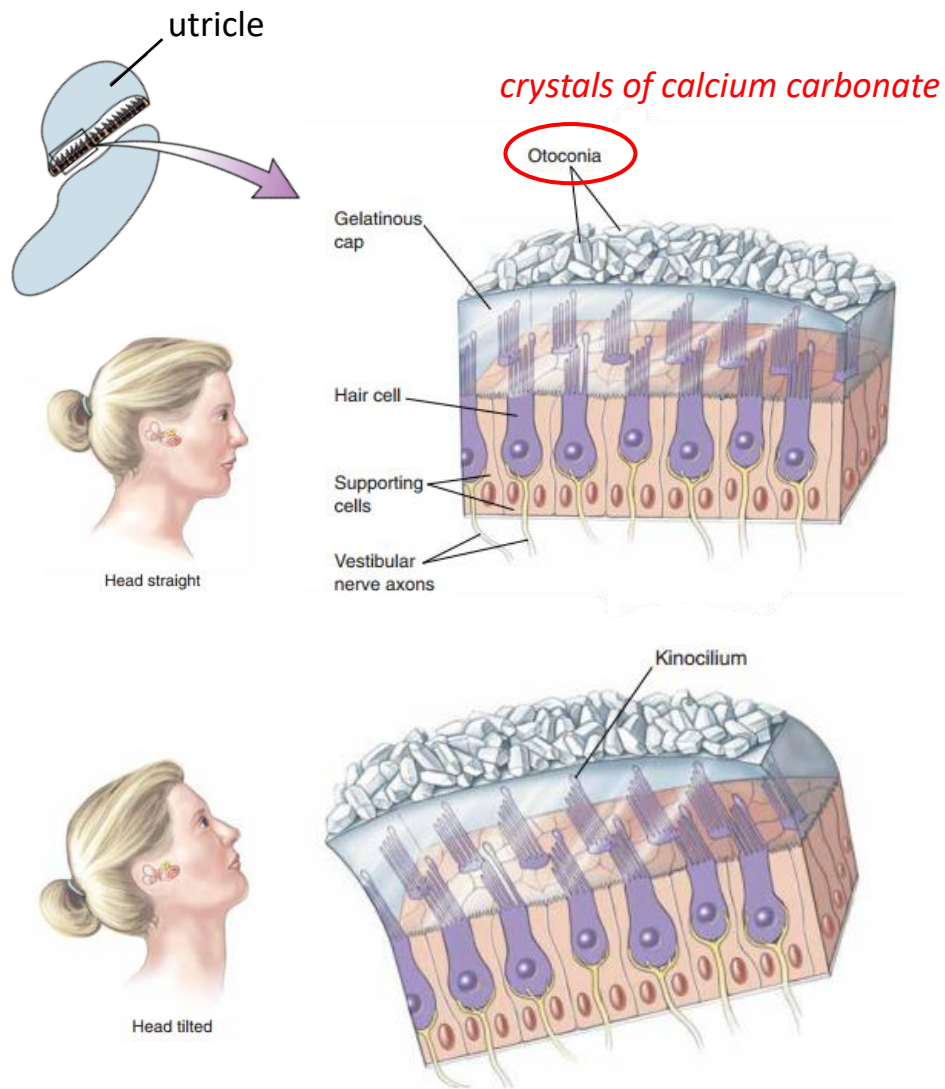
Each otolith organ is filled with **fluid**, and contains a **sensory epithelium** called a **macula**, which is vertically oriented within the saccule and horizontally oriented within the utricle when the head is upright => detect movements in both the **horizontal** and **vertical** direction.



The **macula** consists of a row of **hair cells** embedded in a row of supporting cells. The hairs (i.e., **stereocilia** and **kinocilia**) are connected to a gelatinous mass called the **otolithic membrane**. The other side of the hair cell is connected to **sensory neurons**, whose **axons** form the **vestibular nerve**. <https://tinyurl.com/38d478u8>



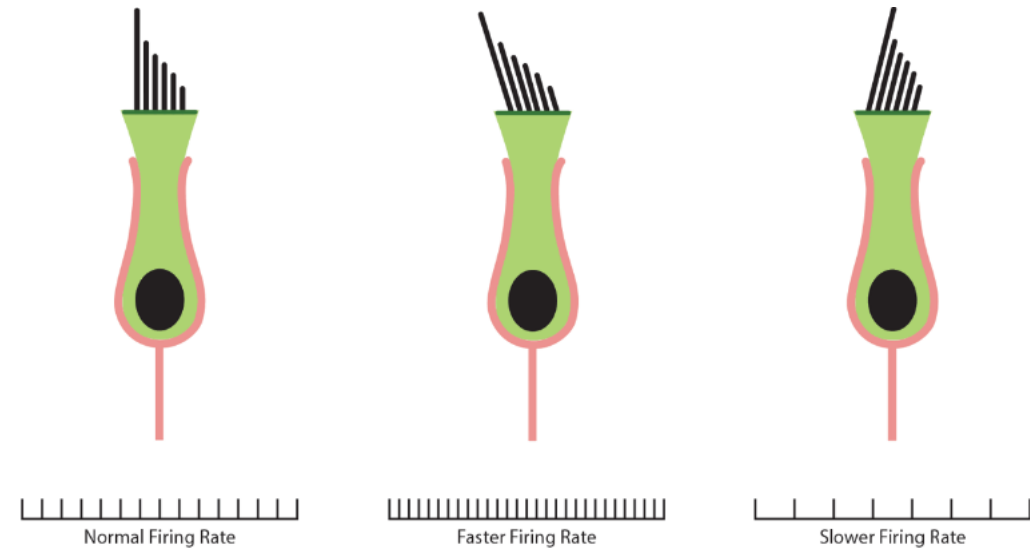
The **kinocilium** is longer than the **stereocilia**. It plays a crucial role in the **firing rate** of the hair cell.



◀ FIGURE 11.29

Macular hair cells responding to tilt. When the utricular macula is level (the head is straight), the cilia from the hair cells also stand straight. When the head and macula are tilted, gravity pulls the otoconia, which deform the gelatinous cap, and the cilia bend.

Bear et al., (2015), p. 405

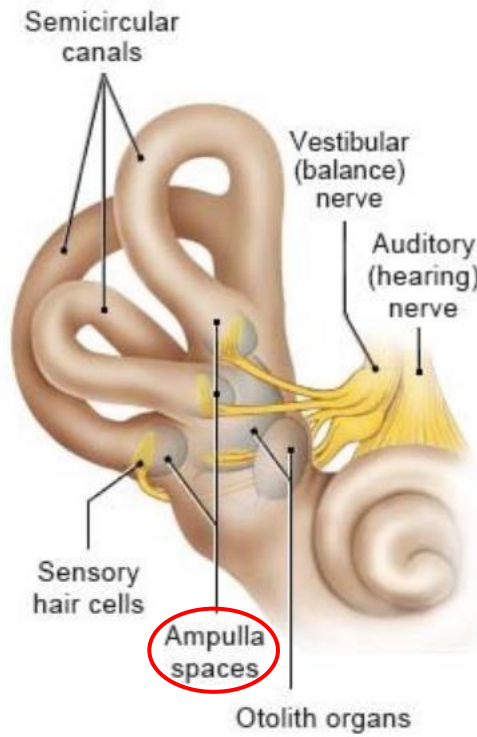


<https://tinyurl.com/yc2wrf39>

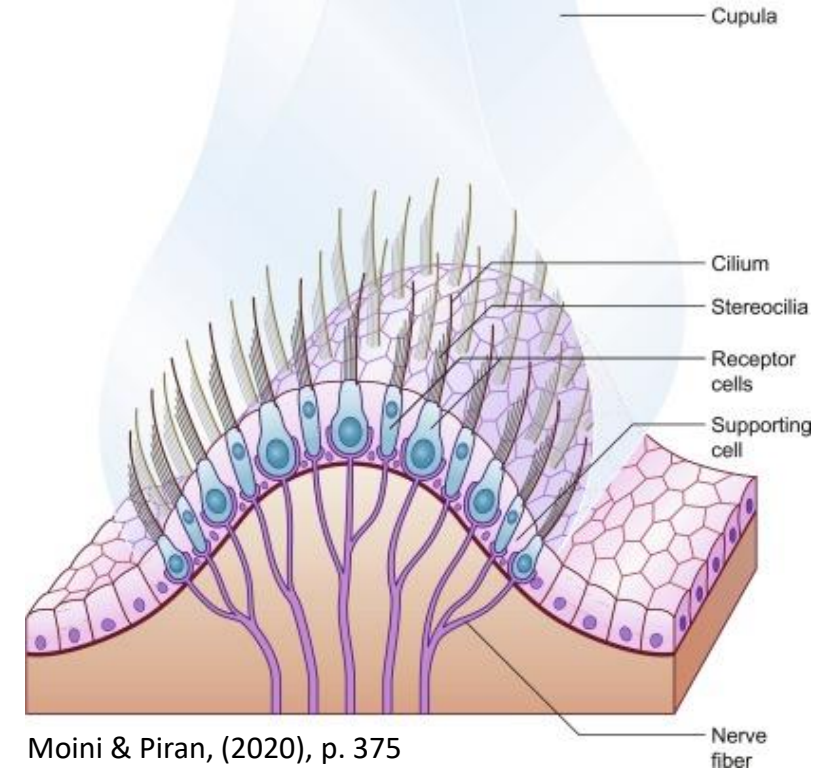
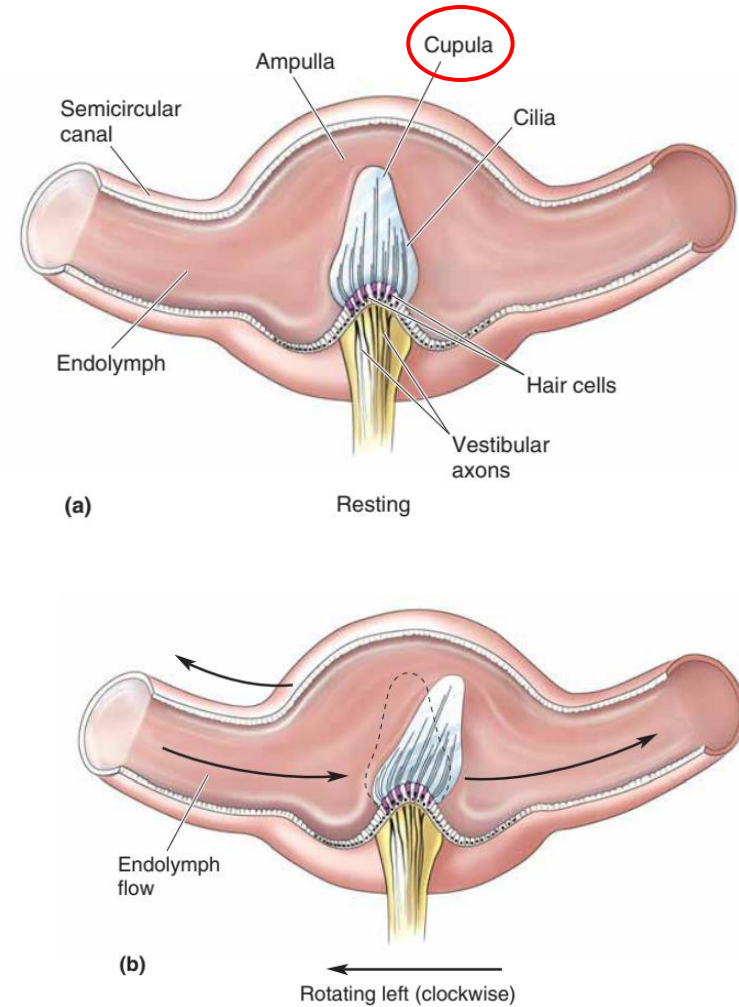
Hair cells are constantly causing the sensory neurons at their base to fire (i.e., the **tonic firing rate**). When the cilia/hairs bend **towards the kinocilium** => the cell is depolarized and the **firing rate increases**, and when they **bend away** => the cell is hyperpolarized and the **firing rate decreases**.

