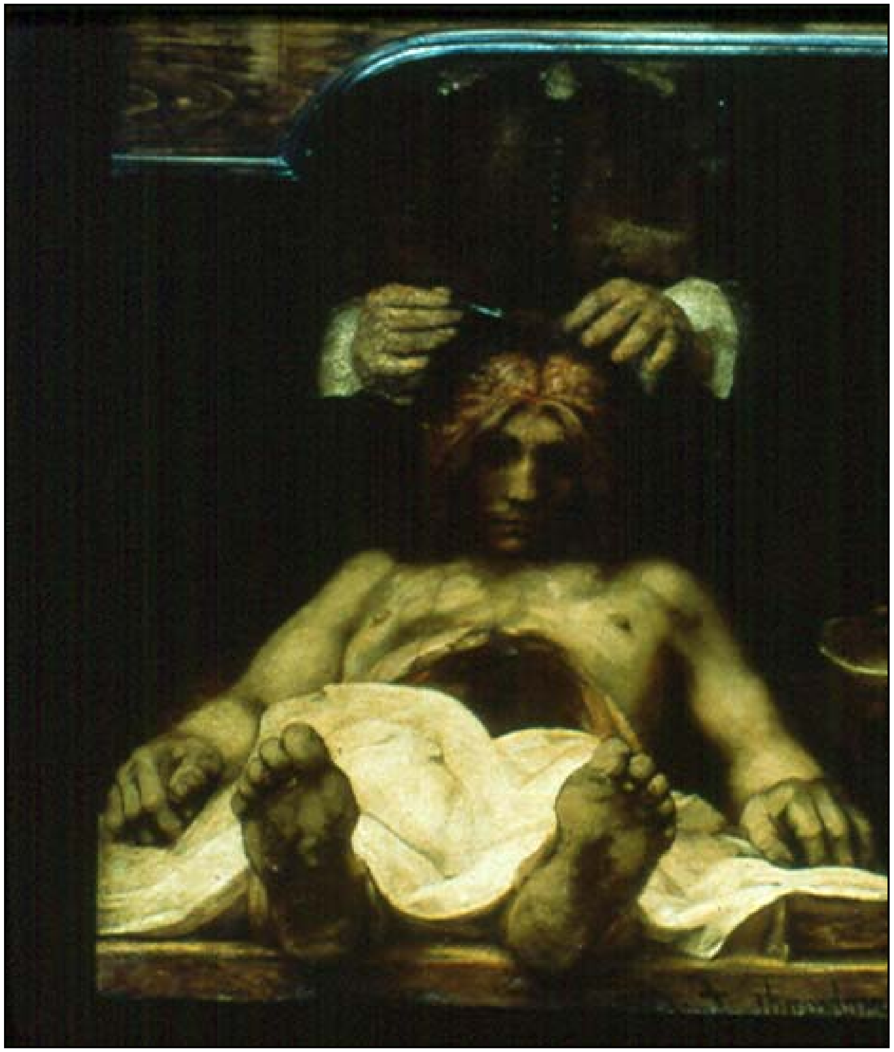
Rudimentary Neuroanatomy

Structure and Function of the Central Controller

How Difficult Can This Be?

•The brain may be the most complex structure to have arisen in the history of the universe, more complex in many ways than the laws that govern the universe.

What Do We Do To Figure It Out?



Anatomy

cell body staining, tract staining, tract tracing, structural imaging, etc.

