Introduction to Cognitive Neuroscience

Brain Control of Movement

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Central motor system and The motor control hierarchy

- The final **common pathway** for behavior in **peripheral somatic motor system** is the **alpha motor neuron**, that the activity of this cell is under the control of **sensory feedback** and **spinal interneurons**.
- The central motor system is arranged as a **hierarchy** of **control levels**, with the **forebrain** at the top and the **spinal cord** at the bottom.

Level	Function	Structures
High	Strategy	Association areas of neocortex, basal ganglia
Middle	Tactics	Motor cortex, cerebellum
Low	Execution	Brain stem, spinal cord

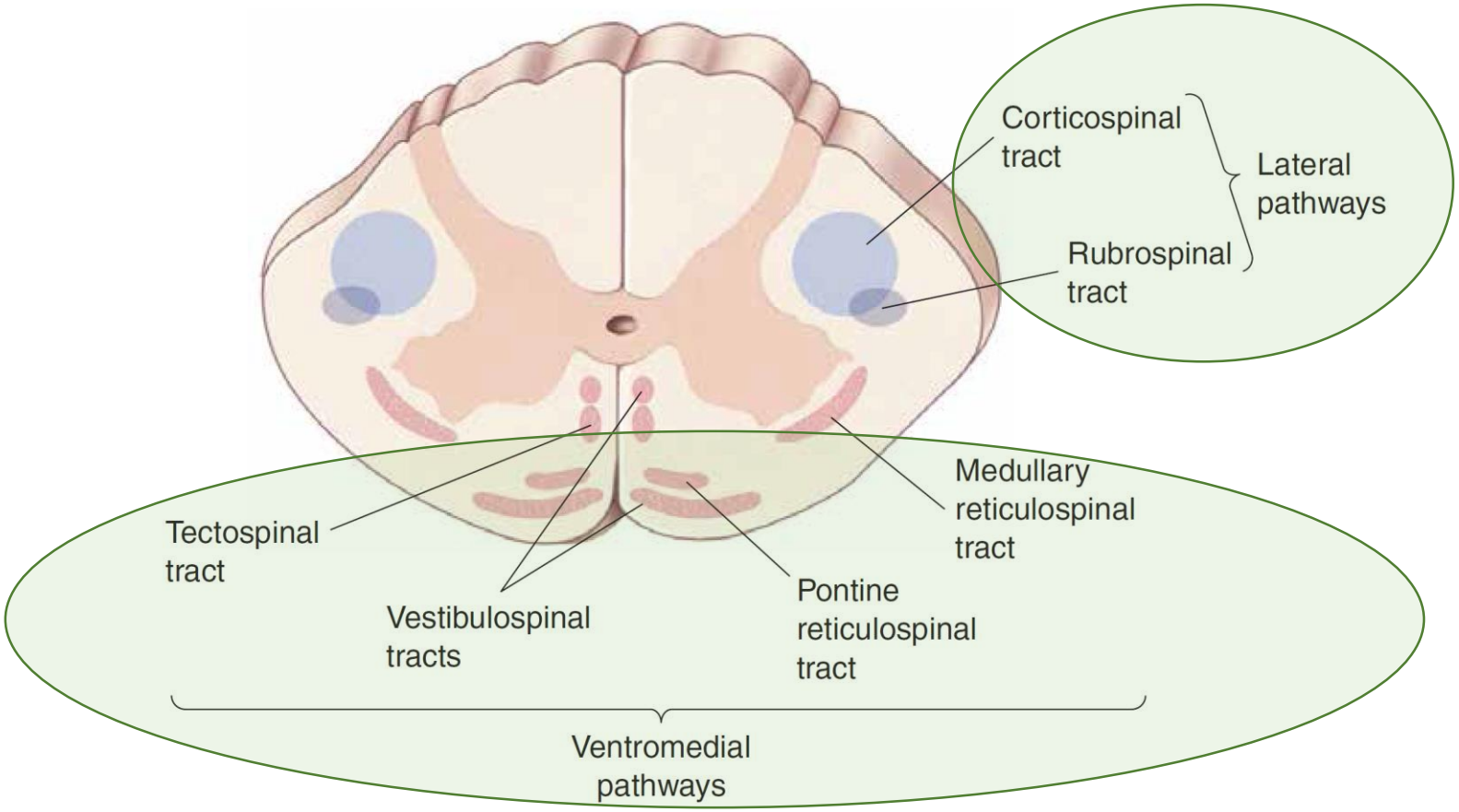
The contributions of the motor control hierarchy.

As a baseball pitcher **plans** to pitch a ball to a batter, **chooses** which pitch to throw, and then throws the ball, he **engages** the three hierarchical levels of motor control.

Sensorimotor system: The motor control hierarchy relies so heavily on sensory information

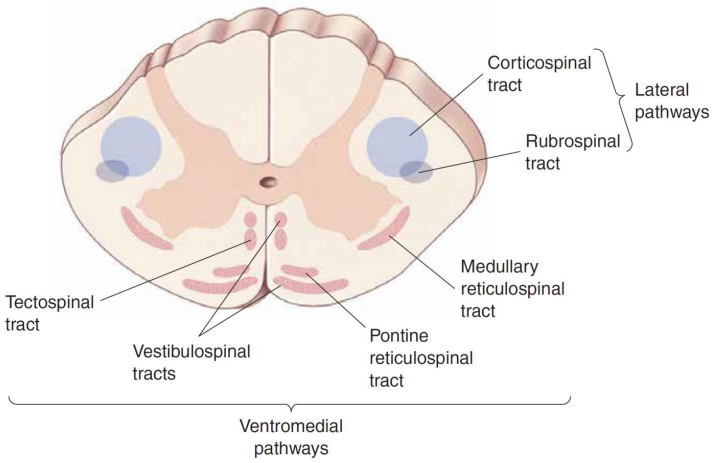
The descending tracts of the spinal cord

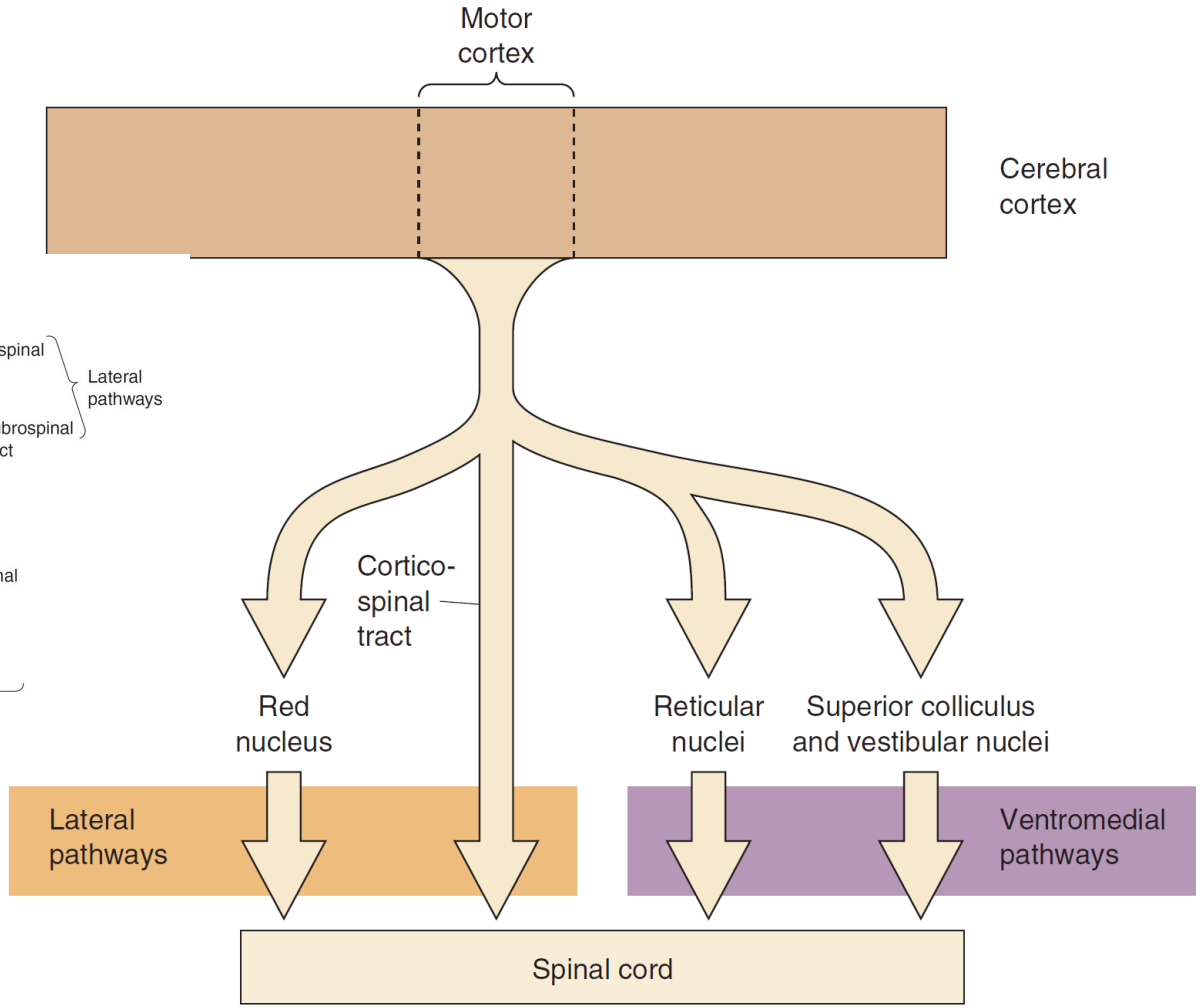
Voluntary movement of the **distal** musculature and are under direct **cortical control**