When a hair cell in a semicircular canal is bending **towards** the **kinocilium** on **one side** of the head, the **functionally paired** hair cell on the other side of the head is **decreasing** its activity.

The semicircular canals enable the detection of angular acceleration (turning movements of the head)



<https://tinyurl.com/m3wzvtdm>



Moini & Piran, (2020), p. 375

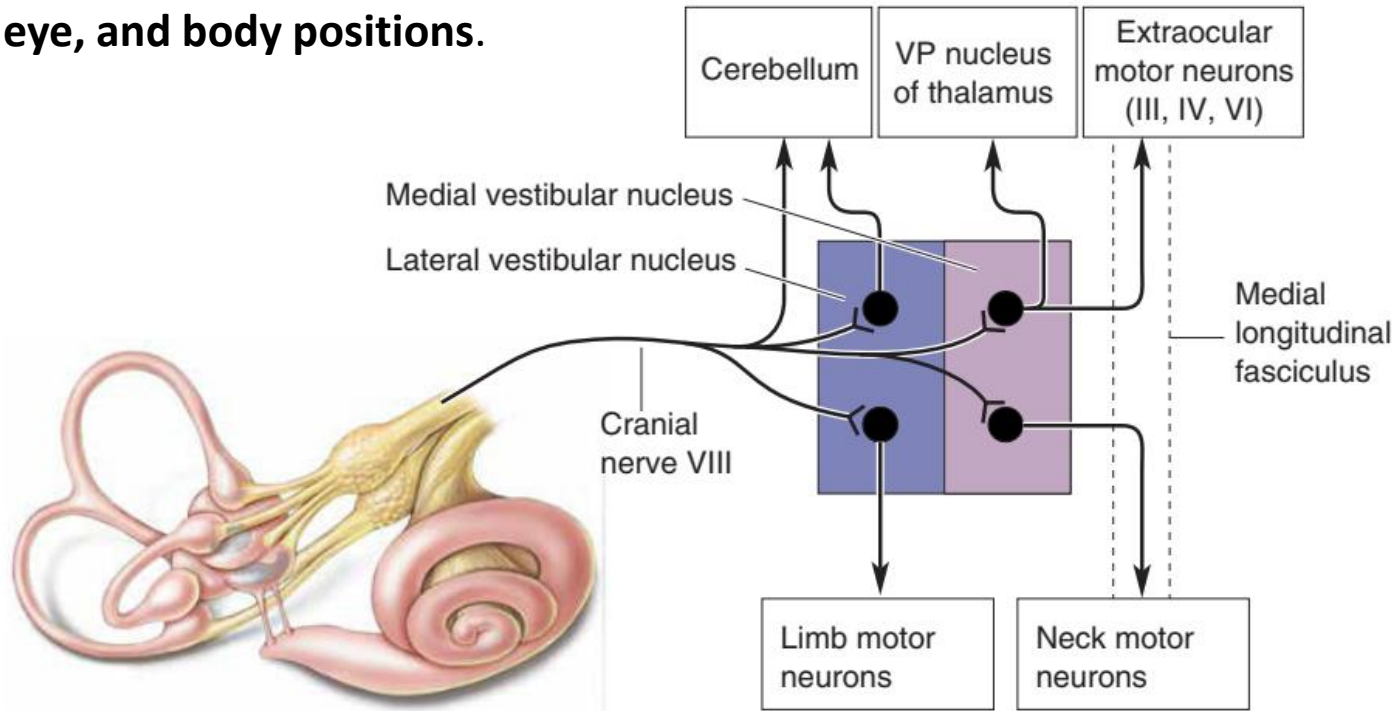
▲ FIGURE 11.31

A cross section through the ampulla of a semicircular canal. (a) The cilia of hair cells penetrate into the gelatinous cupula, which is bathed in the endolymph that fills the canals. (b) When the canal rotates leftward, the endolymph lags behind and applies force to the cupula, bending the cilia within it.

Bear et al., (2015), p. 407

The central vestibular pathways

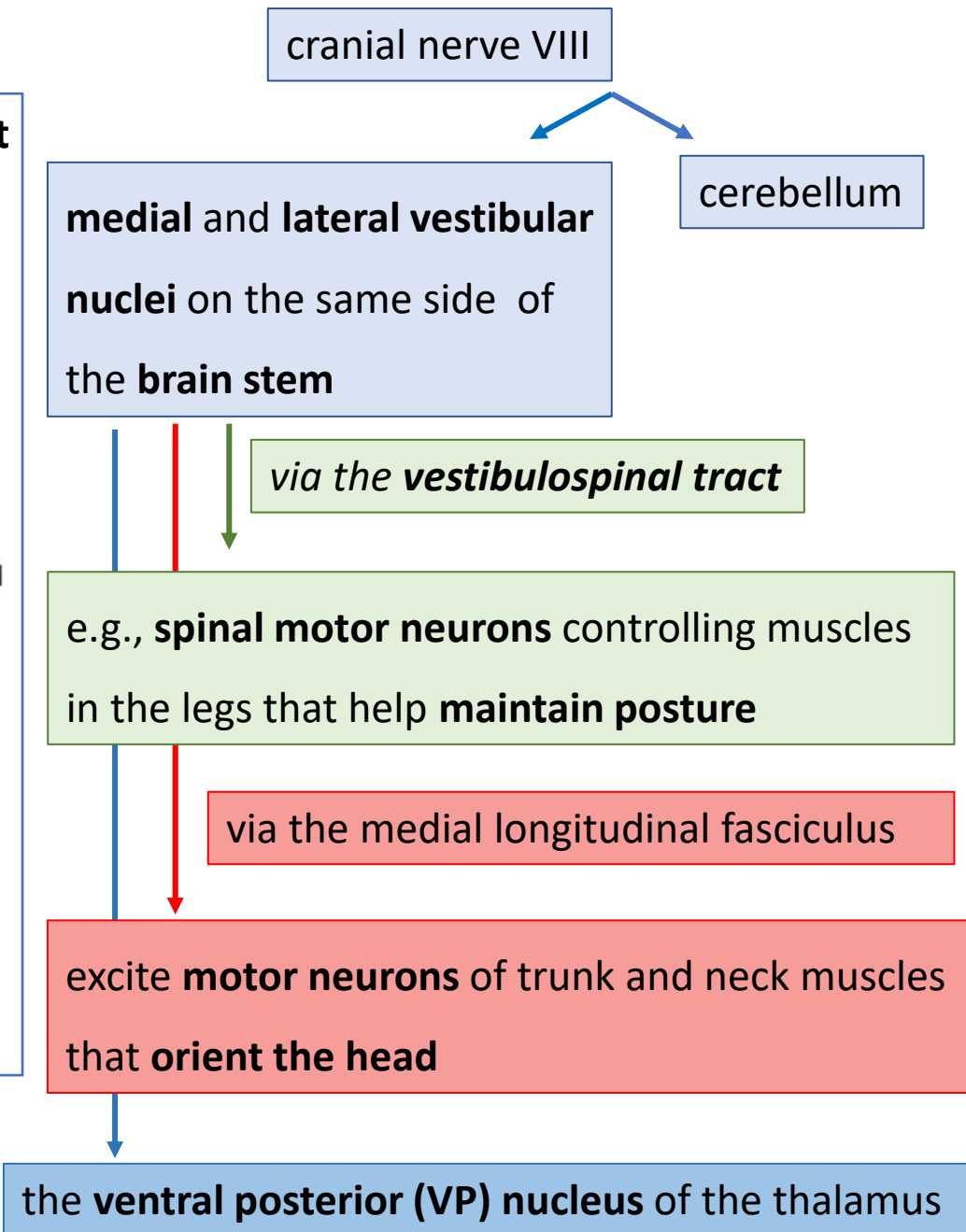
Coordinate and integrate information about **head and body movement** and use it to control the **output of motor neurons** that **adjust head, eye, and body positions.**



▲ **FIGURE 11.33**
A summary of the central vestibular connections from one side.

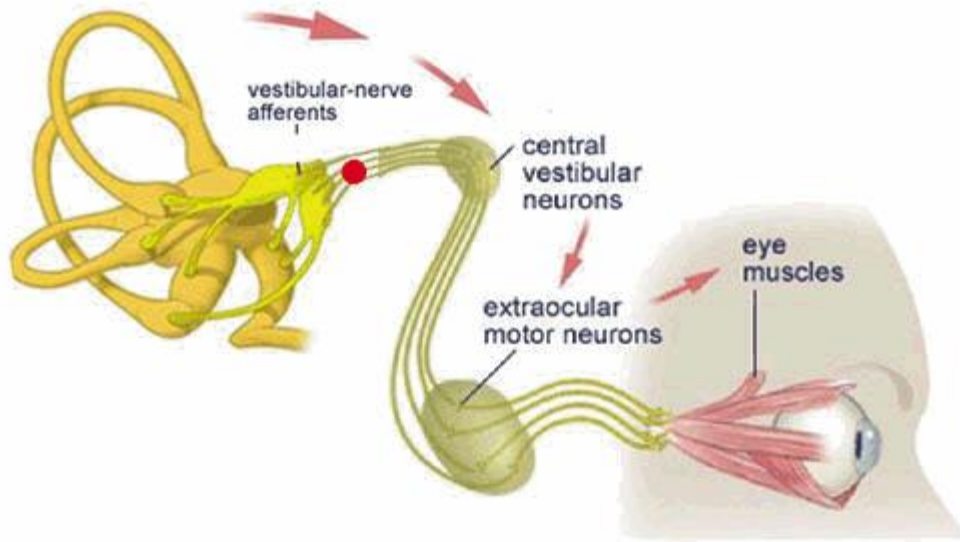
Bear et al., (2015), p. 408

Projects to regions close to the representation of the face in the primary somatosensory and primary motor areas of cortex



The vestibulo-ocular reflex

Unblurred vision is only possible if the eye is **stationary** (fixed) with respect to a viewed object => the **vestibulo-ocular reflex** helps maintain **stationary vision** when we **move** our head.



<https://tinyurl.com/brhffhks>

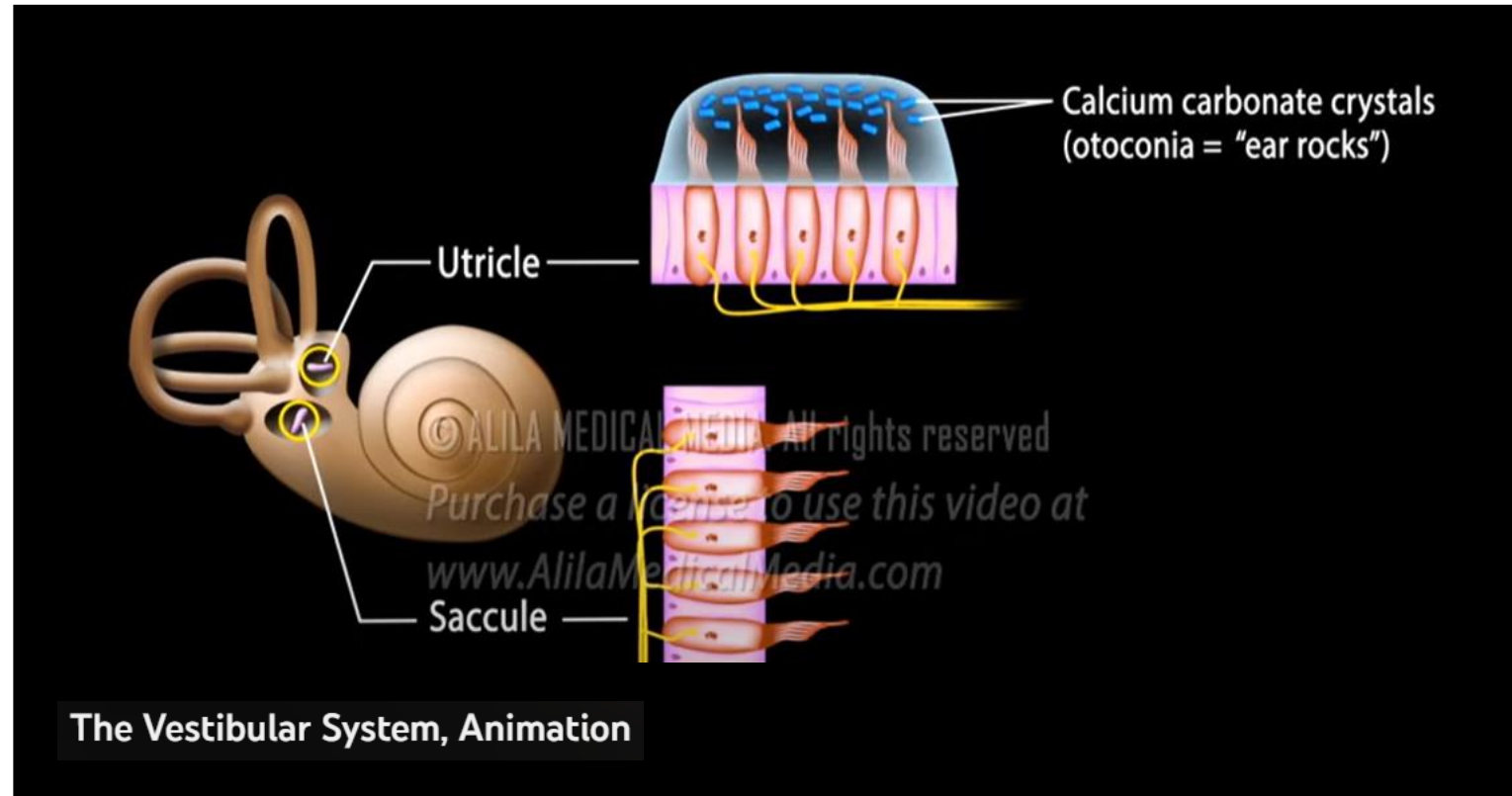
If the head is turned to the left, this reflex causes the eyes to move to the right (i.e., in the **opposite direction** of the head movement).