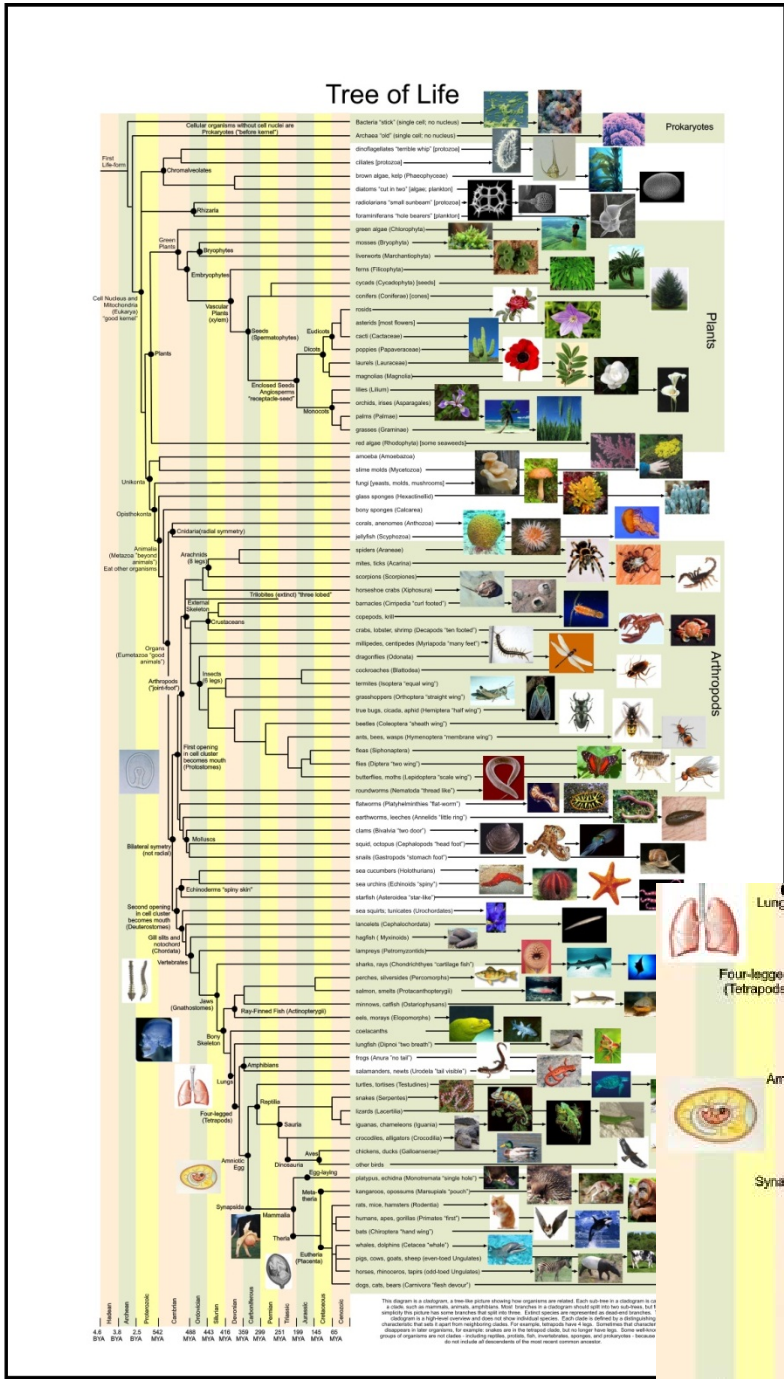
Physiology

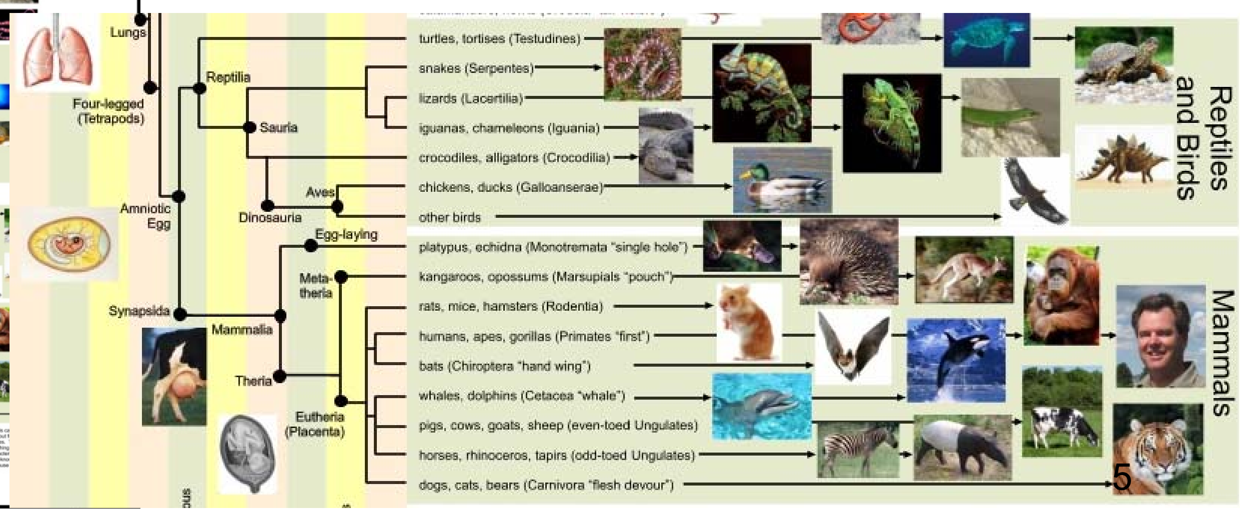
intracellular and extracellular recording, functional imaging, EEG (ElectroEncephaloGraph), etc.

What Would Be A Computer Analogy?

"Computer Physiology": using a voltmeter to identify software.

Can a computer be figured out this way?





- How relevant are animal studies?
  - All basic neuroanatomical features found in humans are found in animals
  - But remember the evolutionary constraint: humans may have "re-purposed" older structures giving them new importance

INTELLIGENCE?

Georges Cuvier’s proposal: intelligence is proportional to the ratio of body weight to brain weight.
Cuvier's fraction E/S (where E = brain weight and S = body weight) for several species:

Species	*E/S ratio*	*Species*	*E/S ratio*
small birds	1/12	lion	1/550
human	1/40	elephant	1/560
mouse	1/40	horse	1/600
cat	1/100	shark	1/2496
dog	1/125	hippopotamus	1/2789
frog	1/172		

The Nervous System

- Central nervous system (CNS) is brain plus spinal cord
- Peripheral nervous system (PNS) is "downstream"
  1) somatic
  2) autonomic

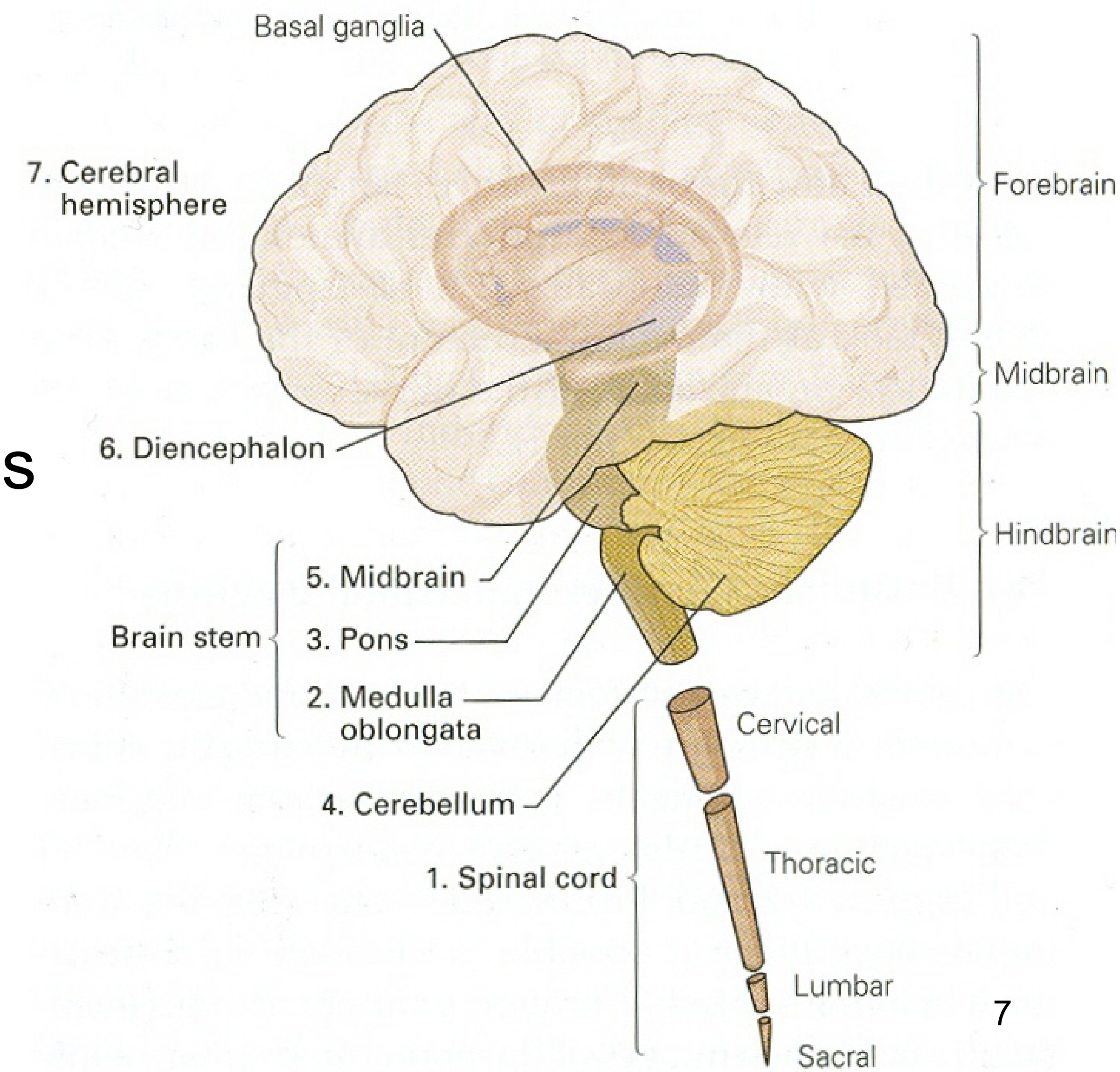
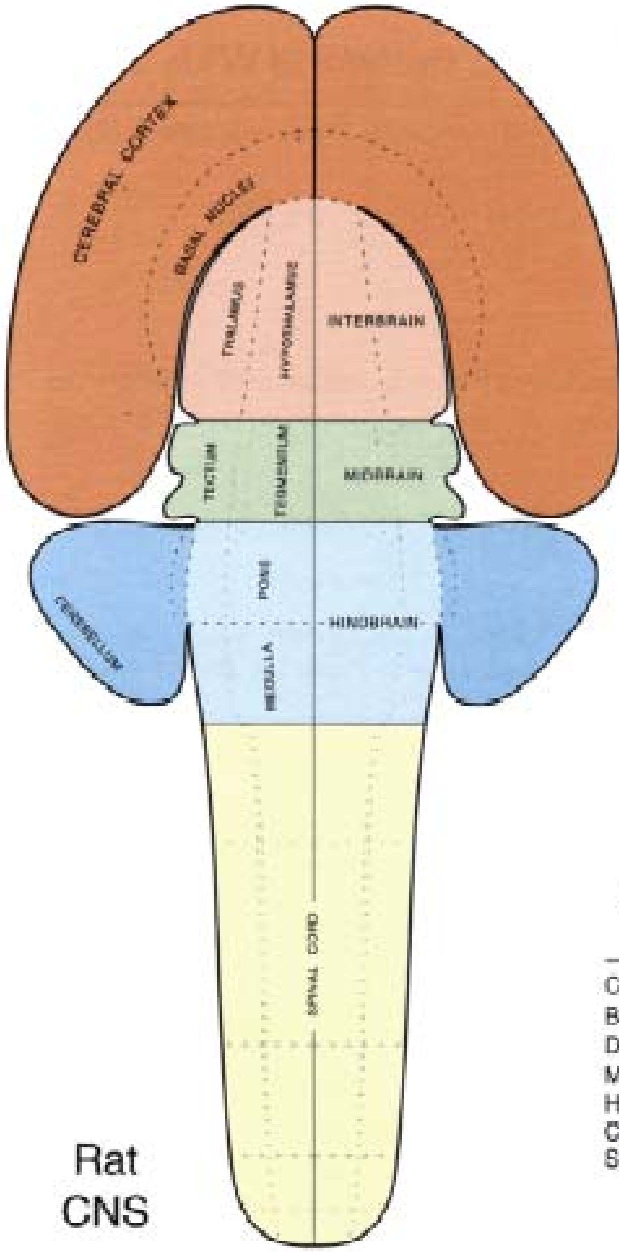