Control of posture and locomotion and are under brain **stem control**

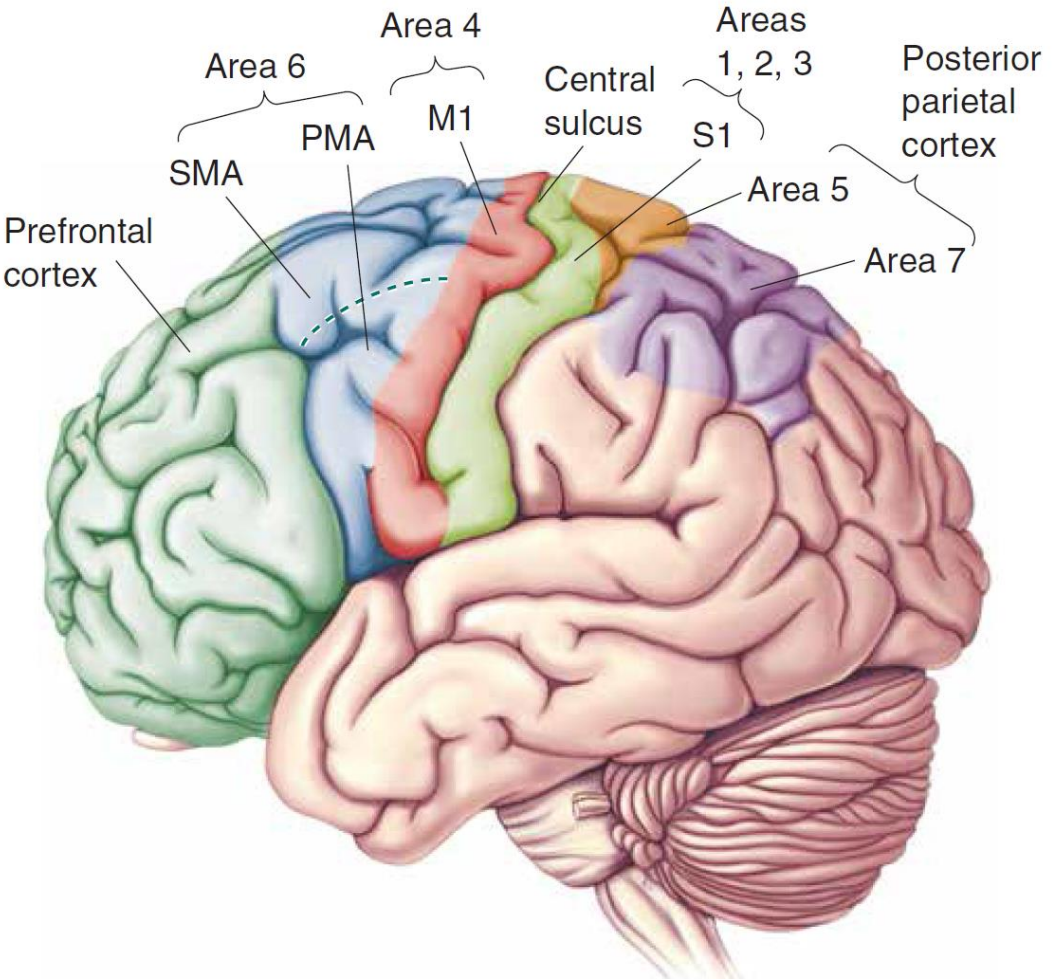
The major descending spinal tracts and their origins



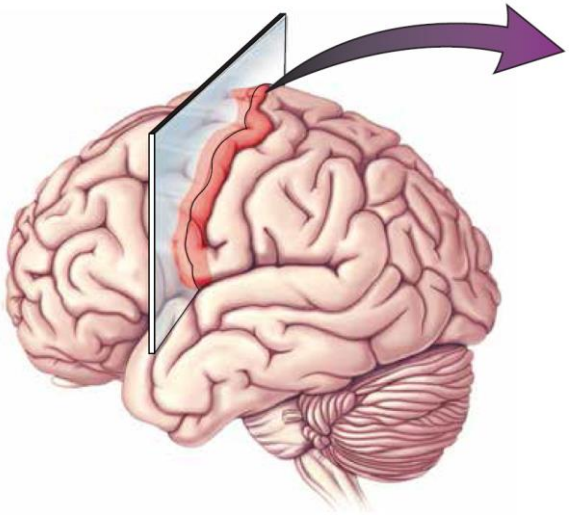


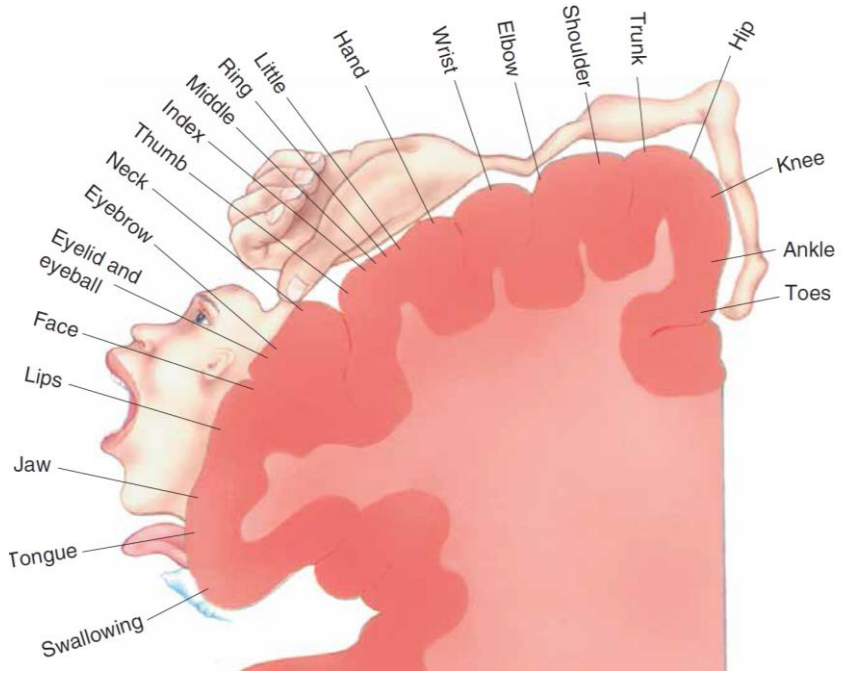
Planning and directing voluntary movements

- Goal-directed movement depends on knowledge of:
  - Where the body is in **space**
  - Where it **intends** to go
- Plan must be held in **memory** until the appropriate time
- Instructions must be issued to **implement the plan**