The oppositely directed **eye movement** occurs at the **same velocity** as the **head movement**, and therefore generates an eye movement which **keeps our line of sight fixed** on the **same point** in visual space both during and following the movement.

Already present **at birth** (i.e., “doll’s eyes reflex”):

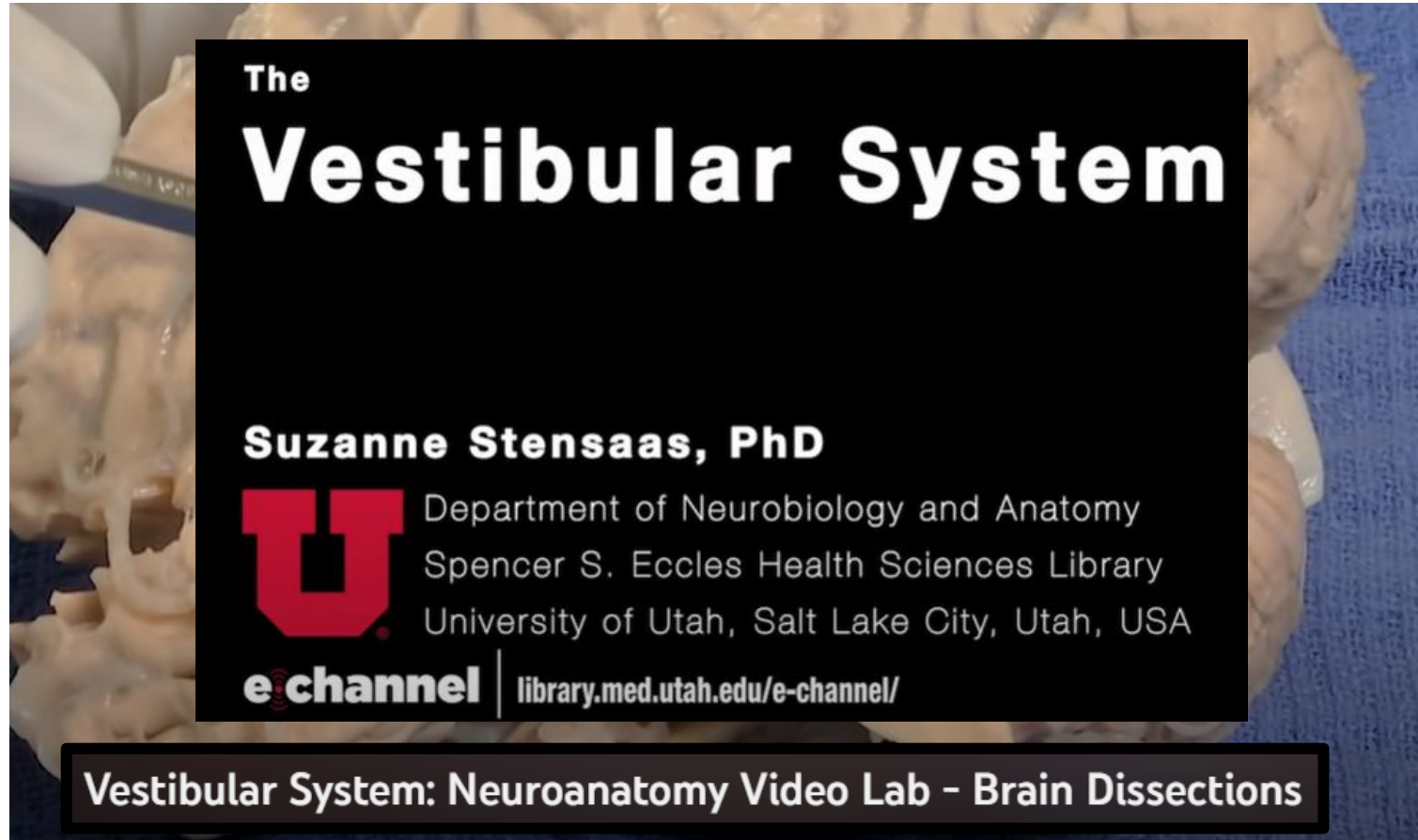
<https://www.youtube.com/watch?v=MpjR5eyu9Pc>

Let's visualize everything we talked about




<https://www.youtube.com/watch?v=ryGMI3SpxCE>

Let's visualize everything we talked about

An anatomical dissection of the vestibular system, showing the internal ear structures. The dissection is performed on a blue surface. A black overlay box contains text and a logo.

The
Vestibular System

Suzanne Stensaas, PhD

 Department of Neurobiology and Anatomy
Spencer S. Eccles Health Sciences Library
University of Utah, Salt Lake City, Utah, USA

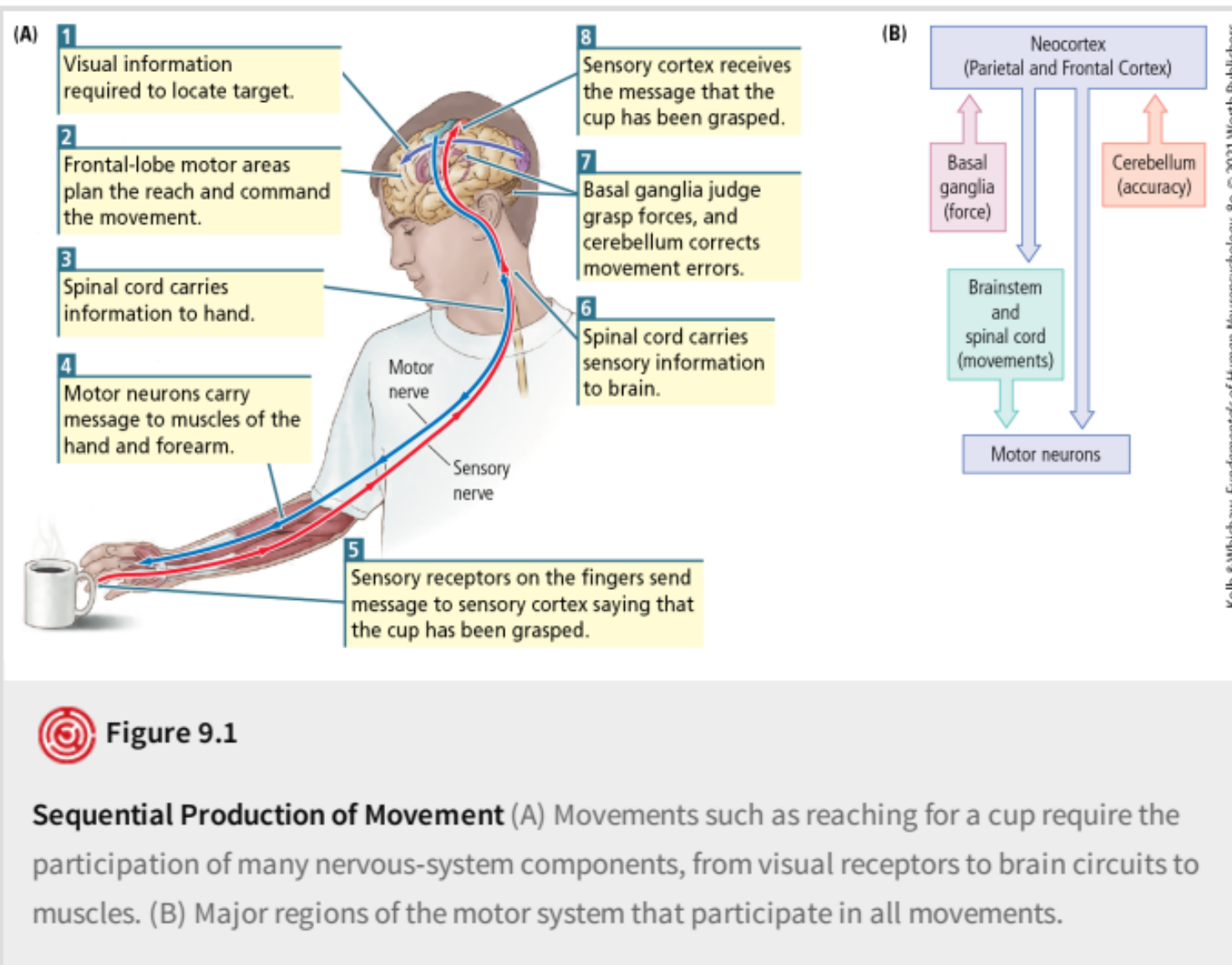
e:channel | library.med.utah.edu/e-channel/