Figure from Kandel, Schwartz & Jessell, Principles of Neural Science, 4th Edition, McGraw-Hill

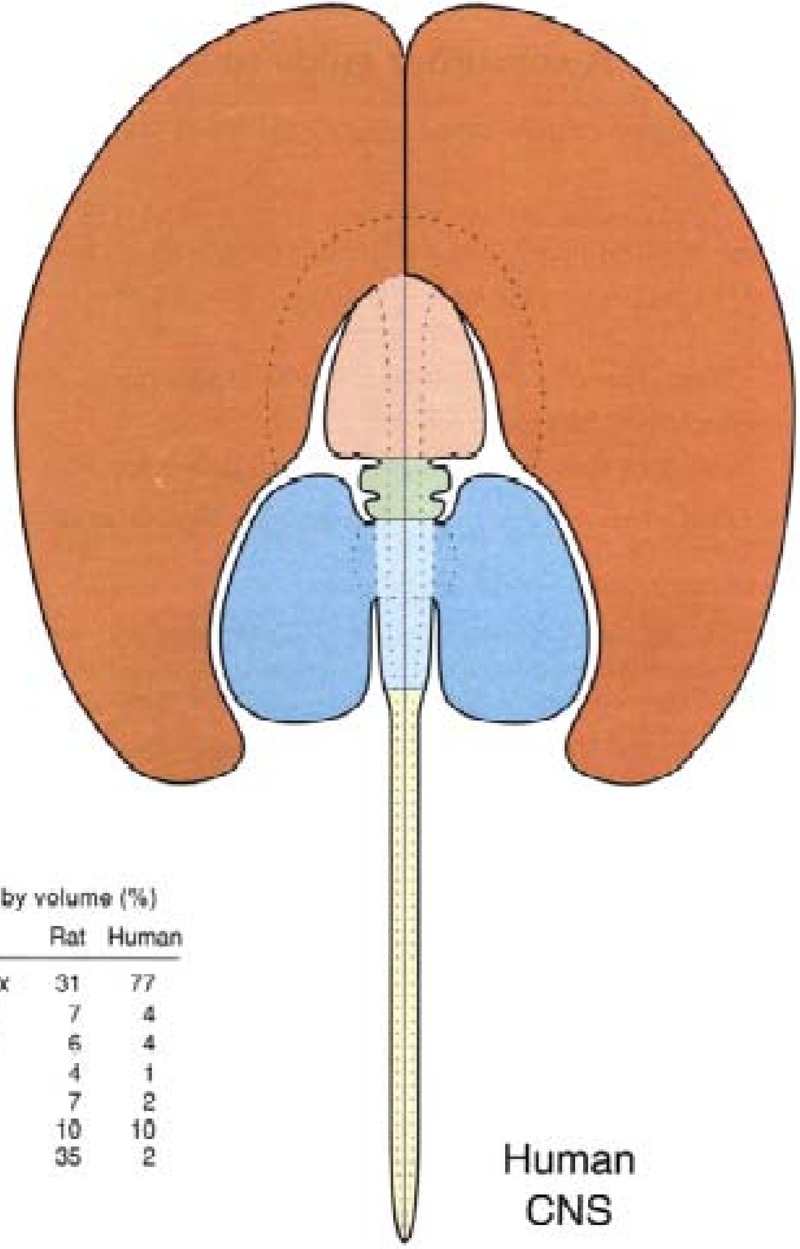
Intelligence Reconsidered



Rat
CNS

Proportions by volume (%)

	Rat	Human
Cerebral cortex	31	77
Basal ganglia	7	4
Diencephalon	6	4
Midbrain	4	1
Hindbrain	7	2
Cerebellum	10	10
Spinal cord	35	2



Human
CNS

Rodent vs. Primate brains

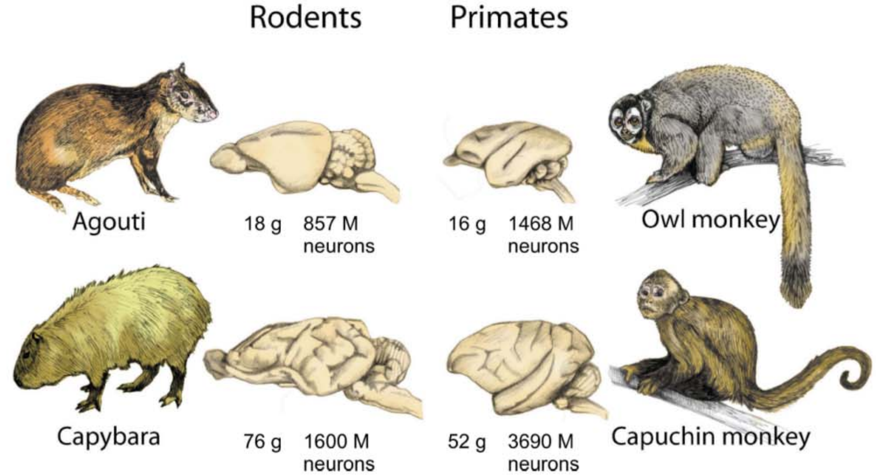


FIGURE 4 | Brain size is not a reliable indicator of number of neurons across orders. Because of the different cellular scaling rules that apply to rodent and primate brains, primates always concentrate larger numbers of neurons in the brain than rodents of a similar, or even larger, brain size. Data from Herculano-Houzel et al. (2006, 2007). Illustration by Lorena Kaz.

Table 2 | Expected values for a generic rodent and primate brains of 1.5 kg, and values observed for the human brain (Azevedo et al., 2009).

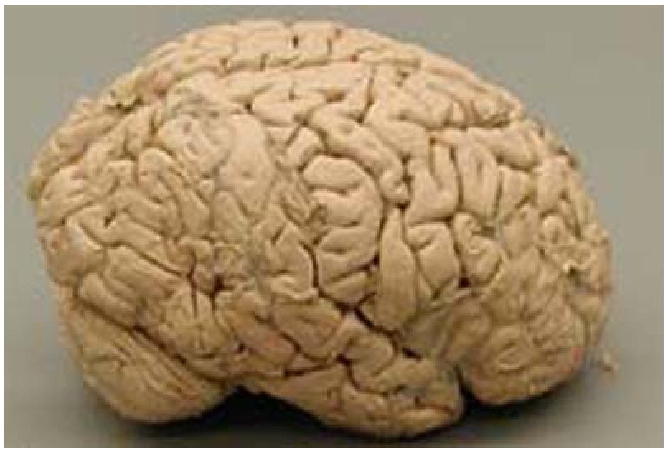
	Generic rodent brain	Generic primate brain	Human brain
Brain mass	1500 g	1500 g	1508 g
Total number of neurons in brain	12 billion	93 billion	86 billion
Total number of non-neurons in brain	46 billion	112 billion	85 billion
Mass, cerebral cortex	1154 g	1412 g	1233 g
Neurons, cerebral cortex	2 billion	25 billion	16 billion
Relative size of the cerebral cortex	77% of brain mass	94% of brain mass	82% of brain mass
Relative number of neurons in cerebral cortex	17% of brain neurons	27% of brain neurons	19% of brain neurons
Mass, cerebellum	133 g	121 g	154 g
Neurons, cerebellum	10 billion	61 billion	69 billion
Relative size of the cerebellum	9% of brain mass	8% of brain mass	10% of brain mass

Notice that although the expected mass of the cerebral cortex and cerebellum are similar for these hypothetical brains, the numbers of neurons that they contain are remarkably different. The human brain thus exhibits seven times more neurons than expected for a rodent brain of its size, but 92% of what would be expected of a hypothetical primate brain of the same size. Expected values were calculated based on the power laws relating structure size and number of neurons (irrespective of body size) that apply to average species values for rodents (Herculano-Houzel et al., 2006) and primate brains (Herculano-Houzel et al., 2007), excluding the olfactory bulb.