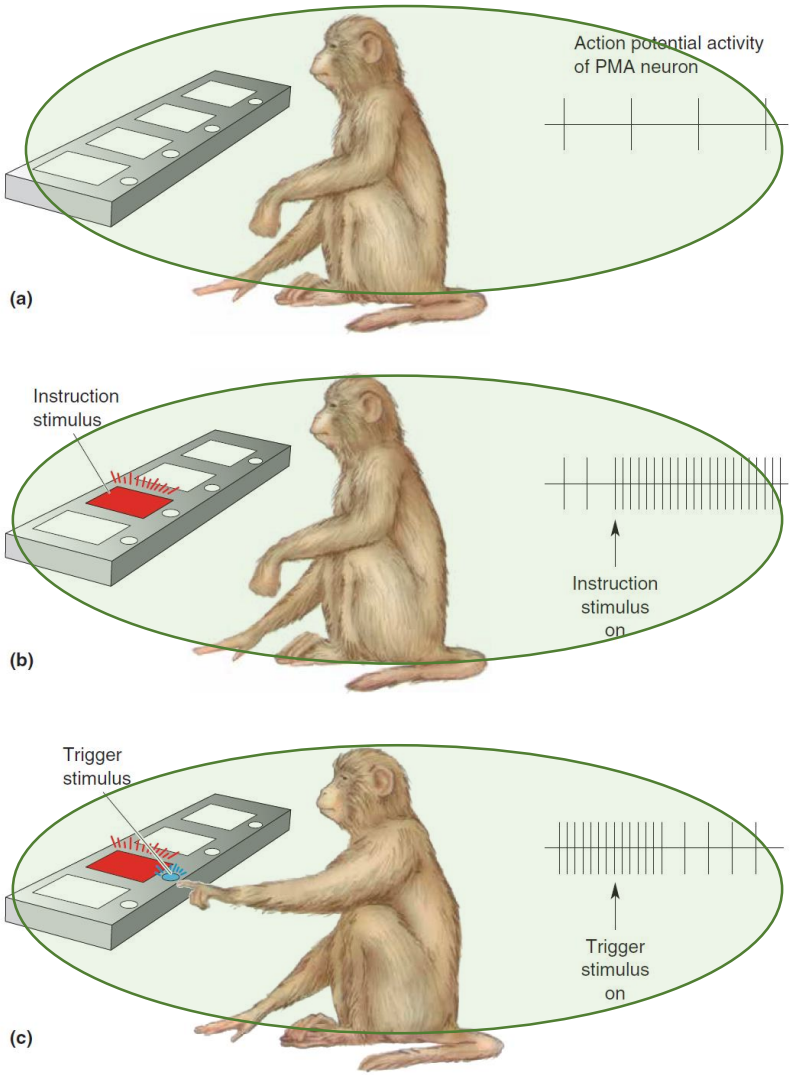
- Area 4: **precentral** gyrus; **primary motor cortex** or **M1**.
- It came from the work of neurosurgeon **Wilder Penfield**
- Area 6 is higher motor area and stimulation of this area evokes **complex movements**
- Penfield found two **somatotopically** organized motor maps in area 6:
  - Lateral region: **premotor area (PMA);** it innervate **distal** motor units
  - Medial region: **supplementary motor area (SMA**); it innervate **proximal** motor units





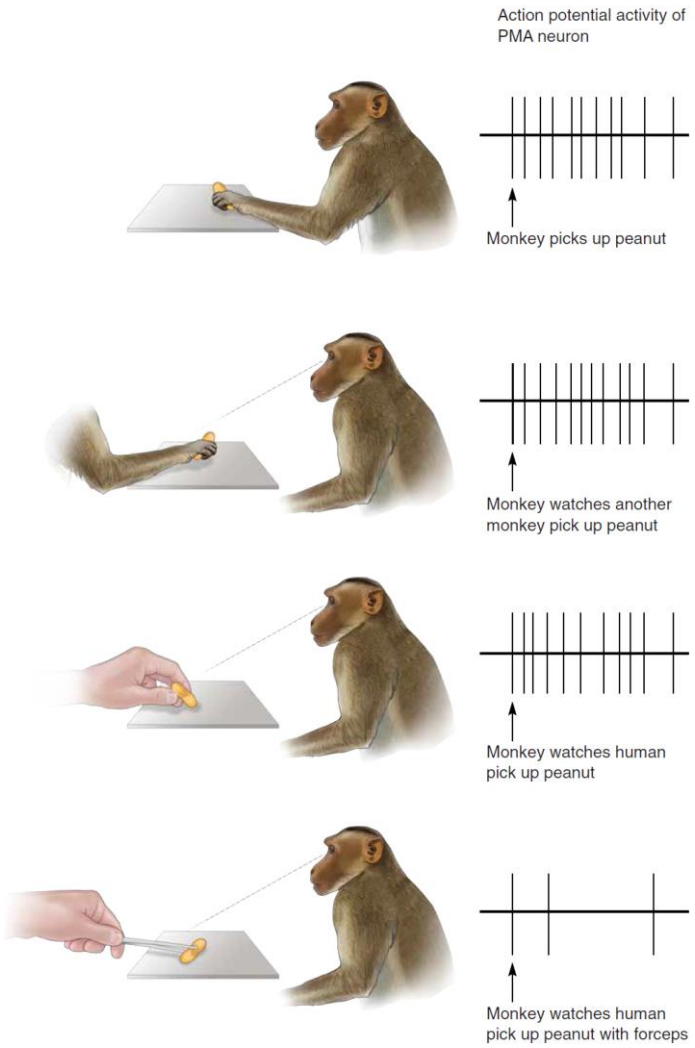
Neuronal correlates of motor planning

- **The discharge of a neuron in the premotor area before a movement (planning stage).**
  - The task is to **wait** for an instruction stimulus that will inform him of the movement required to receive a juice reward, then perform the movement **when a trigger stimulus goes on**. The activity of a neuron in PMA is recorded during the task.
- **(a)** *Ready:* A monkey sits before a panel of lights.
- **(b)** *Set:* The instruction stimulus (one of the square red lights) occurs:
  - The **discharge of the neuron** in PMA.
- **(c)** *Go:* A trigger stimulus (a blue light in one of the buttons) tells the monkey when and where to move.
  - Shortly after the movement is initiated, the PMA cell **ceases firing**.



Mirror Neurons

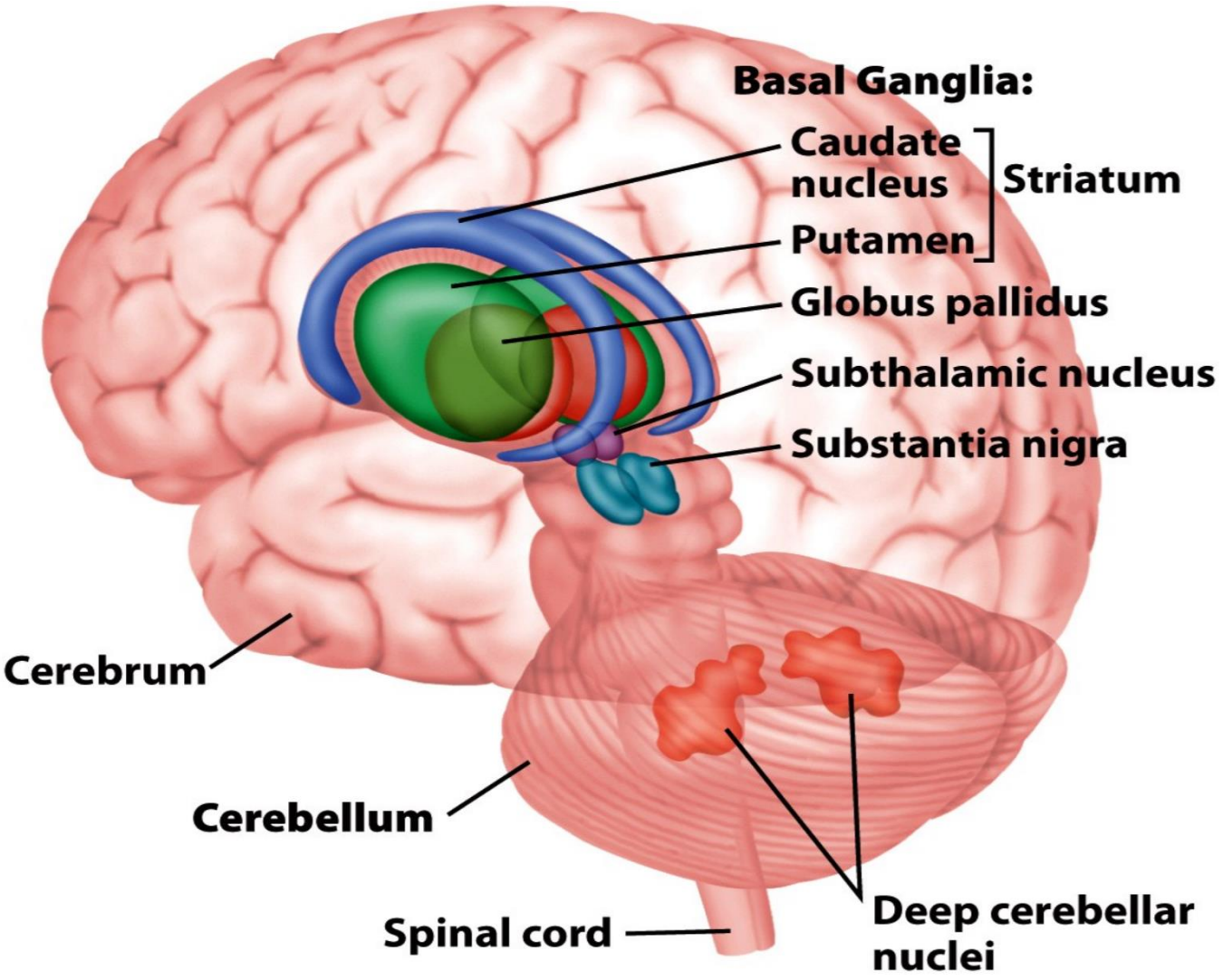
- some neurons fire not only when a monkey makes a specific **movement** himself but also when the monkey simply **observes** another monkey, or even a **human**, making the same type of movement
- by Giacomo Rizzolatti and his colleagues
- It is very likely that humans also have mirror neurons in PMA (some fMRI studies)
- It can be considered to be responsible for our ability to read the **emotions** and sensations of others and to **empathize**.
- dysfunctional mirror neurons are responsible for certain **features of autism**.