Vestibular System: Neuroanatomy Video Lab - Brain Dissections

<https://www.youtube.com/watch?v=KaFVueNzLy8>

The motor system

Motor system overview



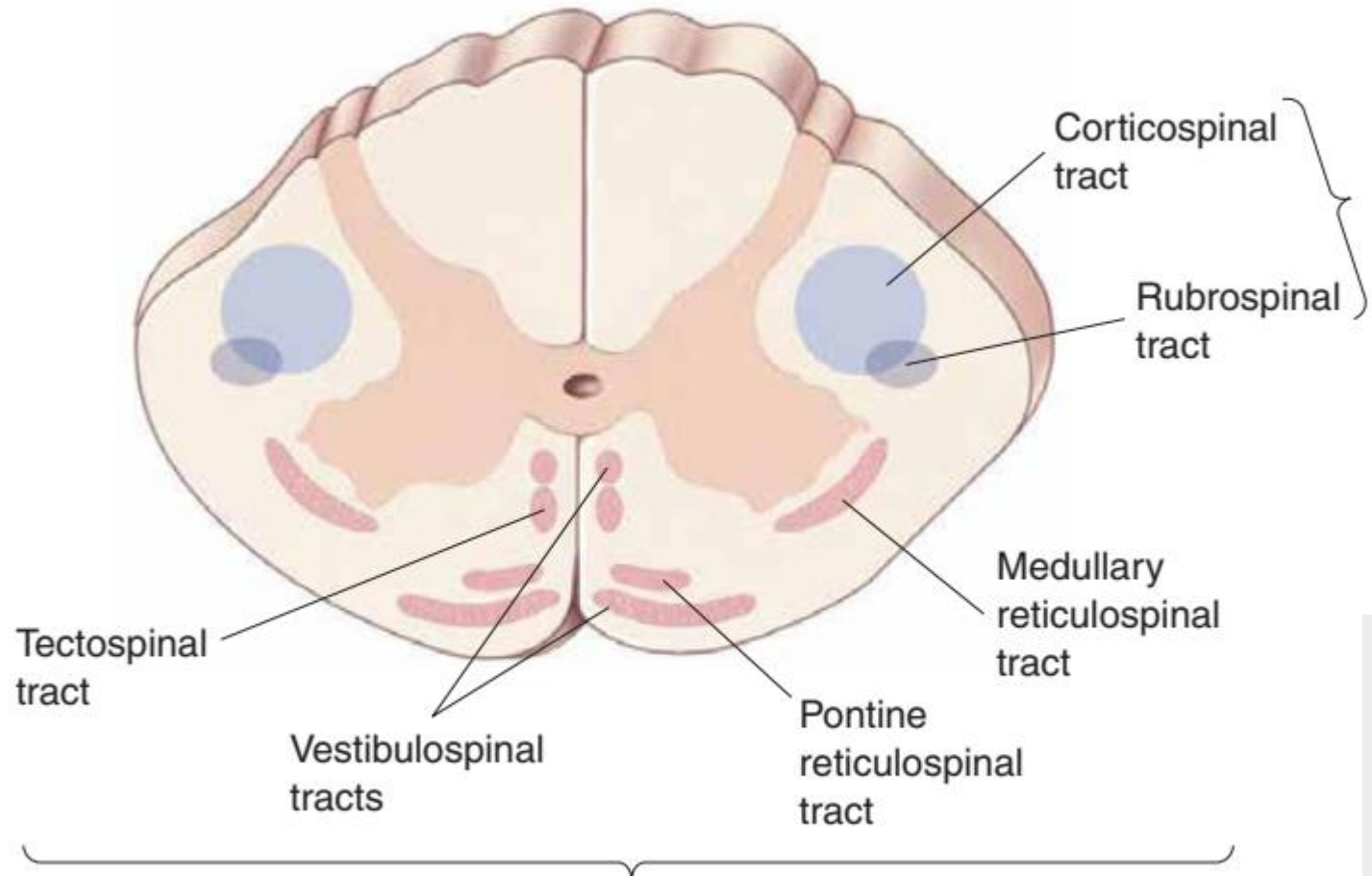
 **Figure 9.1**

Sequential Production of Movement (A) Movements such as reaching for a cup require the participation of many nervous-system components, from visual receptors to brain circuits to muscles. (B) Major regions of the motor system that participate in all movements.

motor system usually references the parts of the nervous system that are most directly involved in **sending information** to the **spinal cord** to **produce movement**.

The **motor system** includes different areas with specific roles: **neocortical regions** (e.g., the **parietal** and **frontal** cortex; planning), the **basal ganglia** (appropriate amount of force), the **cerebellum** (movement's timing and accuracy), and regions of the **brainstem** and **spinal cord** (instructions to muscles).

Descending spinal tracts



Lateral pathways

control *voluntary movements* of the *distal musculature*

REMEMBER: the *ascending tracts* refer to the neural pathways by which *sensory information* from the *peripheral nerves* is transmitted to the *cerebral cortex* => more on this in the next lecture.

Bear et al., (2015), p. 486

Ventromedial pathways
control *postural muscles*

Motor control areas: the motor cortex

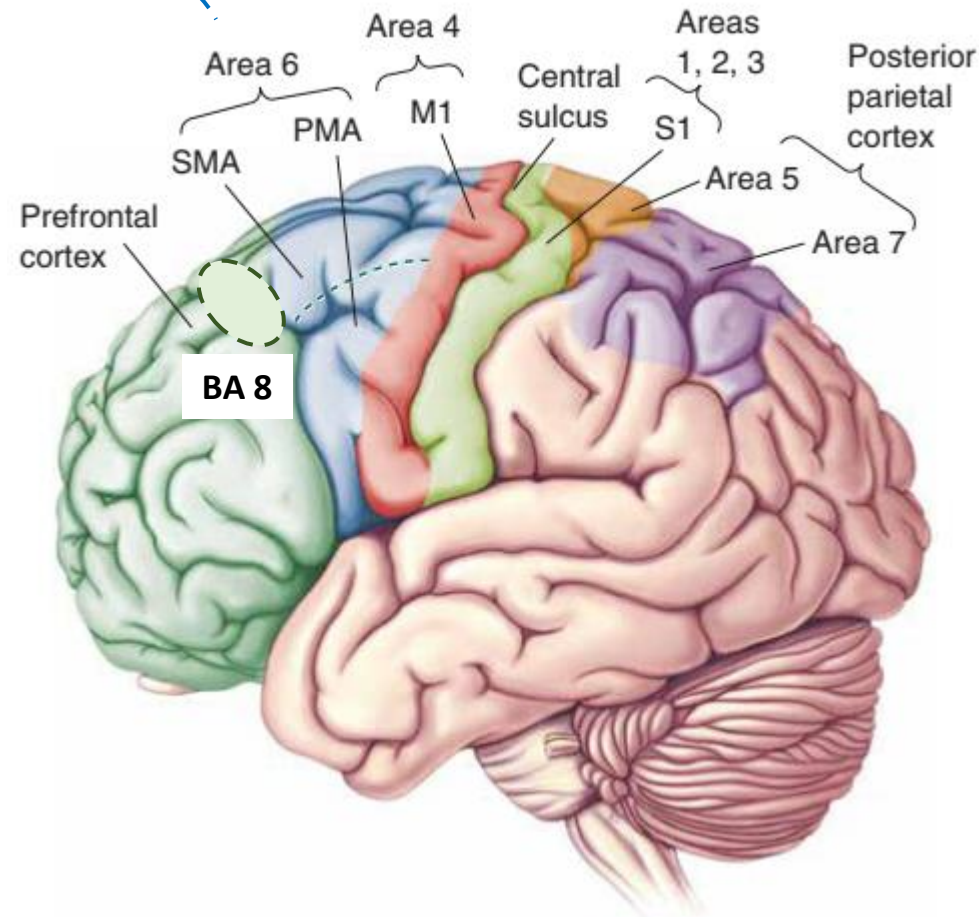
secondary motor cortex
(i.e., Brodmann's areas 6 (& 8))

premotor area (PMA)

connects primarily with reticulospinal neurons that innervate proximal motor units

supplementary motor area (SMA)

sends axons that innervate distal motor units directly



primary motor cortex / M1
(i.e., Brodmann's area 4,
the precentral gyrus)

▲ FIGURE 14.7

Planning and directing voluntary movements. These areas of the neocortex are involved in the control of voluntary movement. Areas 4 and 6 constitute the motor cortex.

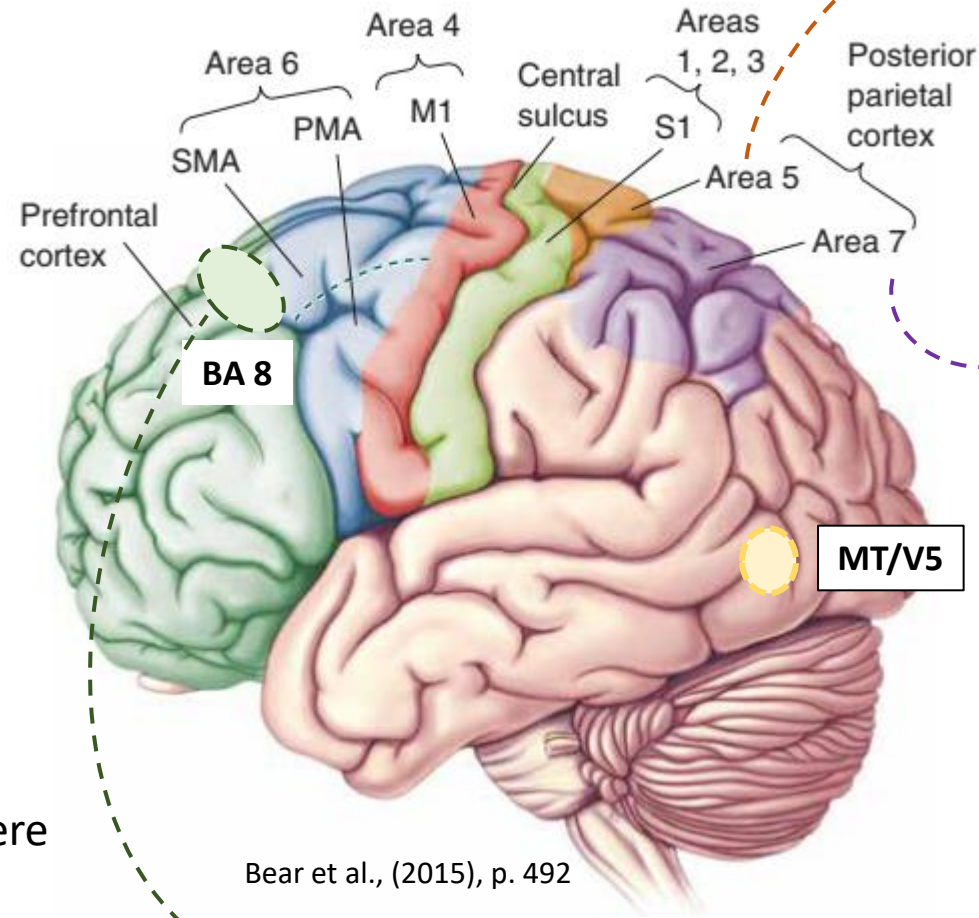
Bear et al., (2015), p. 492

Areas **4 and 6** contribute most of the axons to the descending **corticospinal tract** (in the **lateral pathways**).

Motor control areas: the prefrontal and posterior parietal cortex

The **prefrontal** and **posterior parietal** cortices are the **highest levels** of the **motor control hierarchy**, where decisions are made about **what actions** to take and their **likely outcome**.

The **prefrontal cortex** and **parietal cortex** both **send axons** that **converge** on cortical **area 6** => this area lies at the junction where signals encoding "**what**" actions are **converted** into signals that specify "**how**" the actions will be carried out.



Bear et al., (2015), p. 492

inputs from the **primary somatosensory** cortical areas (BA 1, 2, and 3)

inputs from higher order **visual** cortical areas such as MT (V5)