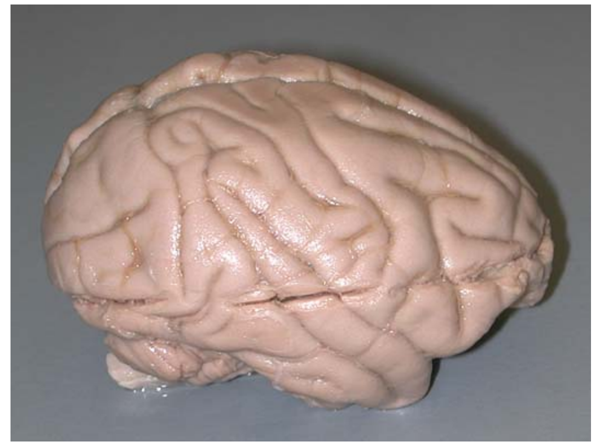
Herculano-Houzel, Frontiers in Human Neuroscience, 2009

CEREBRAL CORTEX: FOLDED

HUMAN

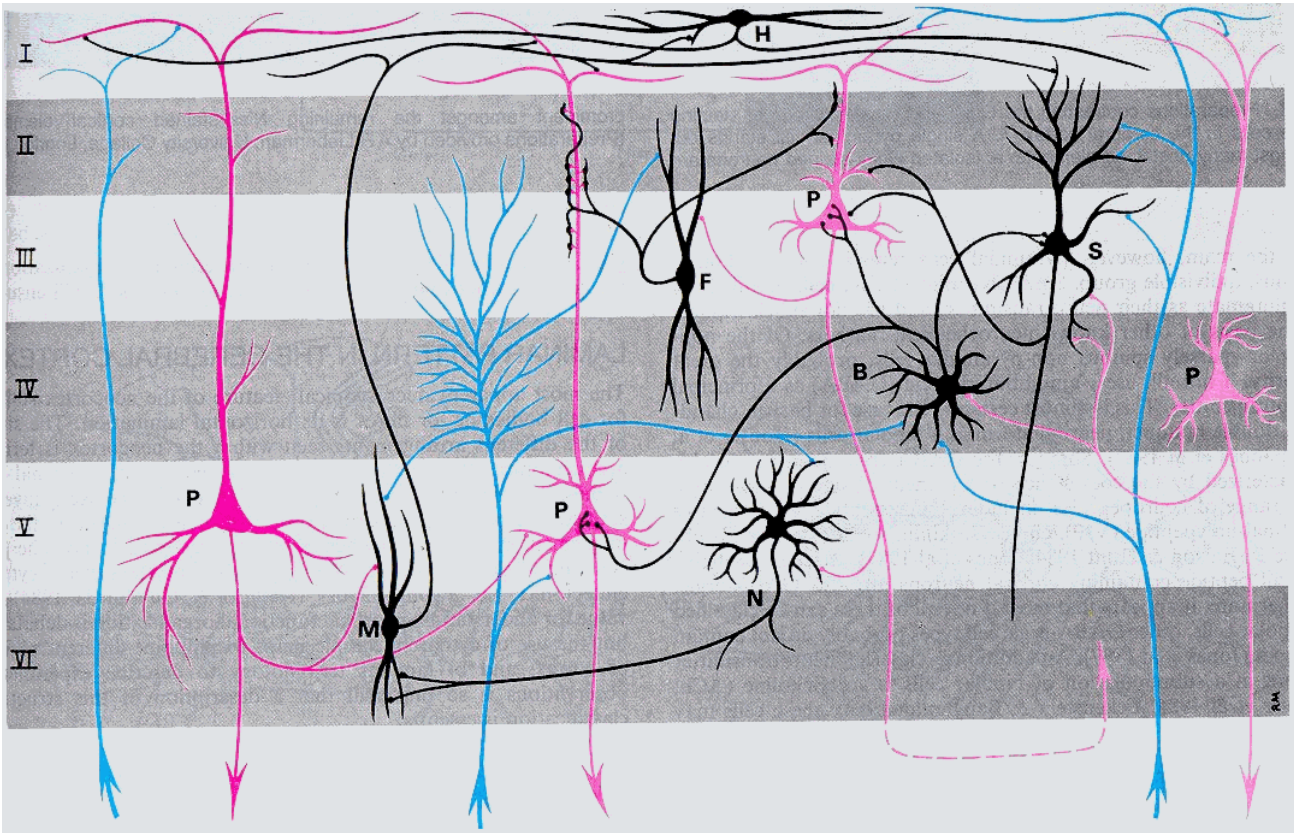


BABOON



SQUIRREL

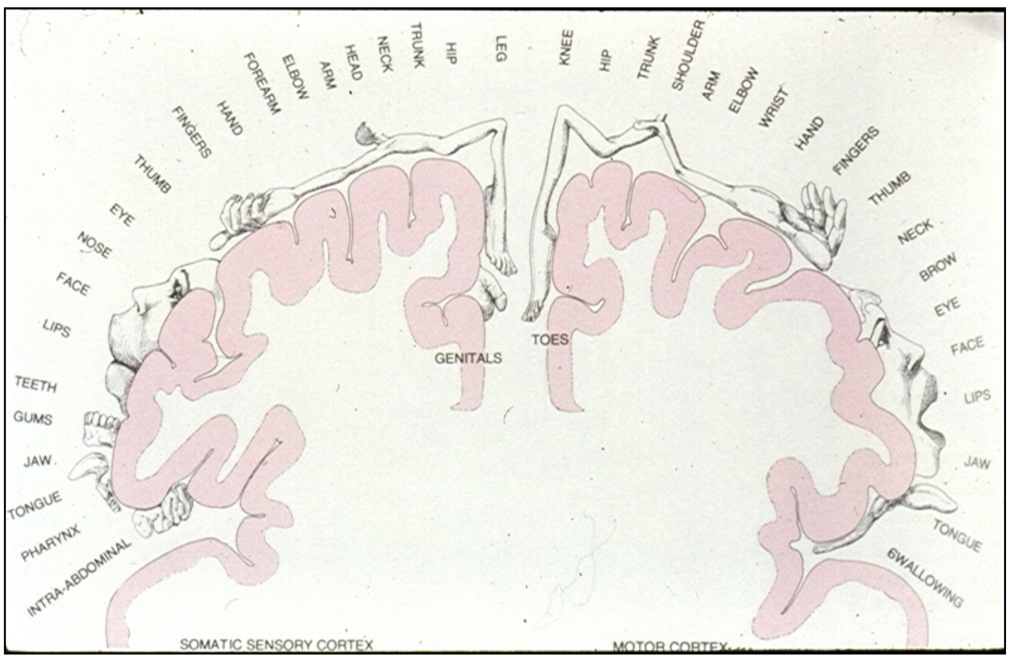
CEREBRAL CORTEX: 6-LAYERED

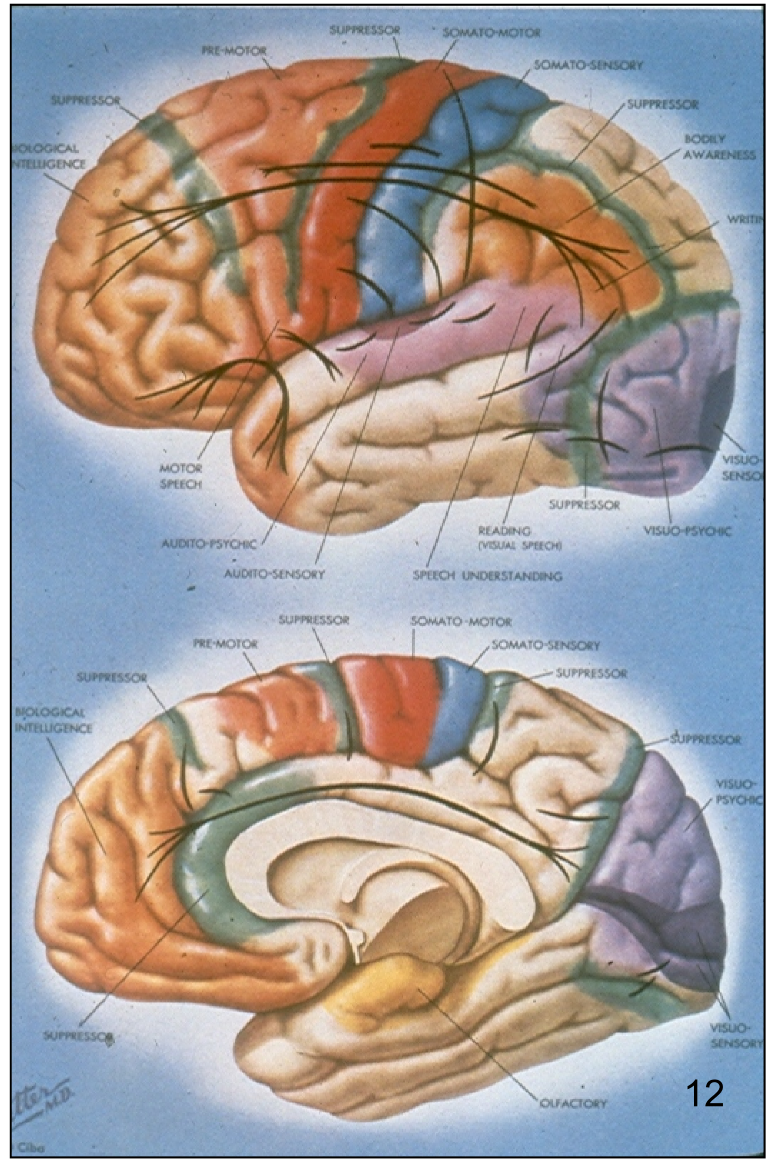