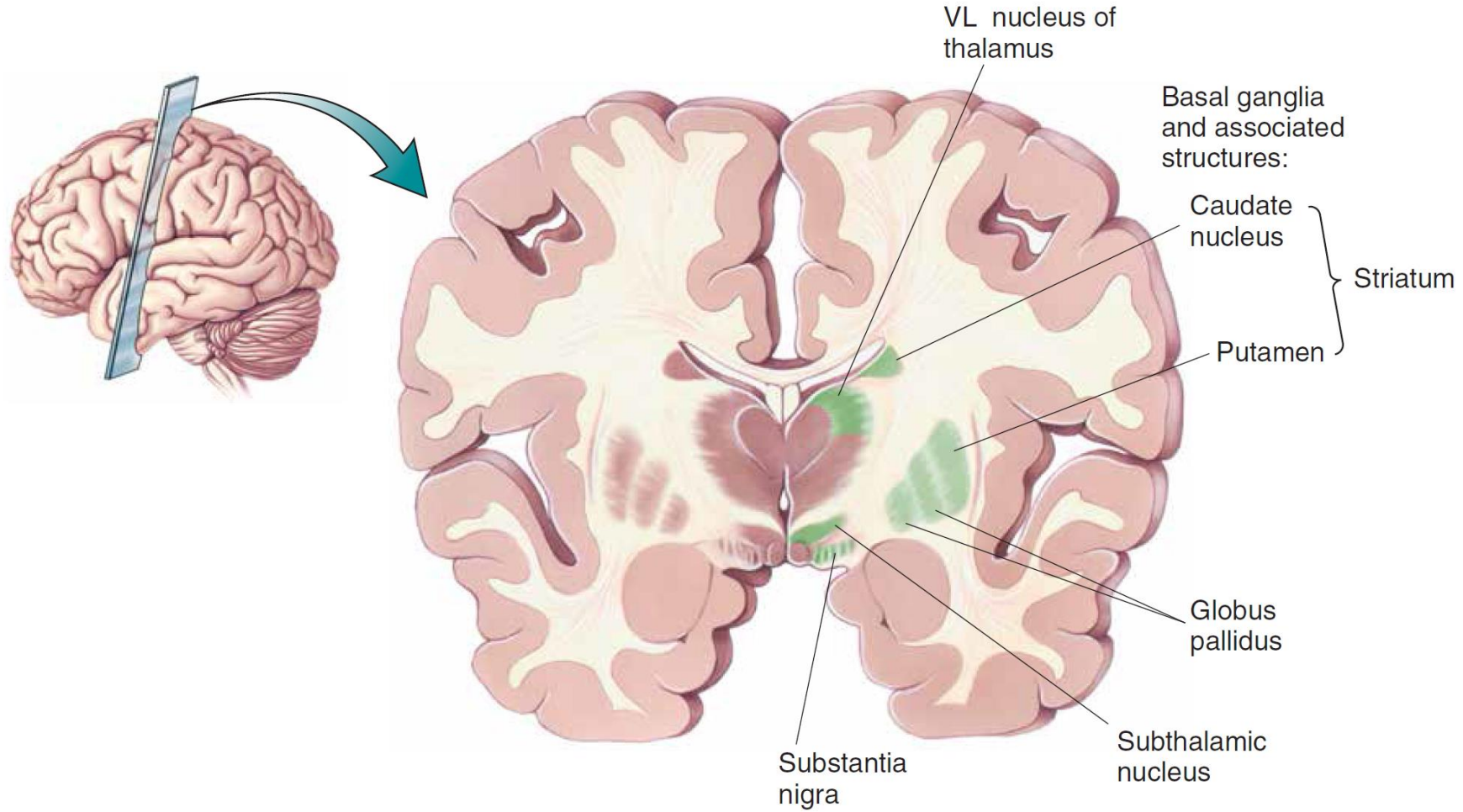
Initiation of willed movements

- We have a **loop** where information **cycles** from the cortex through the basal ganglia and thalamus and then back to the cortex
- The basal ganglia consist of:
  - The **caudate nucleus**,
  - The **putamen**
  - The **globus pallidus** (consisting of an internal segment, Gpi, and an external segment, Gpe),
  - The **subthalamic nucleus**
  - The **substantia nigra**, a **midbrain structure** that is reciprocally connected with the basal ganglia of the **forebrain**
- **Striatum**
  - The caudate and putamen together are called the

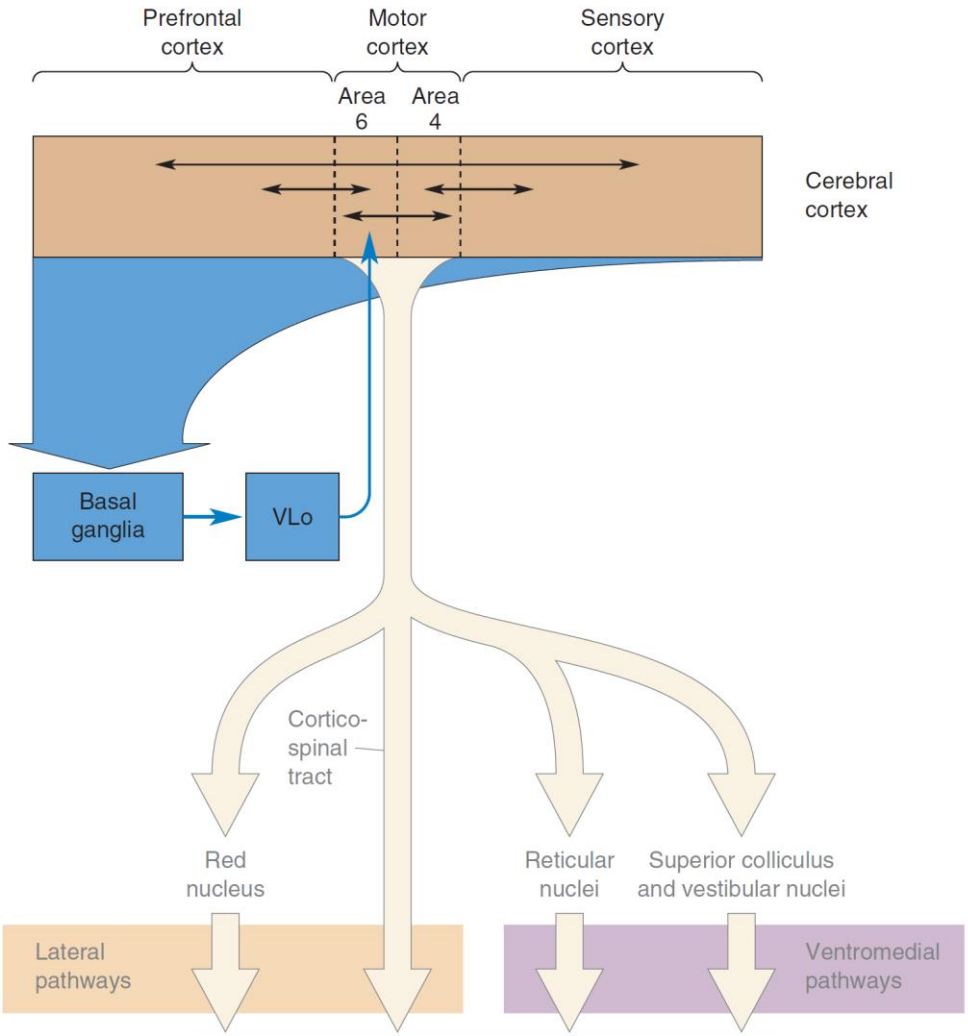
$$\text{Cortex} \rightarrow \text{Striatum} \rightarrow \text{GPi} \rightarrow \text{VLo} \rightarrow \text{Cortex (SMA)}$$


Basal Ganglia:
Caudate nucleus
Striatum
Putamen
Globus pallidus
Subthalamic nucleus
Substantia nigra
Cerebrum
Cerebellum
Spinal cord
Deep cerebellar nuclei

The basal ganglia and associated structures.