BA 8: frontal eye fields

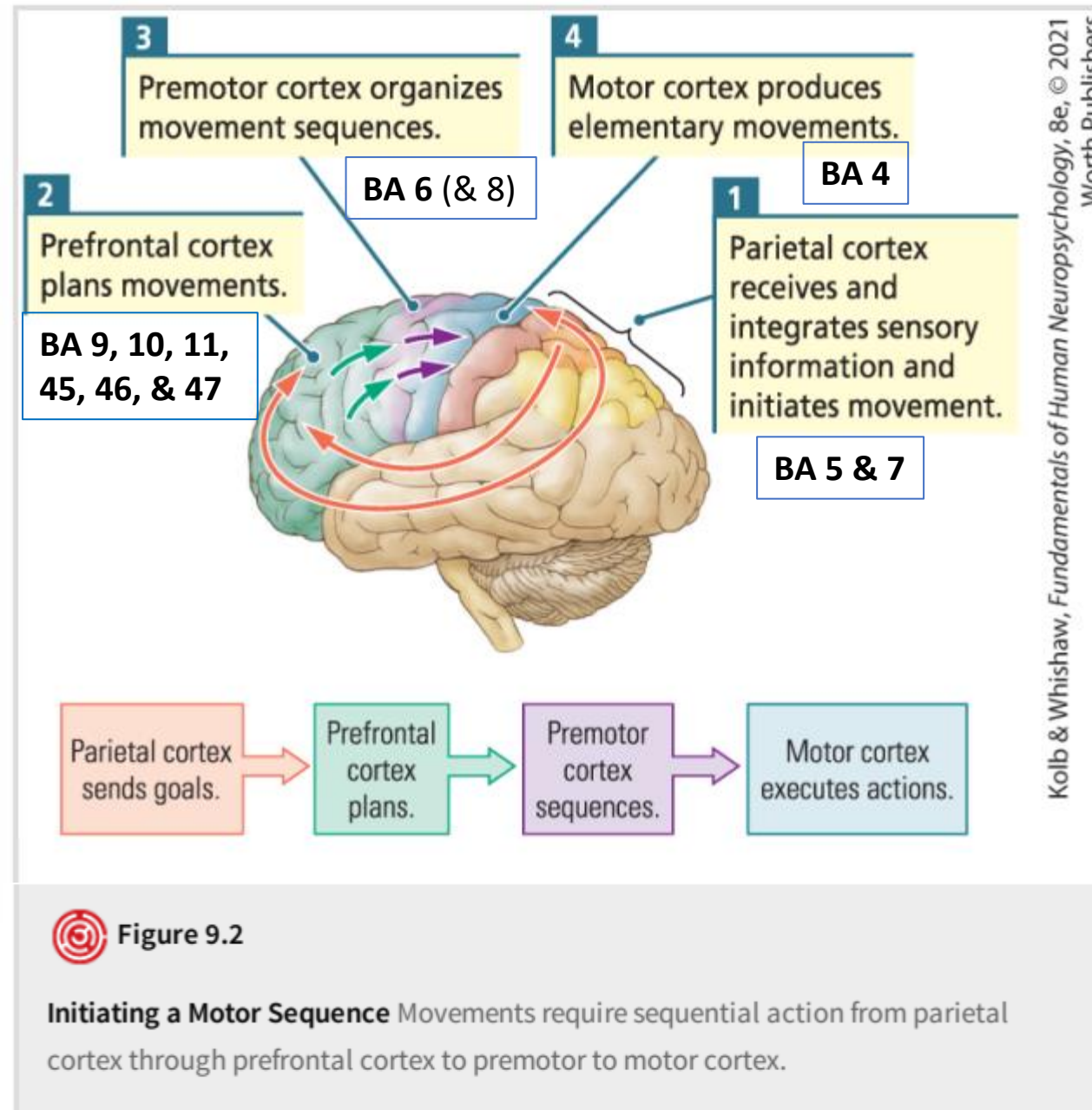
control of eye movements; damage => tonic


deviation of the eyes towards the side of the injury

Motor control

1. Receives and **integrates** information from **vision, touch, and hearing** => **can initiate movements** in response to information from **any** of our **senses**.

2. Generates **plans** for movements that it **passes along** to the **premotor** and **motor** cortex. Prefrontal cortex plans are based on **previous experience** as well as **ongoing sensory input**.



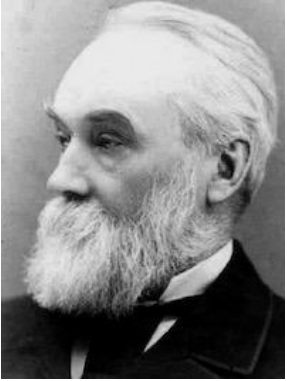
 **Figure 9.2**

Initiating a Motor Sequence Movements require sequential action from parietal cortex through prefrontal cortex to premotor to motor cortex.

3. Involved in making **whole-body** movements, **rhythmic** movements (e.g., walking), and **coordinated** movement (e.g., involving both hands) => **organizing action sequences** (e.g., when playing a sport or when organizing a meaningful sequence of words).

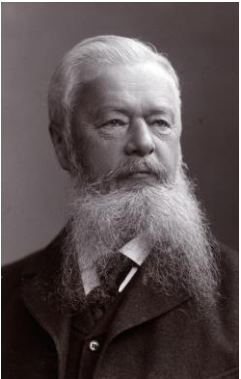
4. Involved in making more **elementary movements** (e.g., hand movements to manipulate tools, **pick up** objects, or bring food to the mouth, and mouth movements for grasping and **chewing** food).

The discovery of the motor cortex



John Hughlings Jackson
(1835 – 1911)

- was studying **epilepsy**, when he noted that epileptic seizures gradually propagated from the hands towards the face ("*Jacksonian march*");
- hypothesized that different parts of the body were controlled by different parts of the cortex;
- surmised that **aberrant electrical activity** in the brain gave rise to epileptic seizures.



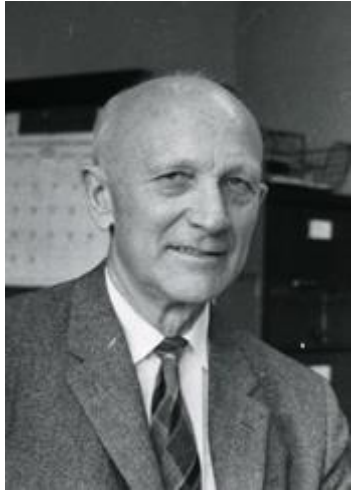
Gustav Fritsch
(1838 – 1927)



Eduard Hitzig
(1838 – 1907)

- in 1870, they identified the motor cortex **experimentally**, by electrically stimulating the motor cortex of a dog;
- they showed the **contralateral** correspondence between stimulation site and the elicited movement;
- further supported their conclusion with **targeted lesion** studies of the motor cortex, in dogs.

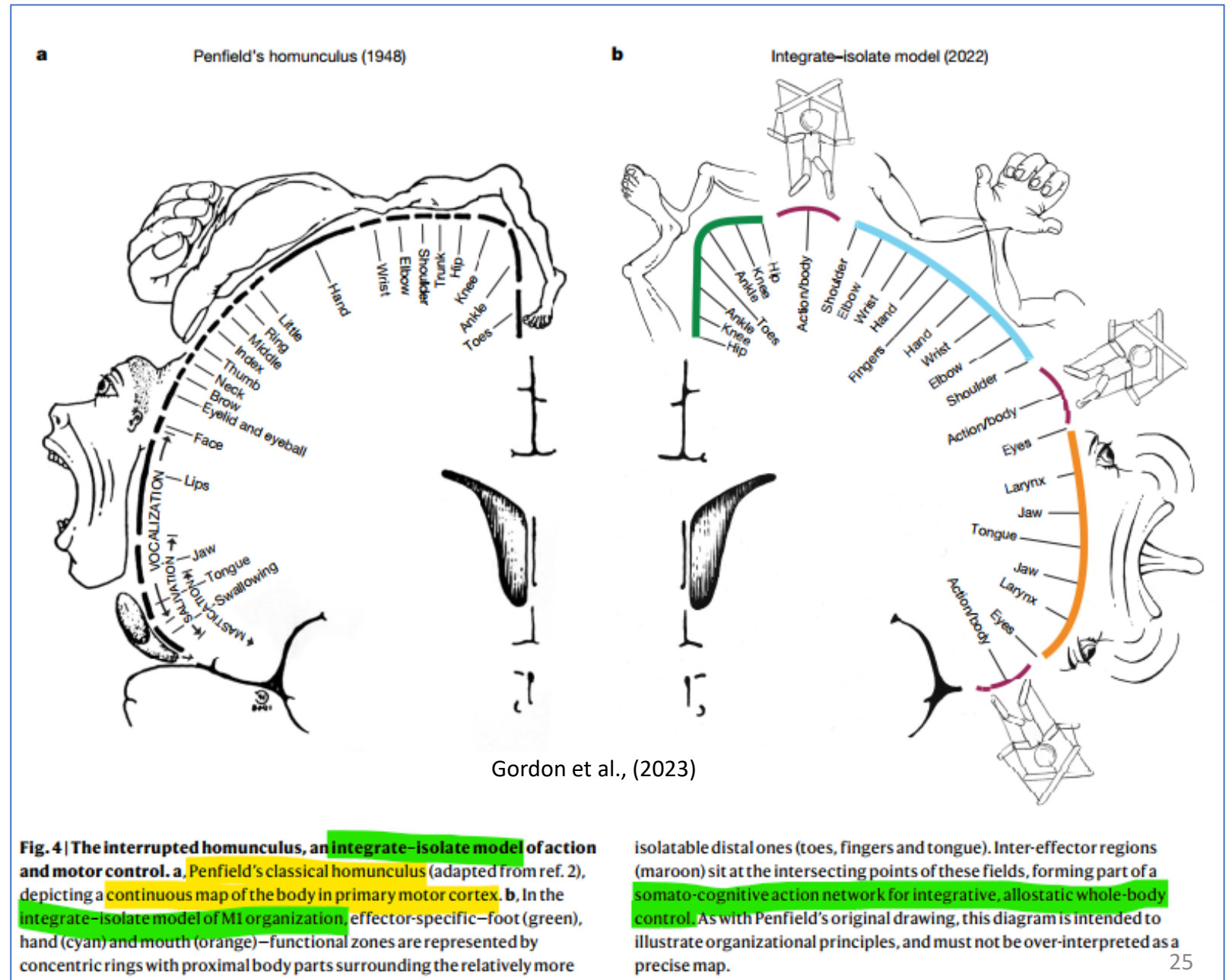
Functional organization of the primary motor cortex: the “homunculus”