Location Affects Function

- Major faculties (vision, movement, etc.) are concentrated in distinct regions.
- Adjacent regions tend to map topologically to adjacent body regions.

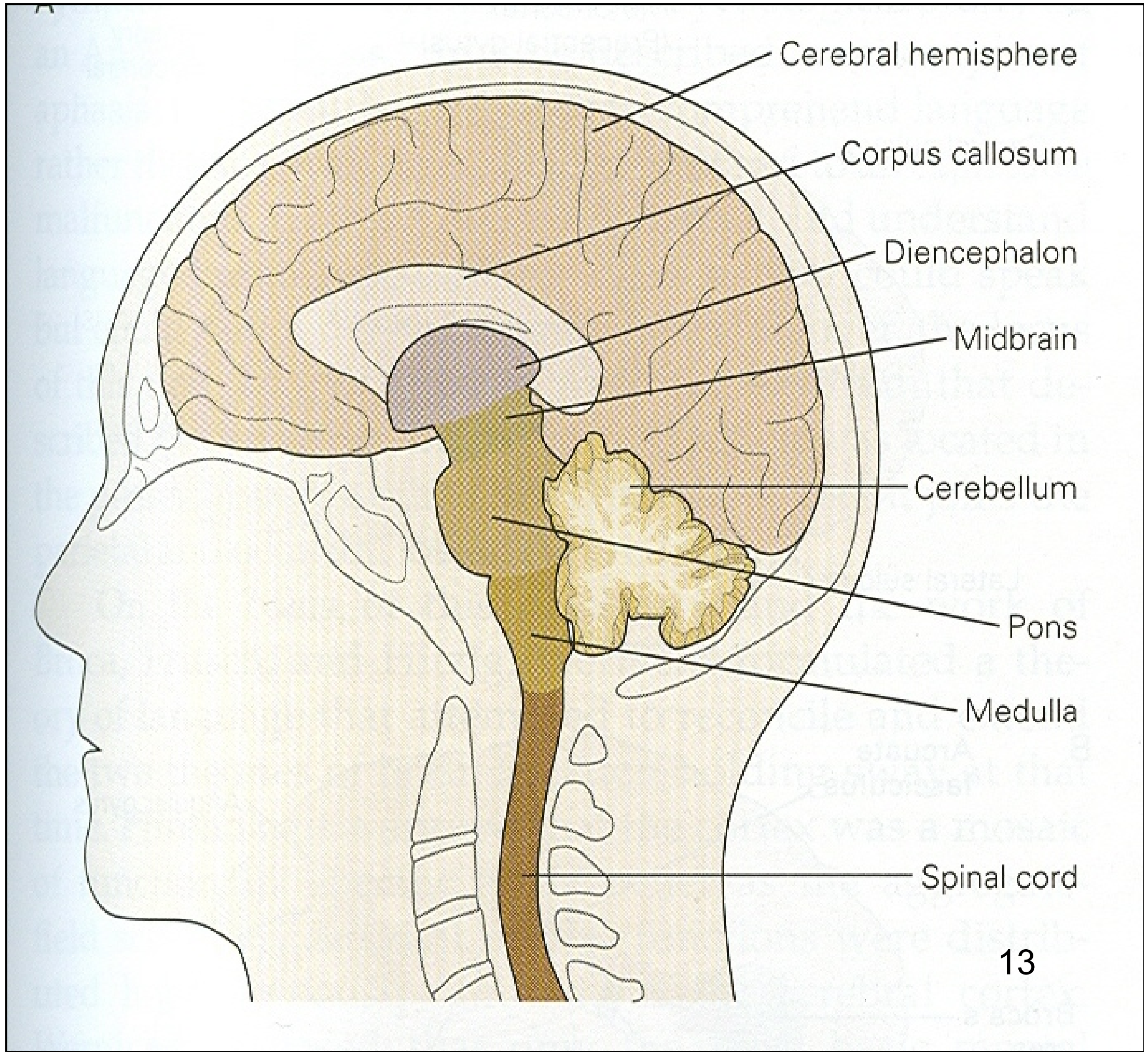
  But there are usually multiple maps, e.g., sensory, motor …