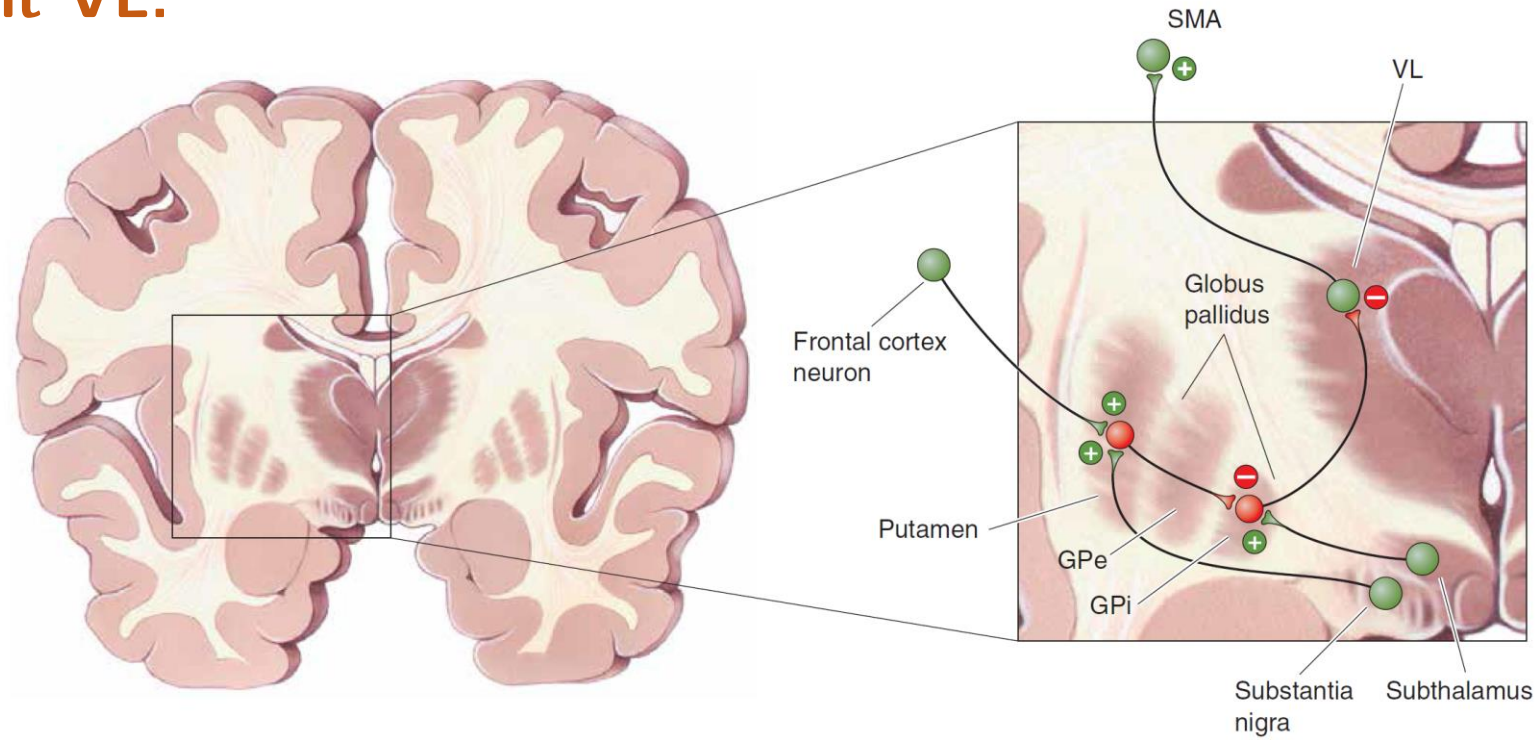
A summary of the motor loop from the cortex to the basal ganglia to the thalamus and back to area 6.



$$\text{Cortex} \rightarrow \text{Striatum} \rightarrow \text{GPi} \rightarrow \text{VLo} \rightarrow \text{Cortex (SMA)}$$

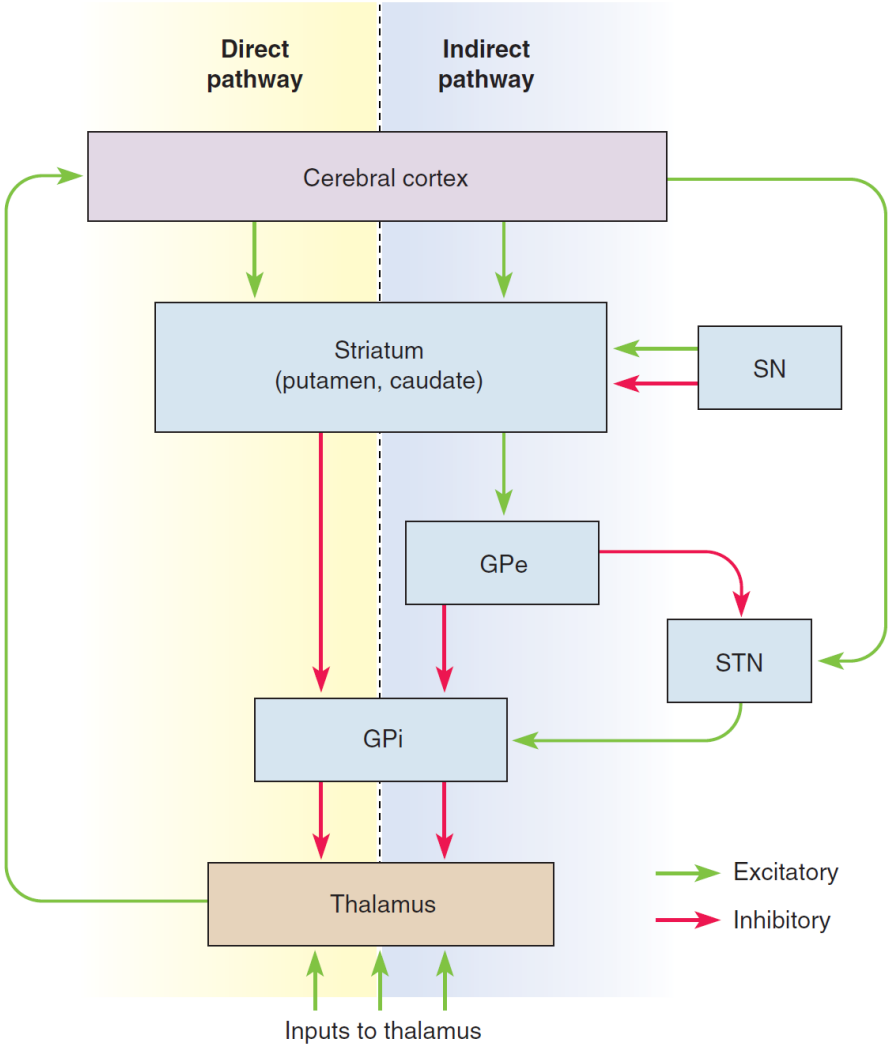
A wiring diagram of the basal ganglia motor loop

Neurons in the internal segment of the globus pallidus are **spontaneously active at rest**, and therefore they **tonically inhibit VL.**



Synapses marked with a plus (+) are **excitatory**; those with a minus (-) are **inhibitory**.