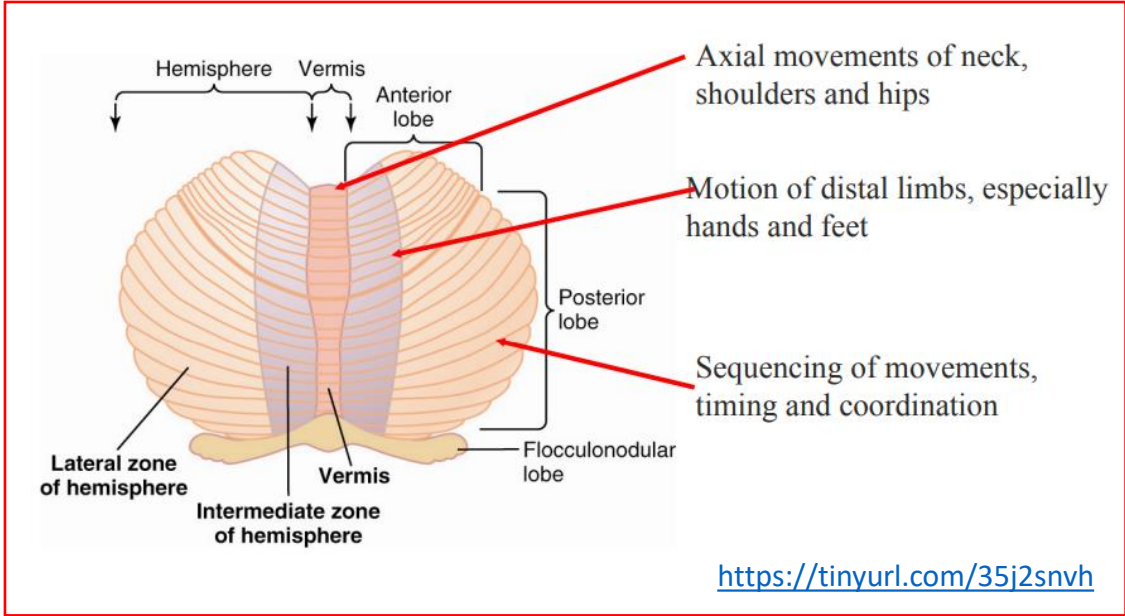
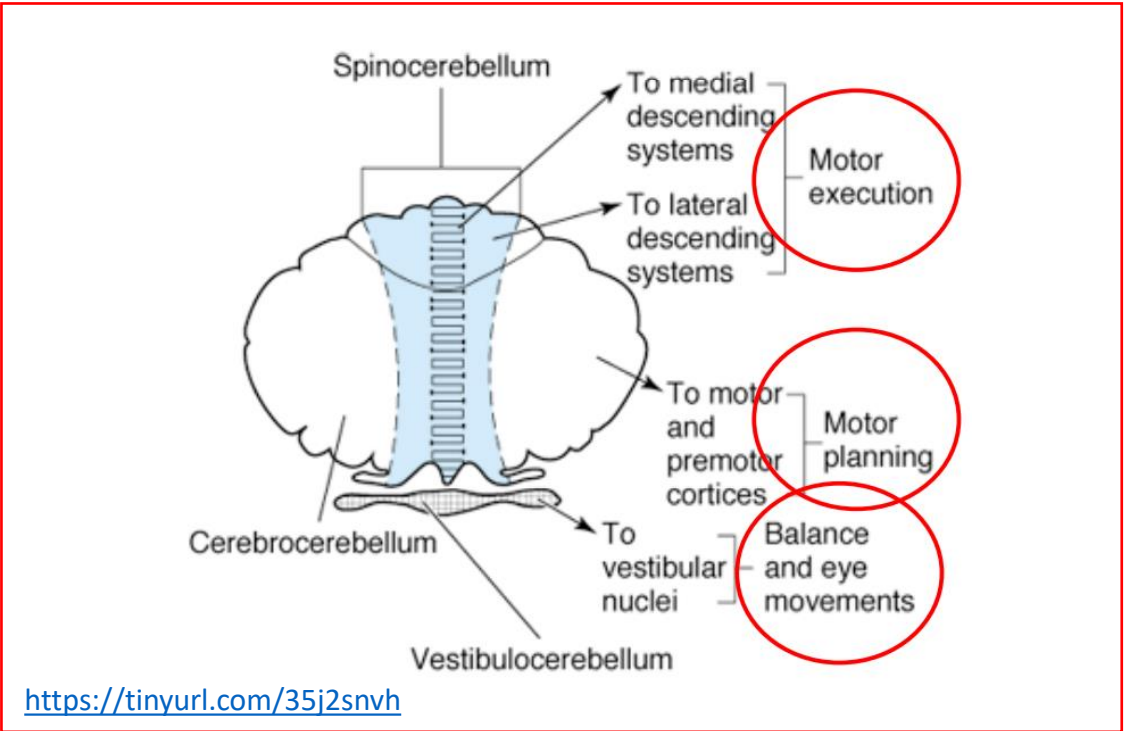
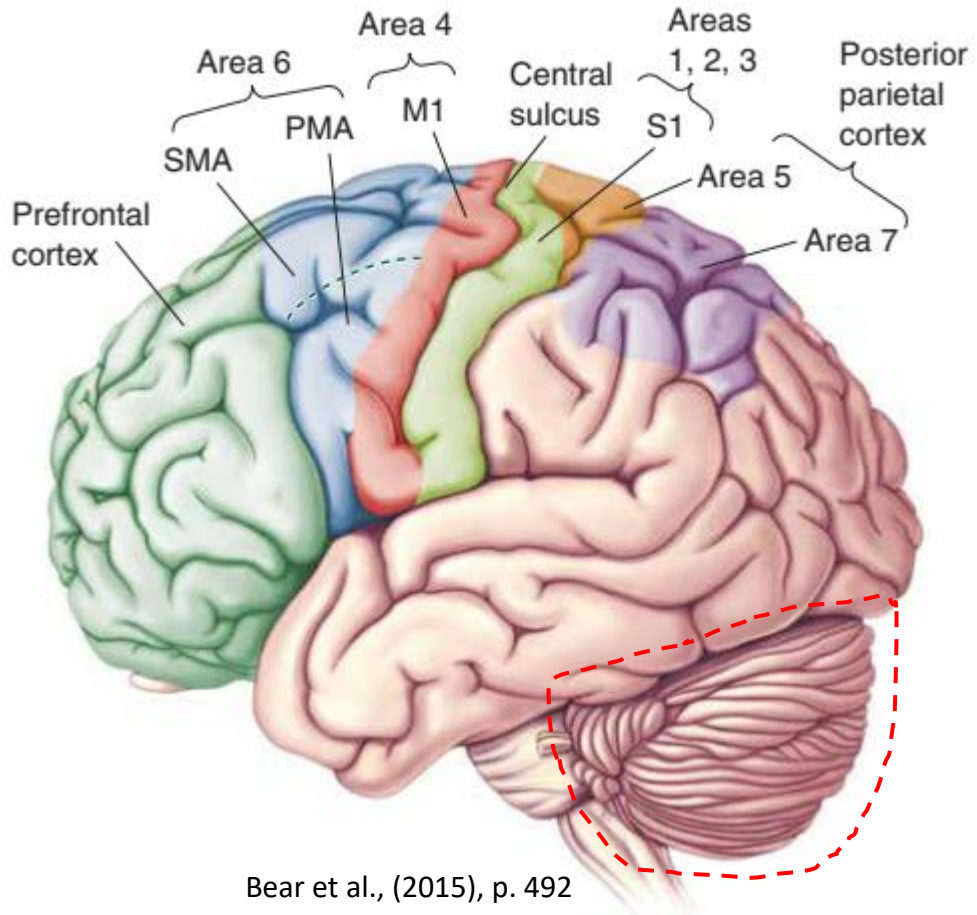
Wilder Penfield
(1891 – 1976)



<https://www.youtube.com/watch?v=A-H9dmn4pMg>

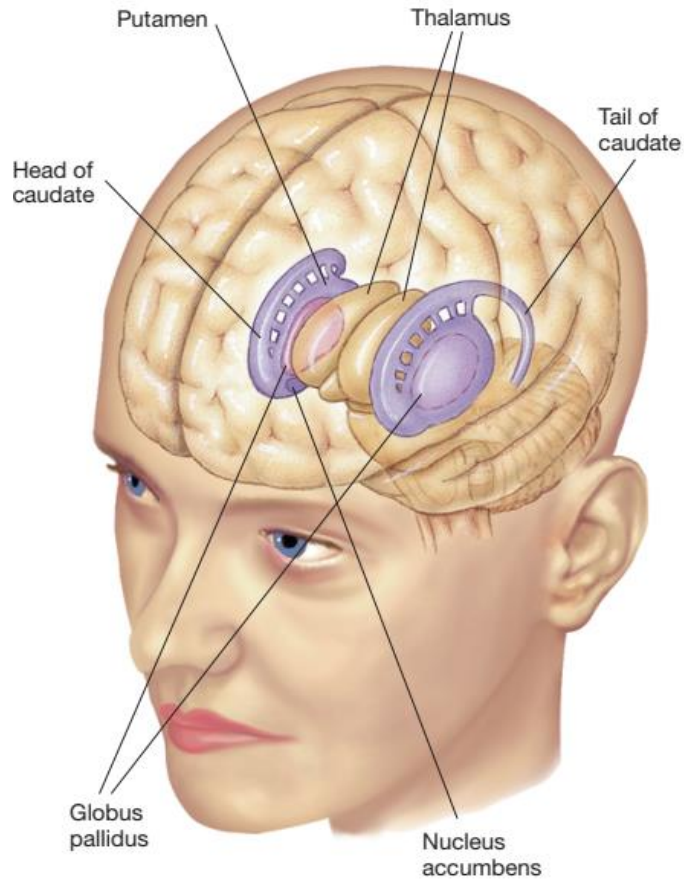


The cerebellum



The basal ganglia

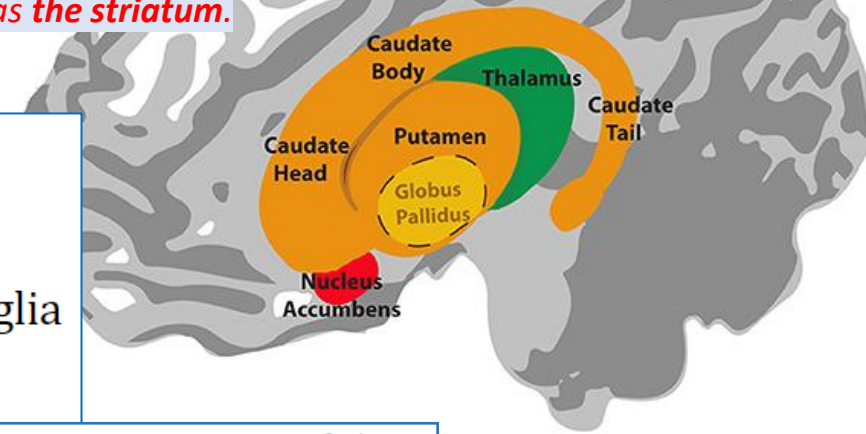
Figure 3.28 The basal ganglia: striatum (caudate plus putamen), and globus pallidus. Notice that, in this view, the right globus pallidus is largely hidden behind the right thalamus and the left globus pallidus is totally hidden behind the left putamen.



Pinel & Barnes, (2021), p. 93

The term **basal ganglia** in the strictest sense refers to nuclei embedded deep in the brain hemispheres (**striatum and globus pallidus**), whereas **related nuclei** consist of structures located in the diencephalon (**subthalamic nucleus**), mesencephalon (**substantia nigra**), and pons (**pedunculo pontine nucleus**).

The **caudate and putamen** are collectively known as **the striatum**.



[Cold Spring Harb Perspect Med.](https://doi.org/10.1101/cshperspect.a009621) 2012 Dec; 2(12): a009621.

doi: [10.1101/cshperspect.a009621](https://doi.org/10.1101/cshperspect.a009621)

Functional Neuroanatomy of the Basal Ganglia

[José L. Lanciego](#), [Natasha Luquin](#), and [José A. Obeso](#)

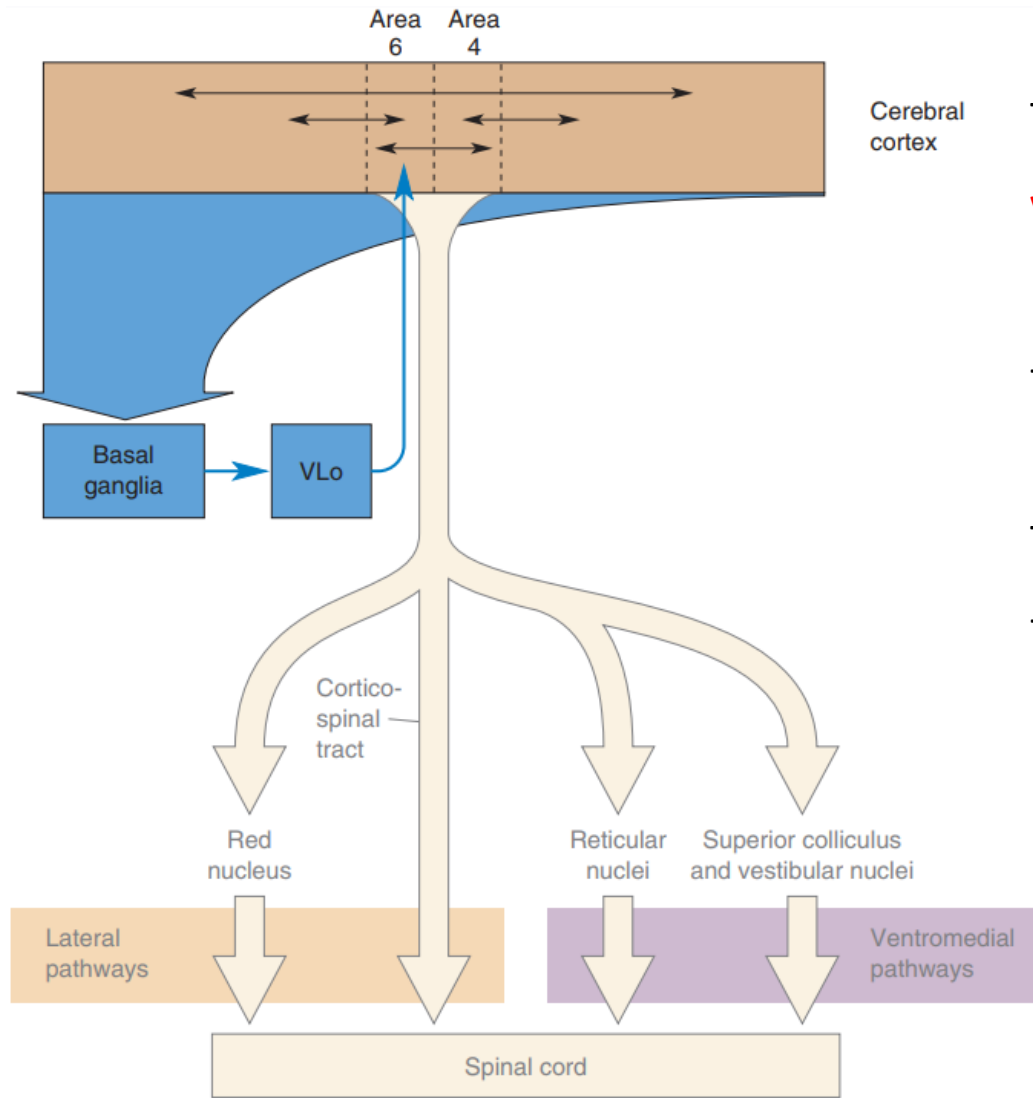
Abstract

Go to: ▶

The “basal ganglia” refers to a group of subcortical nuclei responsible primarily for motor control, as well as other roles such as **motor learning, executive functions** and behaviors, and **emotions**. Proposed more than two decades ago, the classical basal ganglia model shows how information flows through the basal ganglia back to the cortex through two pathways with opposing effects for the proper execution of movement. Although much of the model has remained, the model has been modified and amplified with the emergence of new data. Furthermore, parallel circuits subserve the other functions of the basal ganglia engaging associative and limbic territories. **Disruption of the basal ganglia network forms the basis for several movement disorders**. This article provides a comprehensive account of basal ganglia functional anatomy and chemistry and the major pathophysiological changes underlying disorders of movement. We try to answer three key questions related to the basal ganglia, as follows: What are the basal ganglia? What are they made of? How do they work? Some insight on the canonical basal ganglia model is provided, together with a selection of paradoxes and some views over the horizon in the field.