Brain Structures

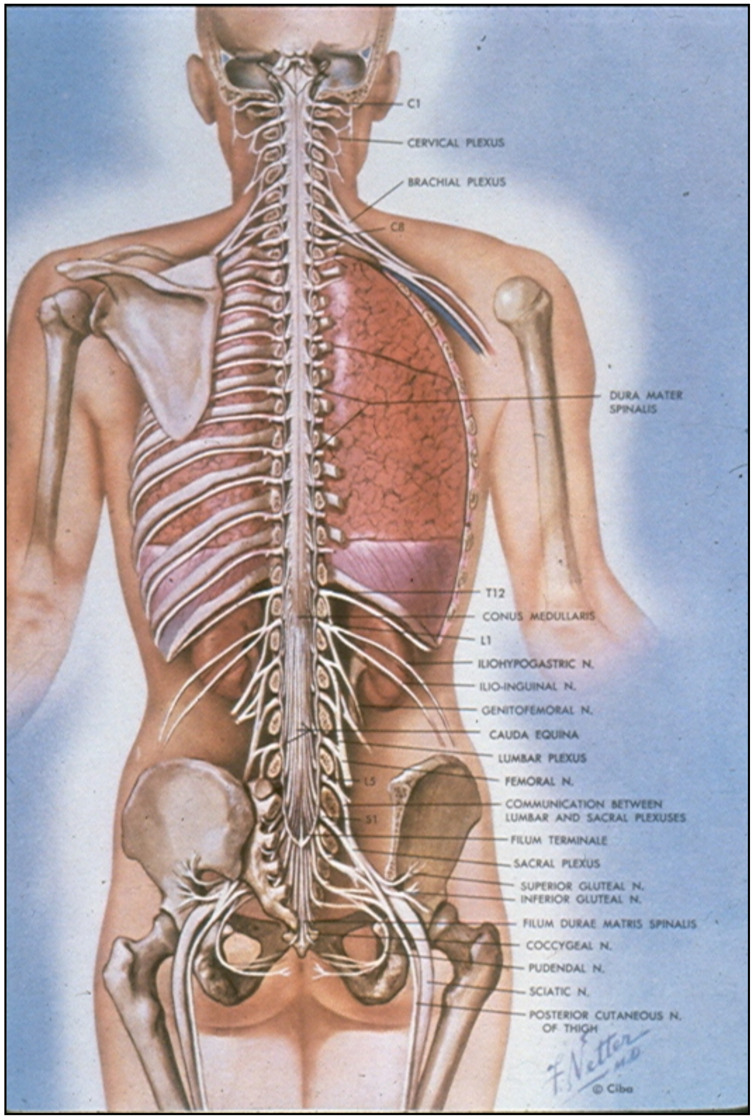
1) Spinal cord
2) Medulla
3) Pons
4) Cerebellum
5) Thalamus & Hypothalamus
6) Midbrain
7) Cerebral Cortex:
   - Basal Ganglia
   - Hippocampus
   - Amygdala

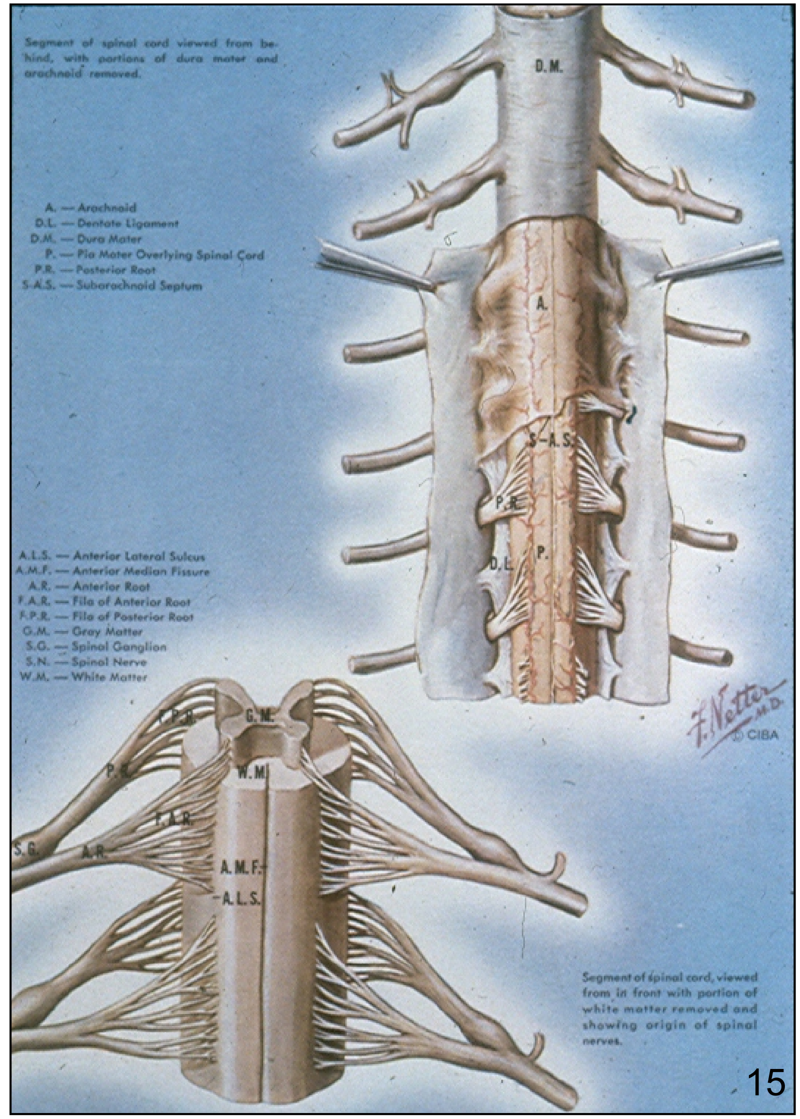


MOTOR-RELATED STRUCTURES

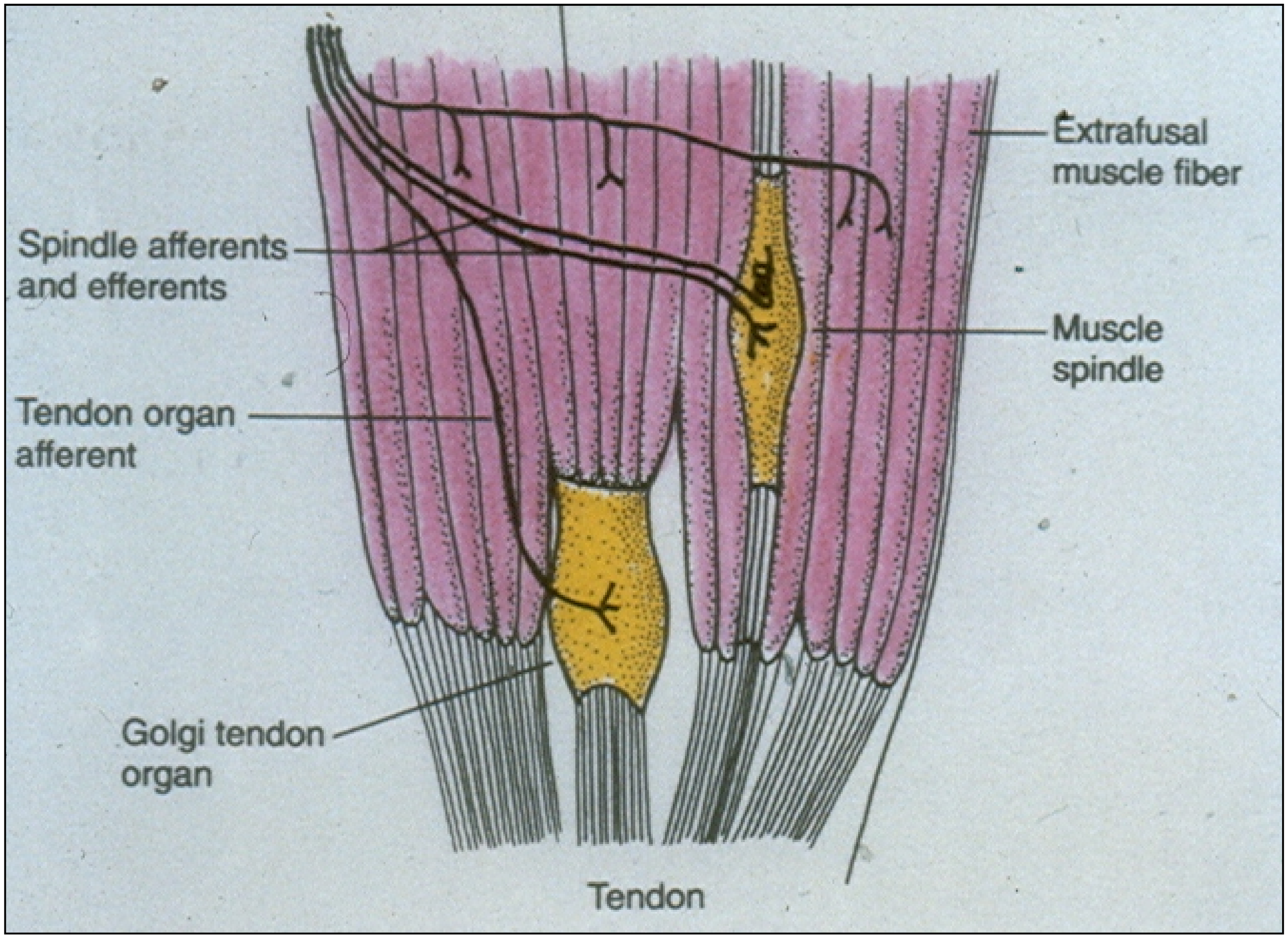
1. Spinal Cord and Periphery
2. Basal Ganglia
3. Cerebellum
4. Primary Motor Cortex
5. Premotor Cortex
6. Supplementary Motor Cortex
7. Corticospinal tract