The direct and indirect pathways through the basal ganglia

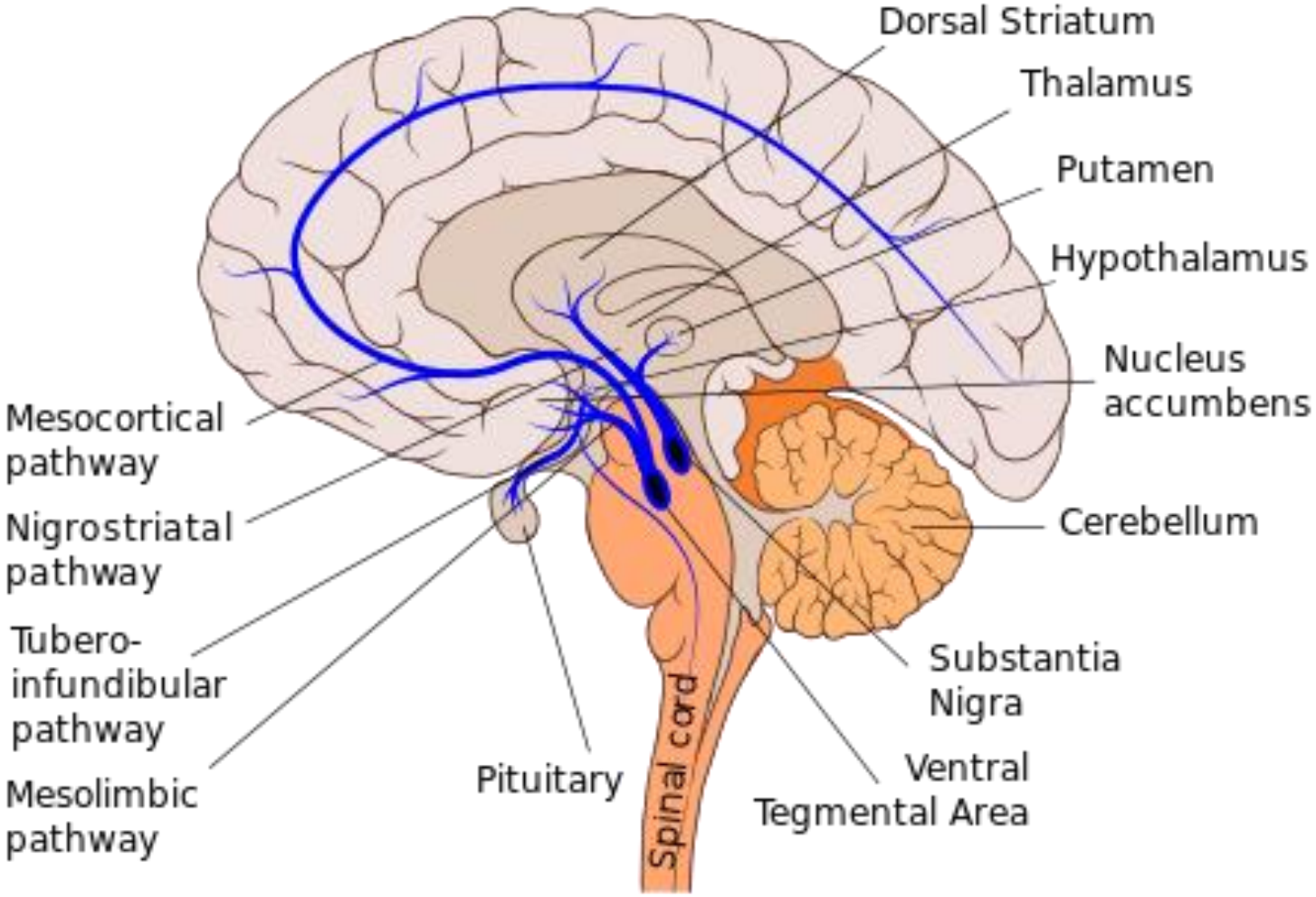


- Direct pathway:
  - To **facilitate** the thalamus and information passing through it,
  - Help to **select** certain motor actions
- Indirect pathway:
  - To **inhibit** the thalamus.
  - Simultaneously **suppresses competing**, and **inappropriate**, motor programs
- **Dopaminergic neurons** of the substantia nigra (**SN**) modulate the putamen and caudate nucleus.
- **STN** stands for subthalamic nucleus

Basal ganglia disorders

- Increased inhibition of the thalamus by the basal ganglia
  - *Hypokinesia* a **paucity** of movement
  - **Parkinson's disease;** affects about **1%** of all people over age 60,
  - The organic **basis of parkinson's** disease is a **degeneration** of certain **substantia nigra** neurons (dopaminergic (DA) neurons) and their inputs to the striatum
  - DA **facilitates** the direct motor loop by **activating cells in the putamen** (which **releases vlo from gpi-induced inhibition**).
  - **L-dopa** crosses the blood–brain barrier and boosts **DA synthesis** in the cells that remain alive in the substantia nigra, thus **alleviating some of the symptoms**
- Decreased basal ganglia output
  - *Hyperkinesia*
  - **Huntington's diseas;** 5–10 people per 100,000
  - Characteristic sign of the disease is **chorea** — spontaneous, uncontrollable, and purposeless movements with rapid, irregular flow and flicking motions of various parts of the body
  - **Pathology**: damage to structures in the basal ganglia and consequent **loss of its inhibitory output to the thalamus**

Dopaminergic pathways



Basal Ganglia Disorders

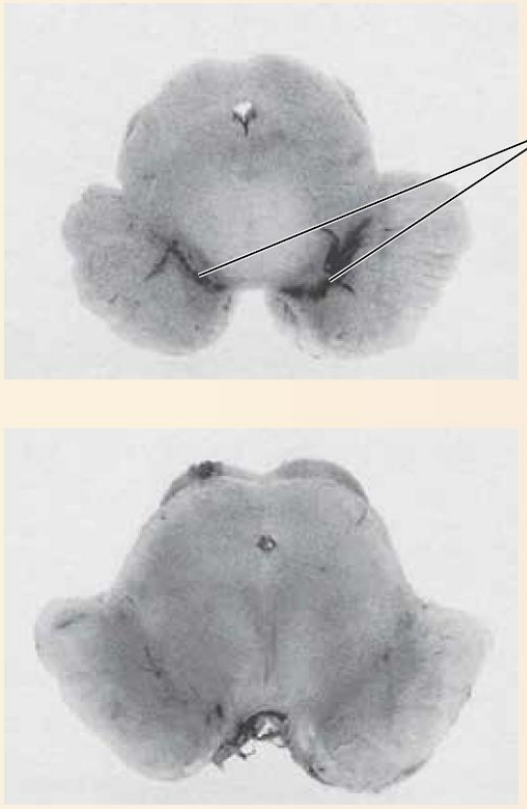


Figure A
Normal (top); Parkinson's disease (bottom). (Source: Strange, 1992, Fig. 10.3.)

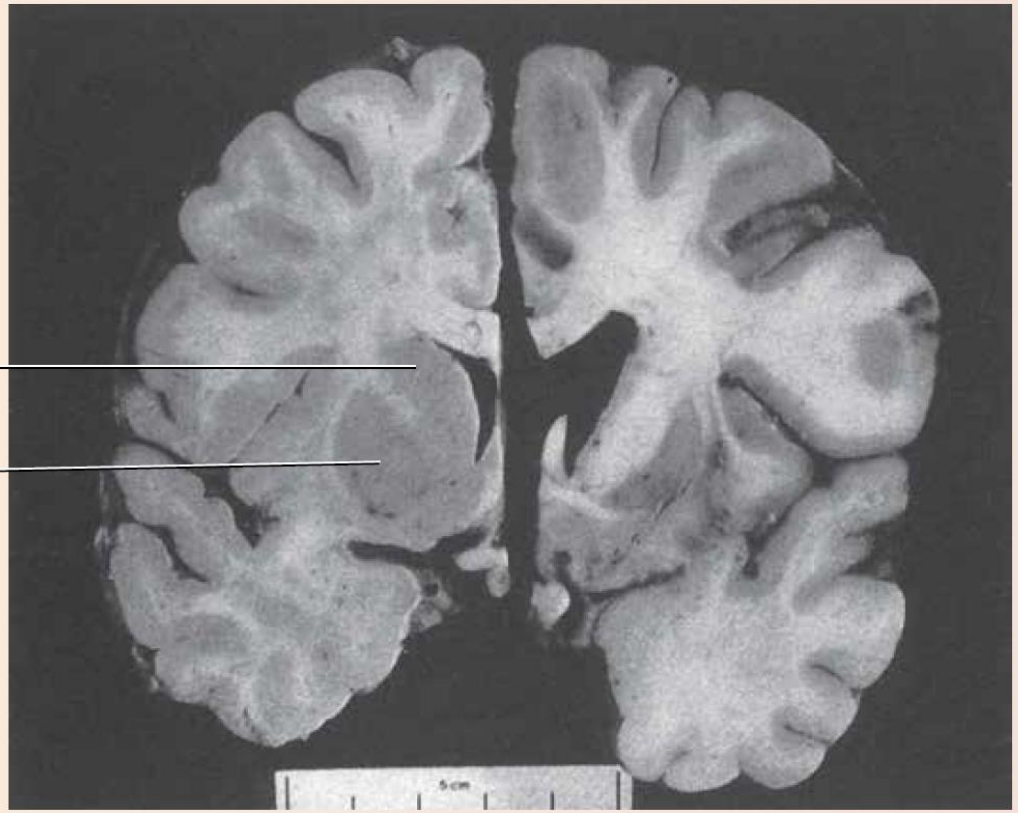
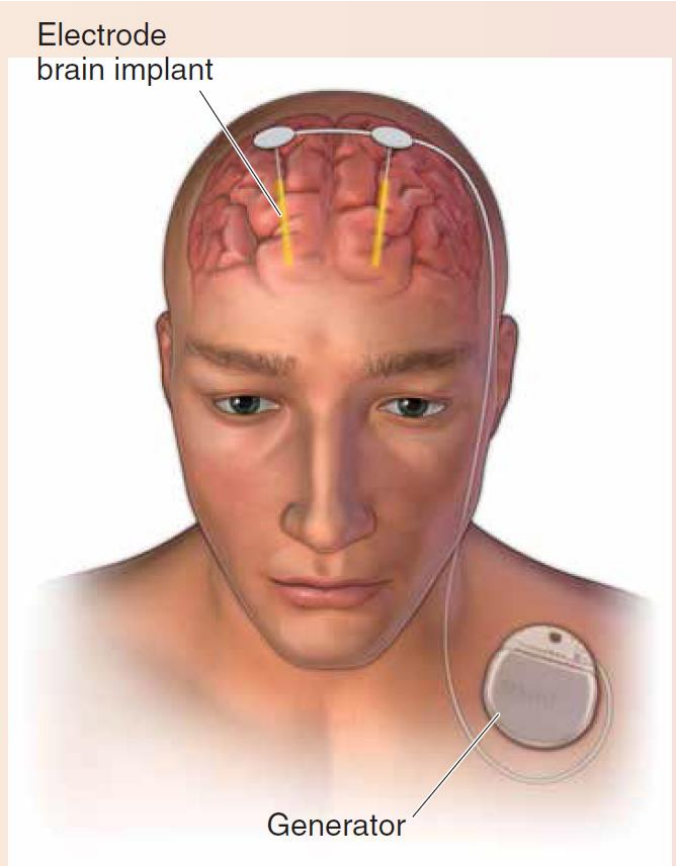


Figure B
Normal (left); Huntington's disease (right). (Source: Strange, 1992, Fig. 11.2.)