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3543080/>

<https://tinyurl.com/395649ae>



◀ **FIGURE 14.11**
 A summary of the **motor loop** from the cortex to the basal ganglia to the thalamus and back to area 6.

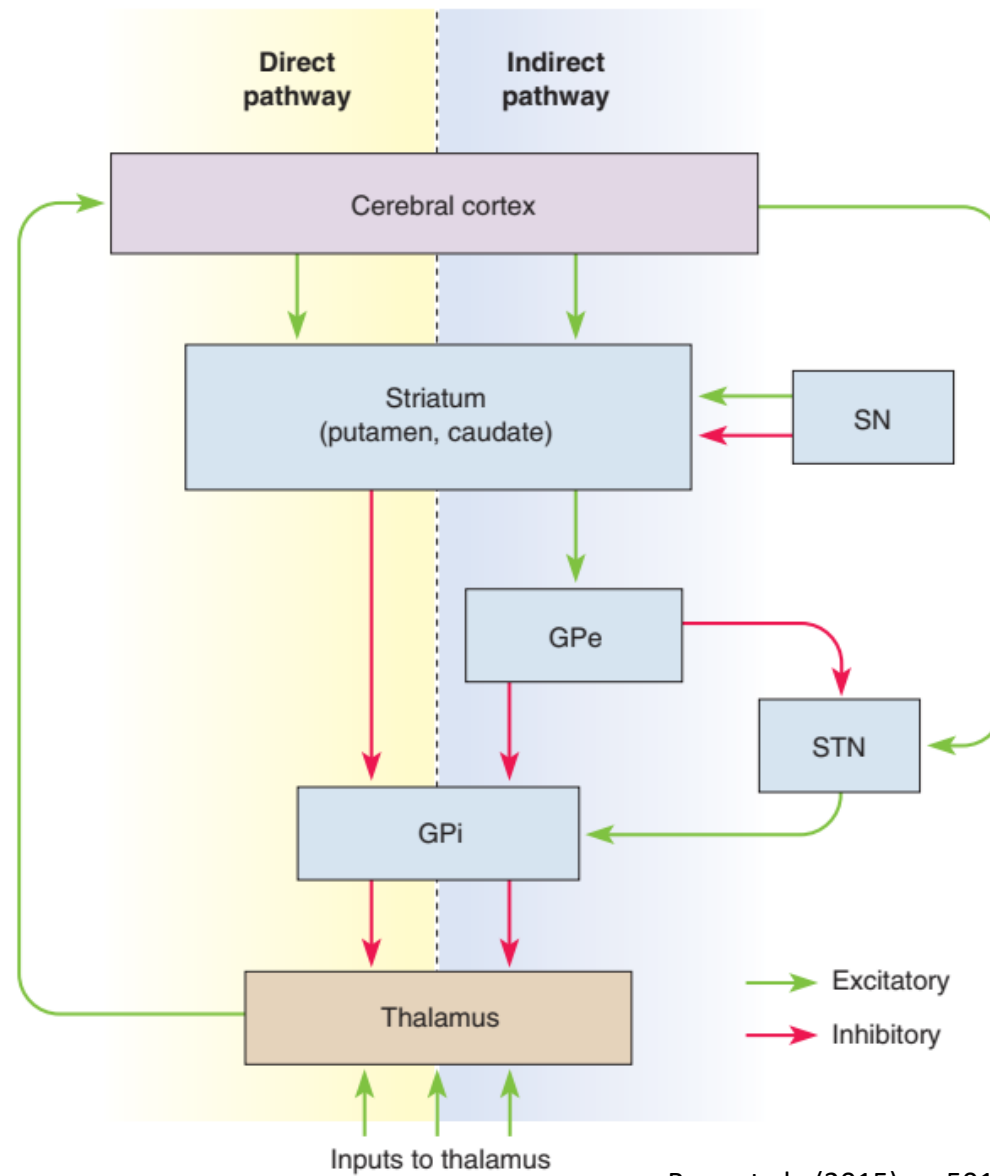
Bear et al., (2015), p. 499

The major **subcortical input** to **area 6 (SMA & PMA)** arises in the **ventral lateral (VL) nucleus** (in the dorsal thalamus). The input to this part of VL (i.e., Nucleus ventralis lateralis pars oralis/ **VLo**), arises from the **basal ganglia**.

The **basal ganglia**, in turn, are **targets of the cerebral cortex** (i.e., the frontal, prefrontal, and parietal cortex).

Thus, we have a **loop** where information cycles **from the cortex through the basal ganglia and thalamus** and then **back to the cortex** (particularly the SMA). One of the functions of this loop appears to be the **selection** and **initiation** of voluntary movements.

In the **direct pathway** through the **basal ganglia**, synapses from cortical cells **excite** cells in the **putamen**, which make **inhibitory synapses** on neurons in the **internal segment of the globus pallidus (Gpi)**, which in turn make **inhibitory** connections with the cells in **Vlo** (part of the ventral lateral nucleus in the dorsal thalamus). The **thalamocortical** connection (from VLo to SMA) is **excitatory** and facilitates the discharge of movement-related cells in the **SMA**. In general, the direct pathway allows the basal ganglia to **enhance** the initiation of voluntary movements.



▲ **FIGURE 14.14** The direct and indirect pathways through the basal ganglia. Dopaminergic neurons of the substantia nigra (SN) modulate the putamen and caudate nucleus. The GPe and the subthalamic nucleus (STN) are part of the indirect pathway.”

Bear et al., (2015), p. 501

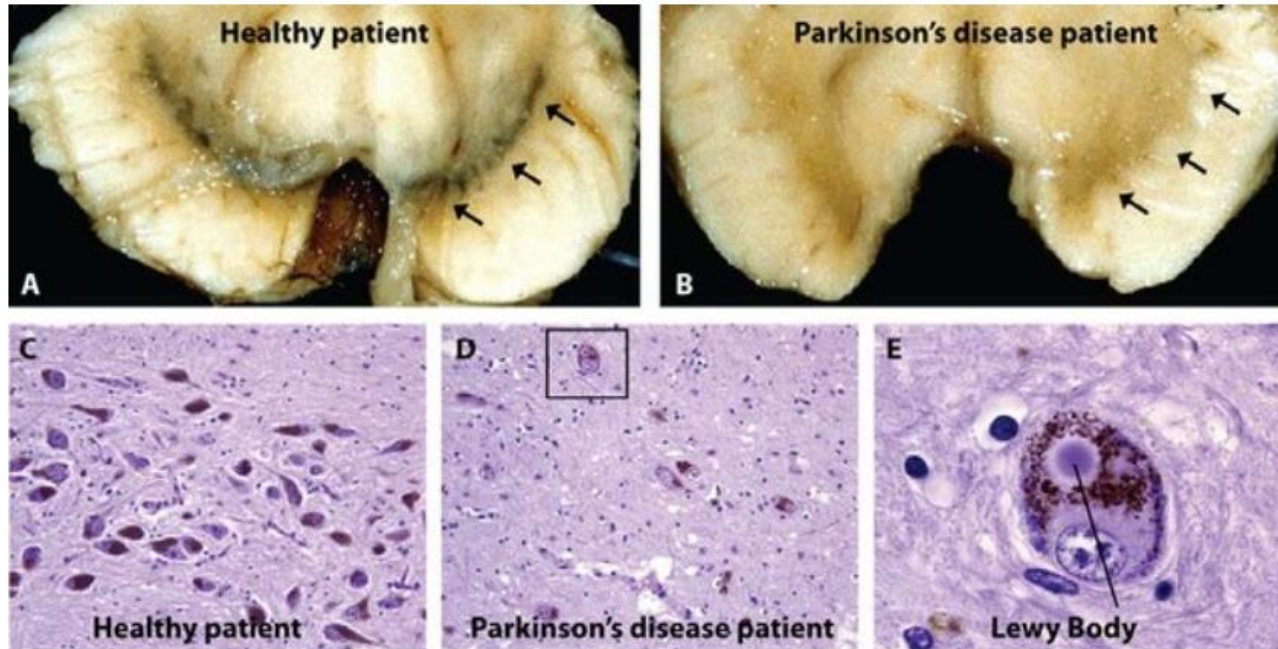
The **indirect pathway** through the basal ganglia tends to **antagonize** the motor functions of the **direct pathway**.

The most unique features of the indirect pathway are the **external segment of the globus pallidus (GPe)**, and the **subthalamic nucleus**. Striatal neurons **inhibit** cells of the GPe, which then **inhibit** cells of both the **internal segment of the globus pallidus (Gpi)** and the subthalamic nucleus.

The subthalamic nucleus is also **excited** by axons from the cortex, and its projections **excite** the neurons of the GPI, which **inhibit** thalamic neurons.

Motor system disorders

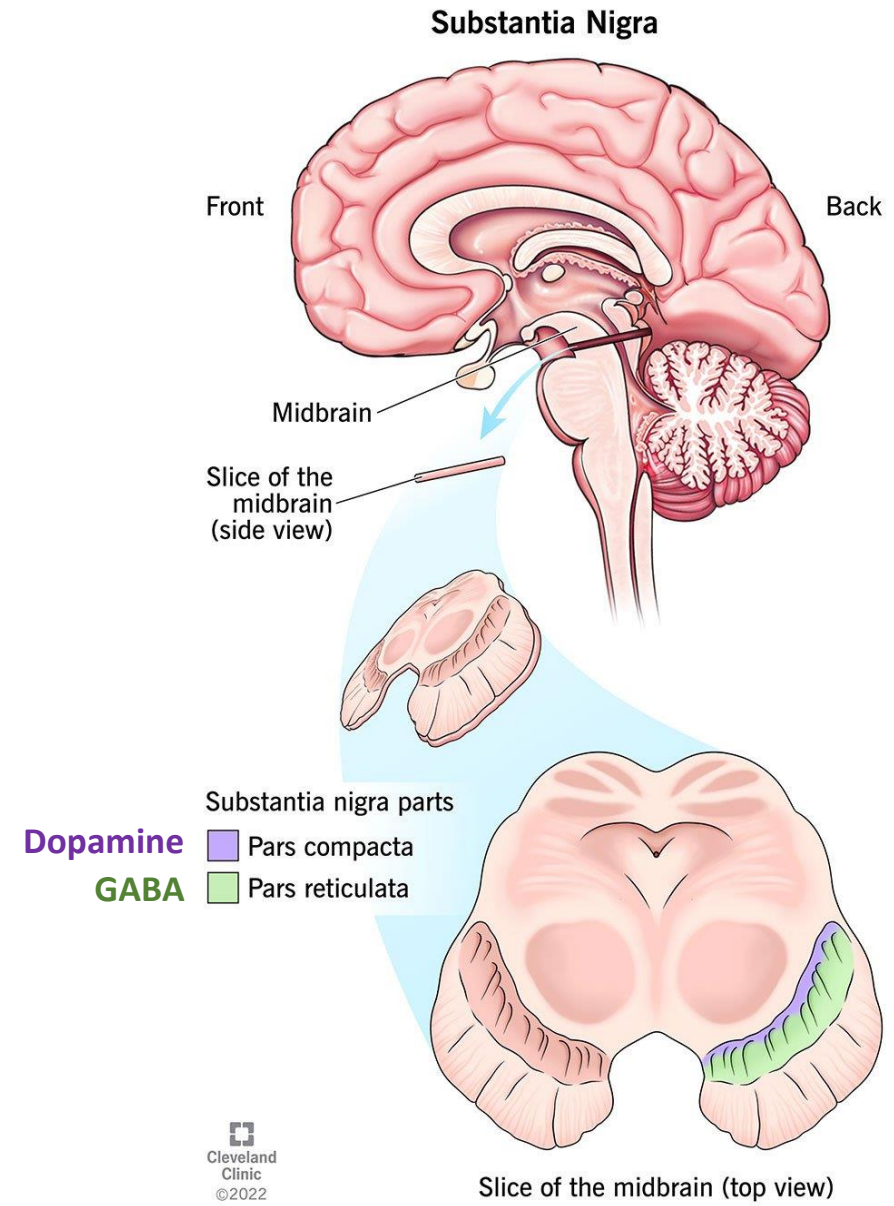
Parkinson's disease



Loss of **substantia nigra (SN) neurons** causes **Parkinson's disease**.
Pathological examination of a healthy patient (A) reveals typical pigmented DA neurons in the SN (arrows); in contrast, loss of SN neurons leads to pigment disappearance in the PD brain (B, arrows).