Rudimentary spinal neuroanatomy



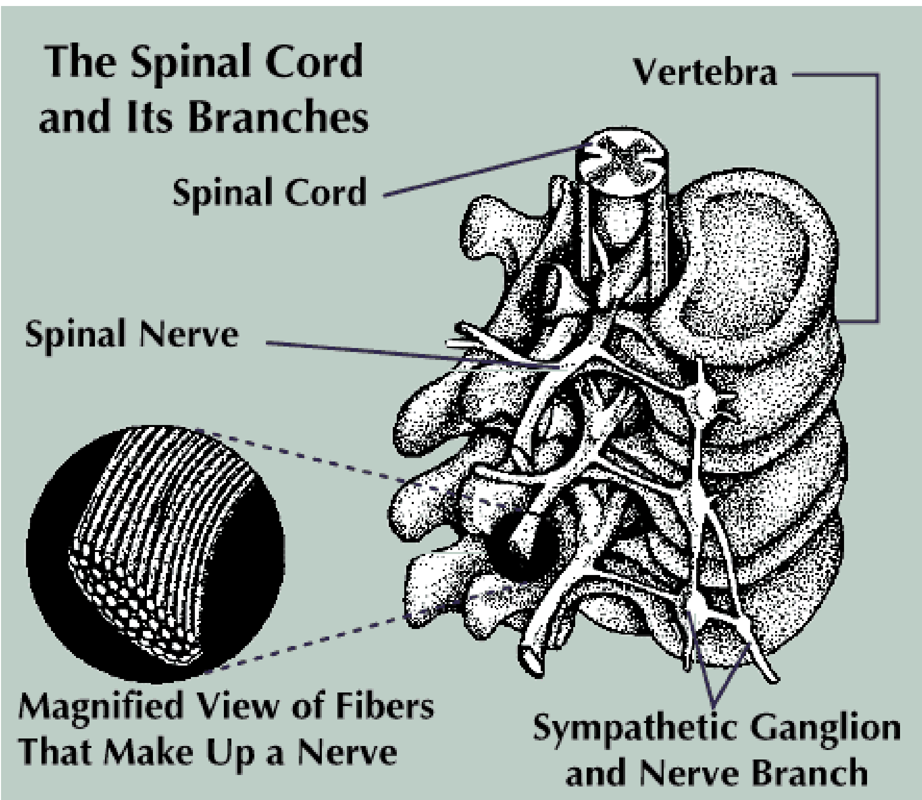


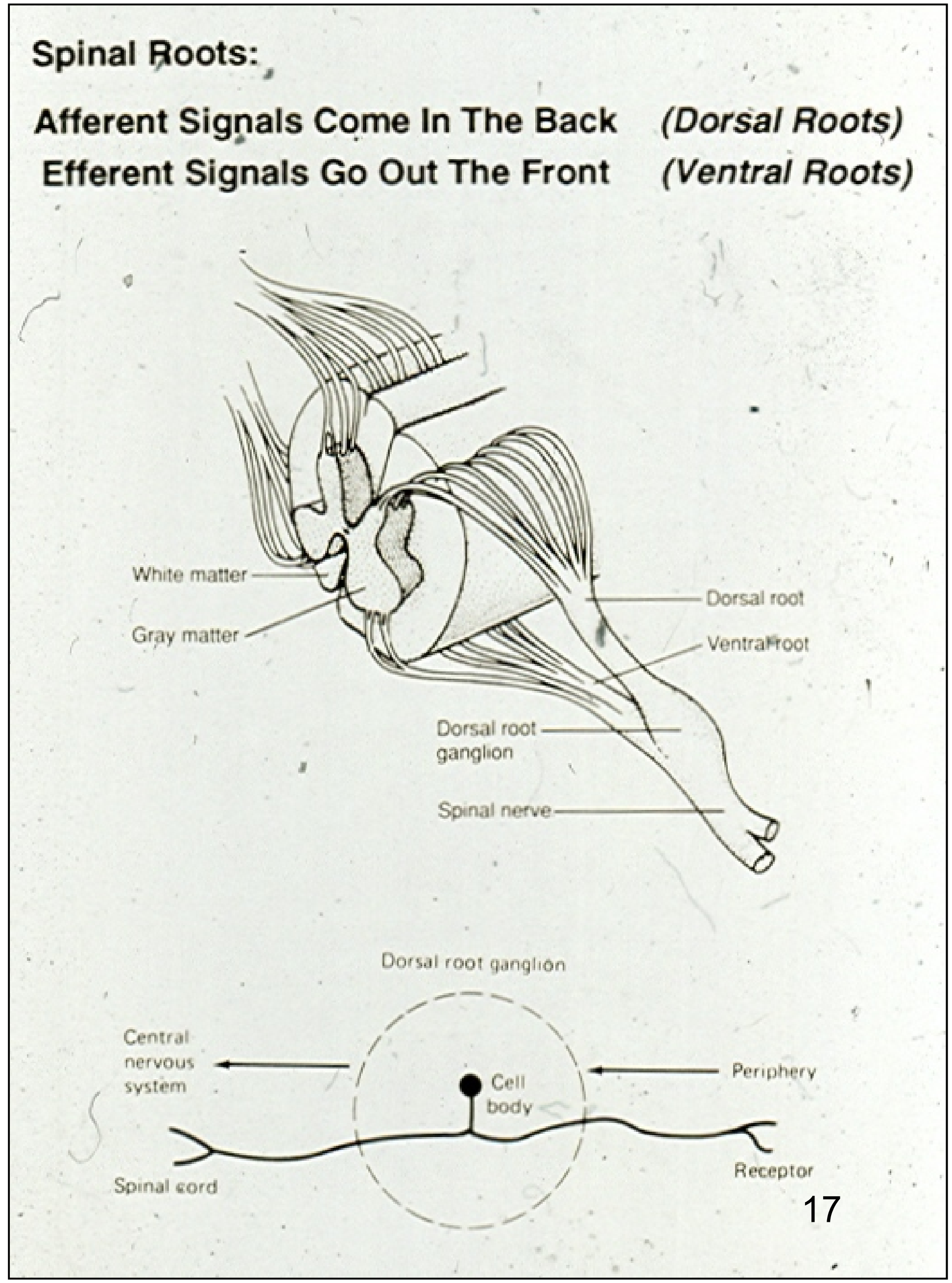
Feedback Sensors in Muscle



Neural feedback

- All neural feedback goes via the spinal cord
- Sensory (afferent) neurons enter the back of the spinal cord
- Motor (efferent) neurons exit the front of the spinal cord