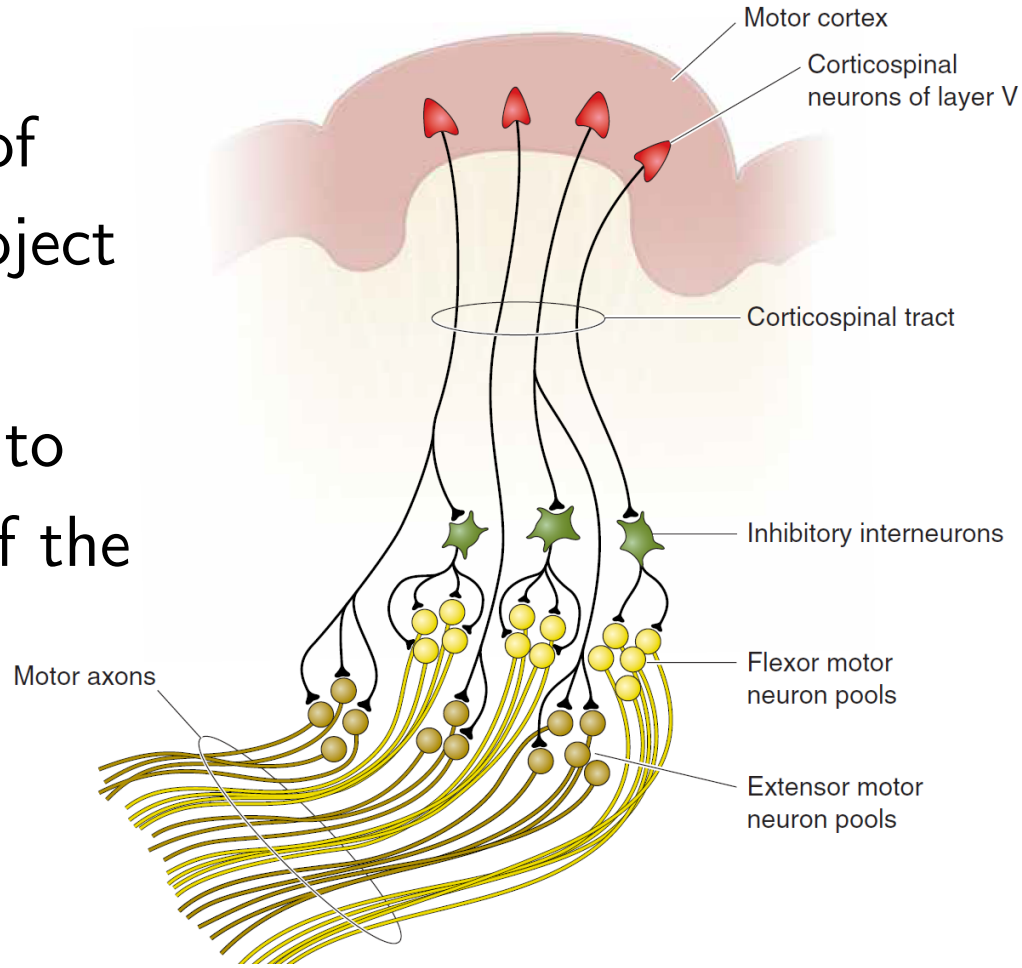
Stimulation: useful therapies for brain disorders

- The ancient Greeks and Egyptians were early advocates of the therapeutic power of **electrical shocks** by electric **eels** and **rays** to heal headache, hemorrhoids, gout, depression, and even epilepsy
- DBS is surgically implanted bilateral electrodes with their tips in the **subthalamic** nuclei or, less often, in the **GPi nuclei**
- DBS is a very **crude** tool
  - Effective stimulation pattern tends to be a continuous stream of brief shocks at very **high frequency** (130–180 Hz).
  - This does not resemble any **natural neural pattern** in the brain
  - It can **block abnormal** firing in some cases.



The initiation of movement by primary motor cortex

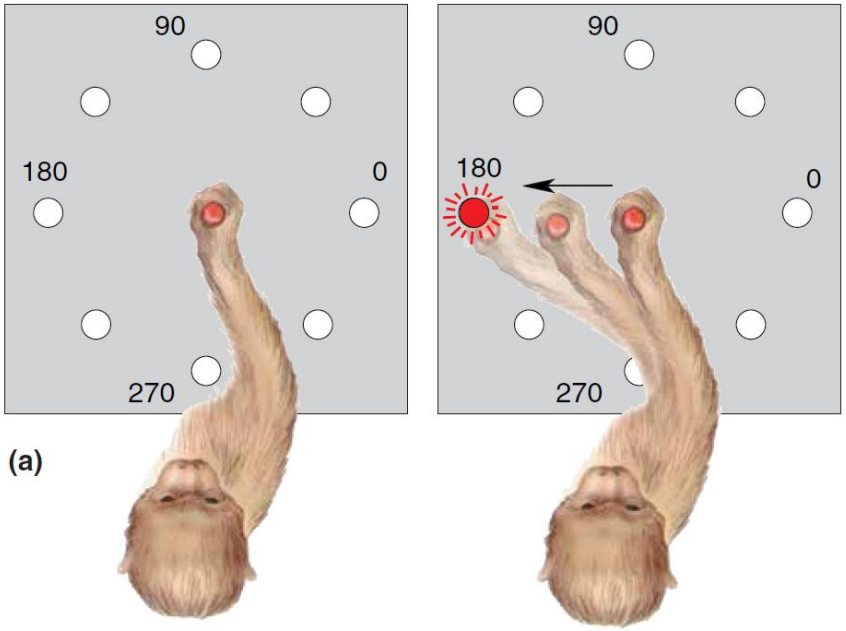
- Large **pyramidal** neurons in **layer V** of the motor cortex project axons, via the **corticospinal** tract, to the **ventral horns** of the spinal cord.

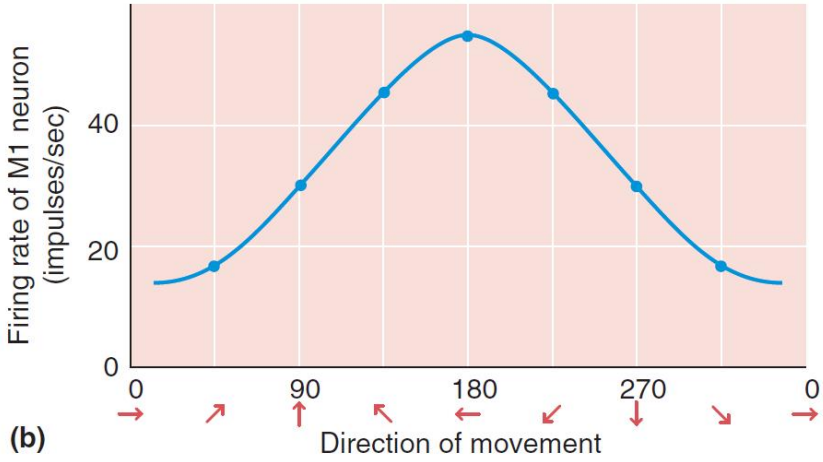


The Coding of Movement in M1

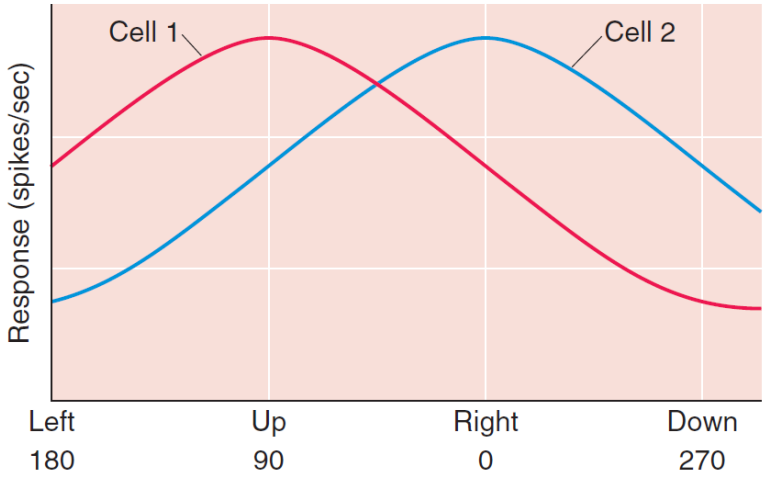
- Researchers previously thought the motor cortex consisted of a **detailed mapping of the individual muscles;** so the activity of a **single pyramidal** cell would lead to activity in a **single motor neuron** pool
- **Modern view**: individual pyramidal cells can **drive numerous motor** neuron pools from a group of different **muscles** involved in moving a limb toward a desired goal.
  - M1 neurons encodes two aspects of the movement: **force** and **direction**

Responses of an M1 neuron during arm movements in different directions.