Aron, (2010), <https://tinyurl.com/yuk3ktjt>

Also see: <https://www.youtube.com/watch?v=ckn9zybpYZ8>

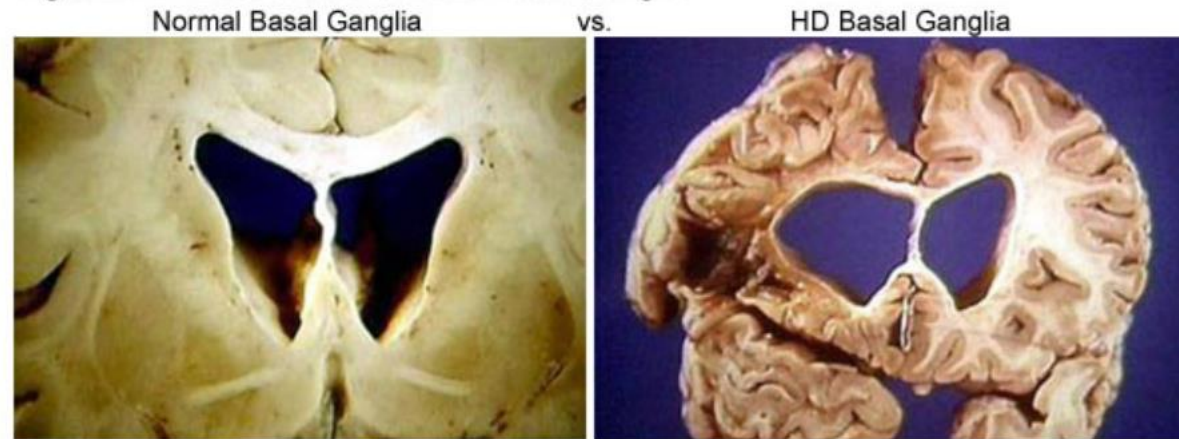


Cleveland Clinic ©2022

<https://tinyurl.com/bdc6ab4d>

Huntington's disease

Figure D-4: Effect of HD on the Basal Ganglia



The basal ganglia of the human brain, showing the impact of HD on brain structure in this region. Note especially that the brain of a person with HD has bigger openings due to the death of nerve cells in that region.

Source: Singer, Jonathan. Huntington's Disease. Online. Available at:
<http://ist-socrates.berkeley.edu/~jmp/HD.html>

<https://tinyurl.com/2f5hx29r>

In persons with HD, the structures of the **basal ganglia** are a lot **smaller** than normal because nerve cells of the **striatum** are the first to **die** as HD progresses.

Although other parts of the brain are also affected during HD, the **basal ganglia** appear to be the **most heavily damaged**.

HD is a **hereditary** disease, and it affect both the **direct** and the **indirect pathways** through the **basal ganglia**.

The loss of motor function can present as:

- uncontrollable **dance-like movements** (chorea);
- **rigidity** (akinesia);
- unusual **fixed** (unchanging) **postures** (dystonia);
- **slurred speech** and problems with **swallowing** (dysphagia), **eating, speaking**, and especially **walking**.

See more at: <https://tinyurl.com/2f5hx29r>

Also watch: <https://www.youtube.com/watch?v=M6Z9bkd7zF8>

Further reading

► Nature. 2023 May;617(7960):351-359. doi: 10.1038/s41586-023-05964-2. Epub 2023 Apr 19.

A somato-cognitive action network alternates with effector regions in motor cortex

Evan M Gordon¹, Roselyne J Chauvin², Andrew N Van^{2 3}, Aishwarya Rajesh⁴, Ashley Nielsen², Dillan J Newbold^{2 5}, Charles J Lynch⁶, Nicole A Seider^{2 7}, Samuel R Krimmel², Kristen M Scheidter², Julia Monk², Ryland L Miller^{2 7}, Athanasia Metoki², David F Montez², Annie Zheng², Immanuel Elbau⁶, Thomas Madison⁸, Tomoyuki Nishino⁷, Michael J Myers⁷, Sydney Kaplan², Carolina Badke D'Andrea^{4 7 9}, Damion V Demeter⁹, Matthew Feigelis⁹, Julian S B Ramirez¹⁰, Ting Xu¹⁰, Deanna M Barch^{4 7 11}, Christopher D Smyser^{4 2 12}, Cynthia E Rogers^{6 12}, Jan Zimmermann¹³, Kelly N Botteron⁷, John R Pruett⁷, Jon T Willie^{2 6 14}, Peter Brunner^{3 14}, Joshua S Shimony⁴, Benjamin P Kay², Scott Marek⁴, Scott A Norris^{4 2}, Caterina Gratton¹⁵, Chad M Sylvester⁷, Jonathan D Power⁶, Conor Liston⁶, Deanna J Greene⁹, Jarod L Roland¹⁴, Steven E Petersen^{4 2 3 11 16}, Marcus E Raichle^{4 2 3 11 16}, Timothy O Laumann⁷, Damien A Fair^{8 17 18}, Nico U F Dosenbach^{19 20 21 22 23 24}

<https://pubmed.ncbi.nlm.nih.gov/37076628/>

Abstract

Motor cortex (M1) has been thought to form a continuous **somatotopic** homunculus extending down the precentral gyrus from foot to face representations^{1,2}, despite evidence for concentric functional zones³ and maps of complex actions⁴. Here, using **precision functional magnetic resonance imaging (fMRI)** methods, we find that **the classic homunculus is interrupted by regions with distinct connectivity, structure and function, alternating with effector-specific (foot, hand and mouth) areas.** These inter-effector regions **exhibit decreased cortical thickness and strong functional connectivity to each other, as well as to the cingulo-opercular network (CON), critical for action⁵ and physiological control⁶, arousal⁷, errors⁸ and pain⁹.** This interdigitation of action control-linked and motor effector regions was verified in the three largest fMRI datasets. Macaque and pediatric (newborn, infant and child) precision fMRI suggested **cross-species homologues and developmental precursors** of the inter-effector system. A battery of motor and action fMRI tasks documented concentric effector somatotopies, separated by the CON-linked inter-effector regions. The inter-effectors lacked movement specificity and co-activated during action planning (coordination of hands and feet) and axial body movement (such as of the abdomen or eyebrows). These results, together with previous studies demonstrating stimulation-evoked complex actions⁴ and connectivity to internal organs¹⁰ such as the adrenal medulla, suggest that M1 is punctuated by a system for whole-body action planning, the somato-cognitive action network (SCAN). In M1, two parallel systems intertwine, forming an integrate-isolate pattern: effector-specific regions (foot, hand and mouth) for isolating fine motor control and the SCAN for integrating goals, physiology and body movement.

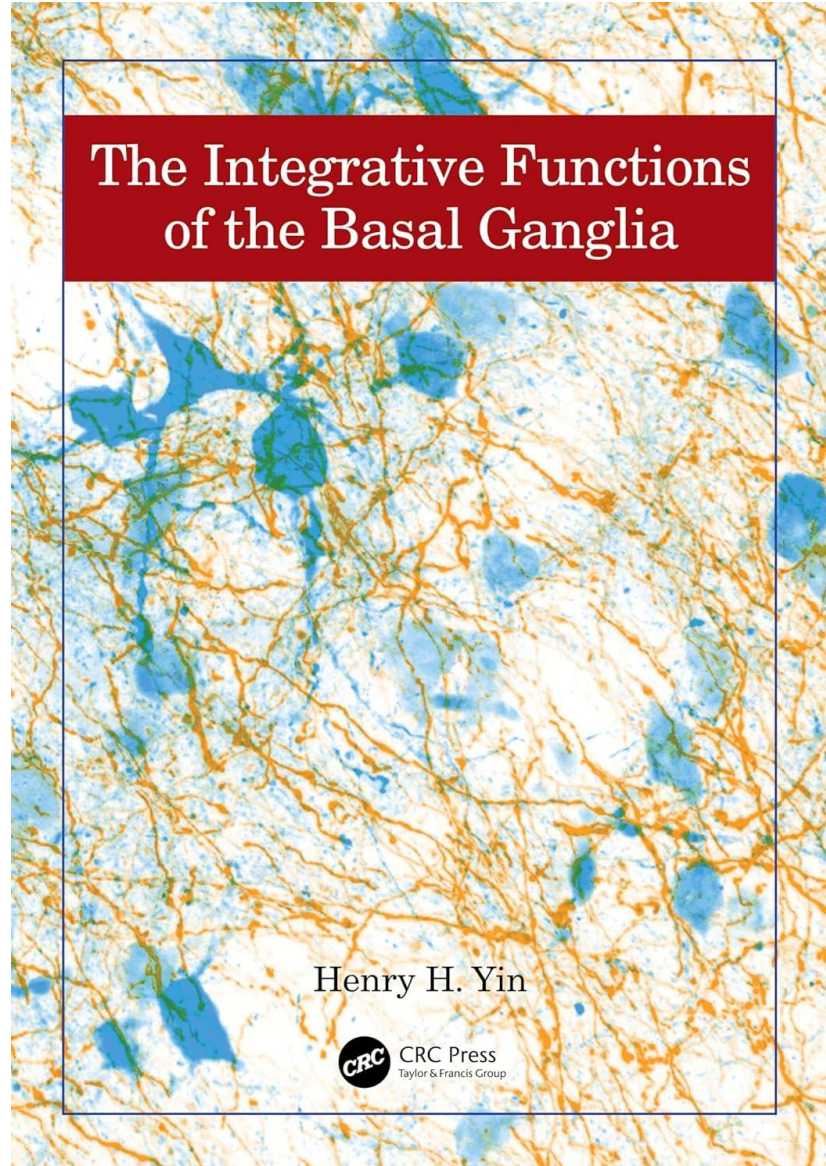


Table of Contents

1. Introduction
2. Anatomical Organization of the Basal Ganglia
3. Synaptic Transmission and Plasticity in the Basal Ganglia
4. Current Ideas on BG Function
5. Behavior and Control
6. The Place of the BG in the Hierarchy
7. Transition Control
8. Higher-Order Transitions and Cognition
9. Motivation
10. Actions and Goals
11. Corticostriatal Contributions to Habits and Behavioral Automaticity
12. Dopamine and Reinforcement Learning
13. Reorganization, Exploration, and Plasticity
14. Interpretation of Clinical Symptoms
15. Synthesis

Further resources



Something Hidden - A Portrait of Wilder Penfield

<https://www.youtube.com/watch?v=ygrT34F0Hrc>