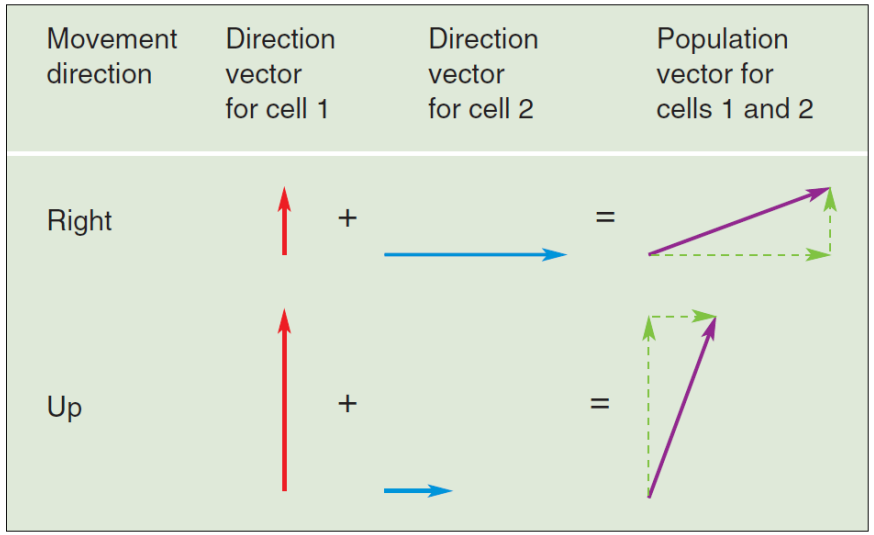




Direction vectors and population vectors



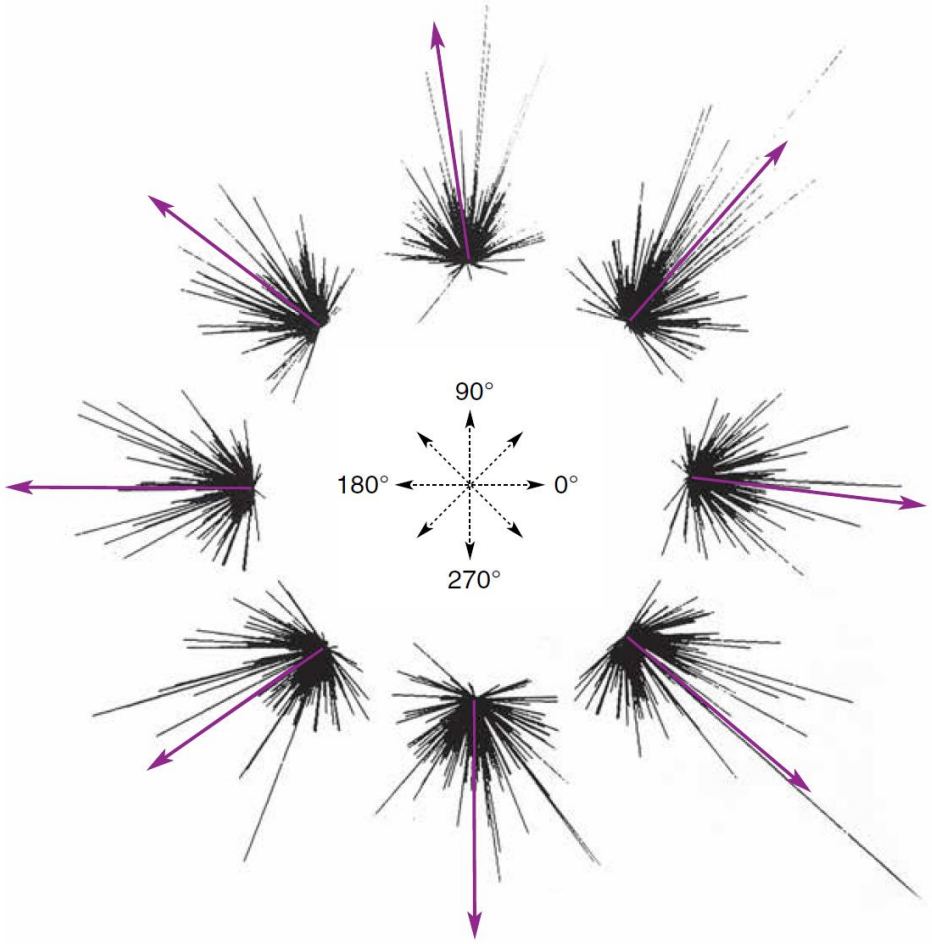
(a)



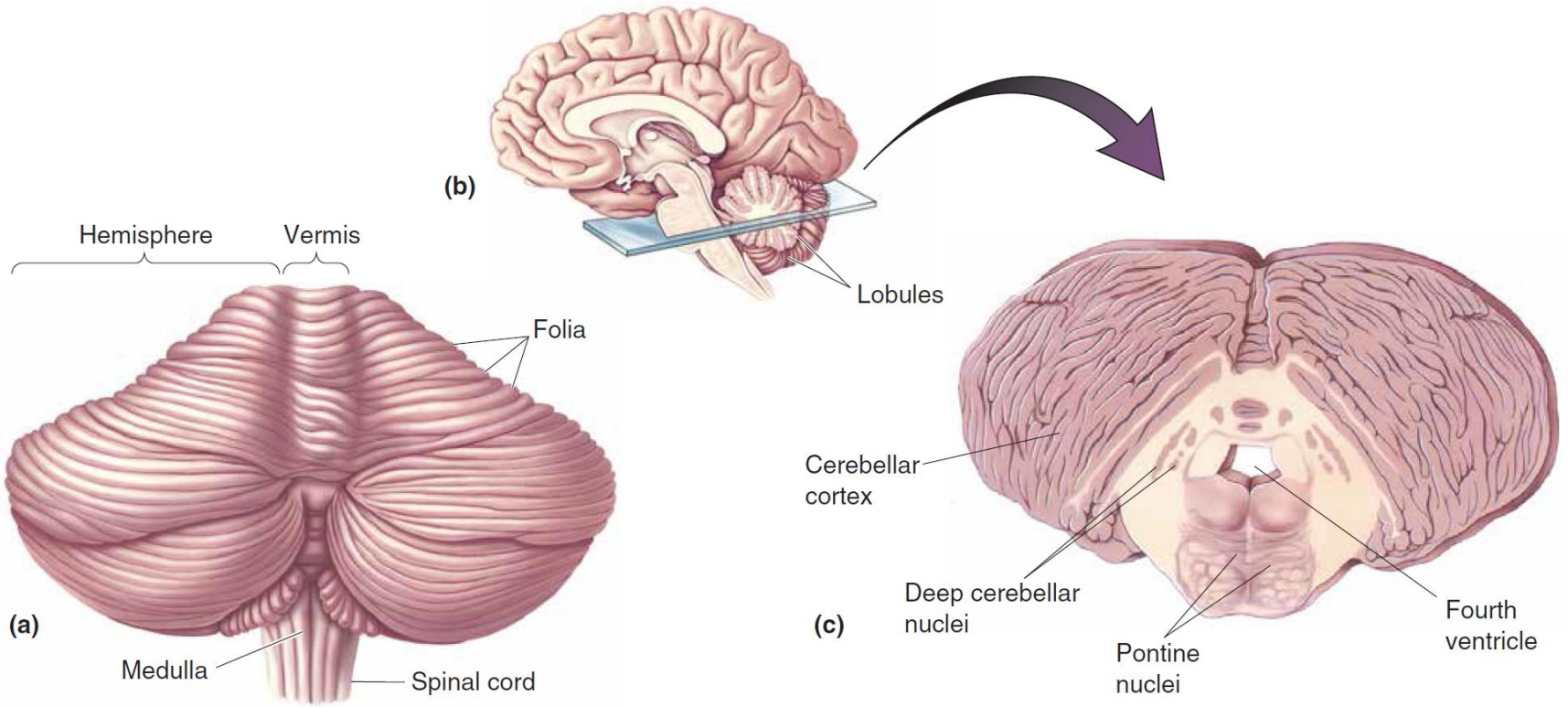
(b)

Predicting the direction of movement by population vectors

- Each **cluster** of lines reflects the direction vectors of **many cells in M1**.
- Line **length** reflects the **discharge** rate of each cell during a movement in one of eight different directions.
- **Arrows represent** the average population vectors, which predict the movement direction of the monkey's arm



The cerebellum



The motor loop through the cerebellum.