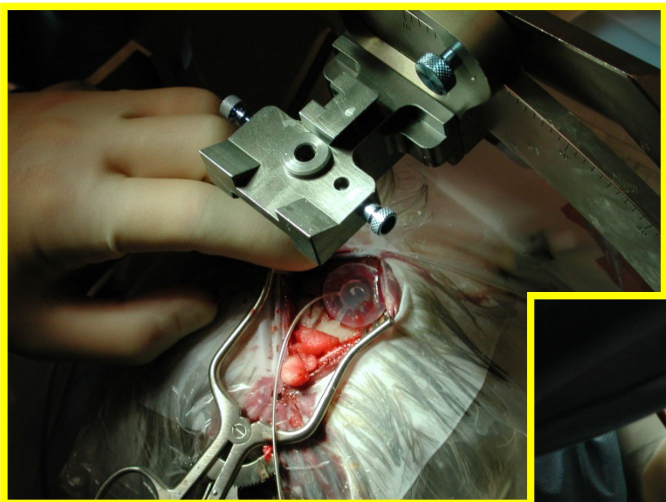


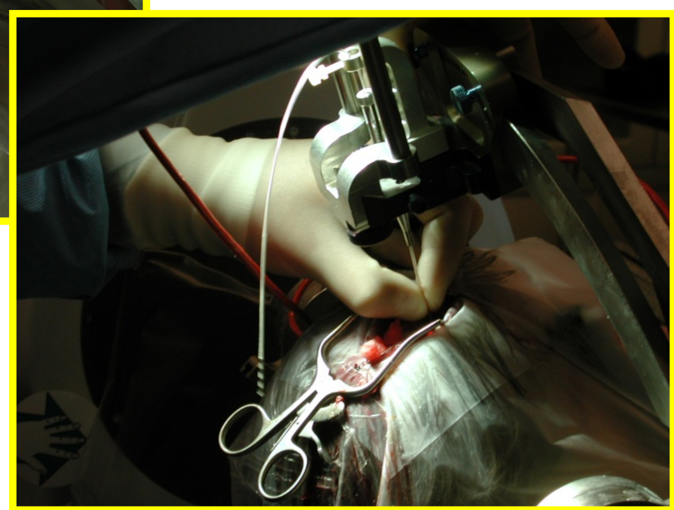


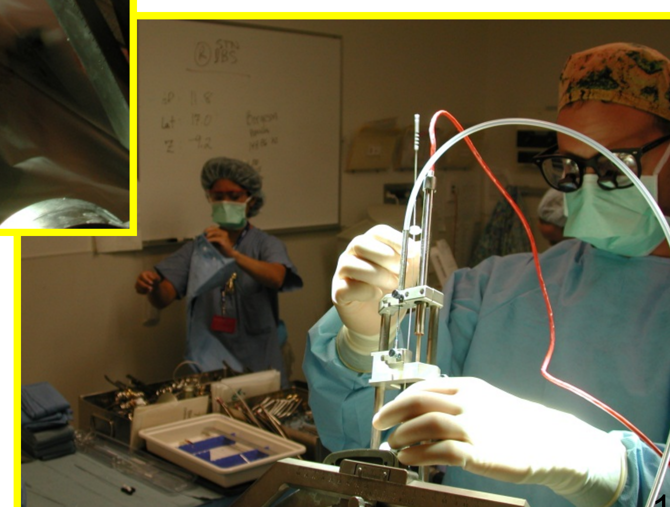
BASAL GANGLIA

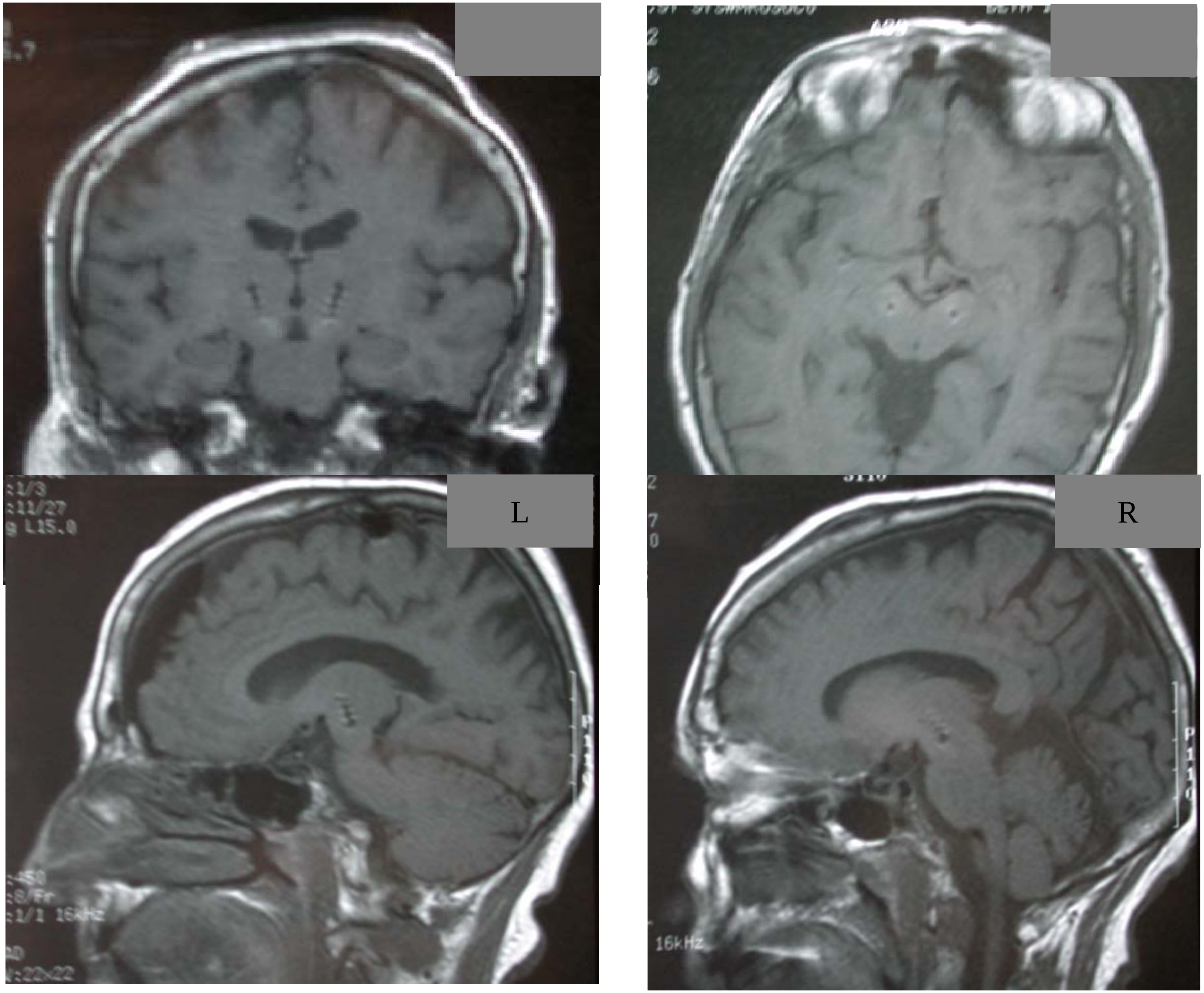
1. Five related ganglia (plural of ganglion)
2. No direct sensory inputs or motor outputs
3. Involved in movement initiation, sequencing
4. Motivation?
5. Habits and Addiction
6. HUGE in birds
7. Dopamine, Parkinson's disease
8. Deep Brain Stimulation

Deep Brain Stimulation





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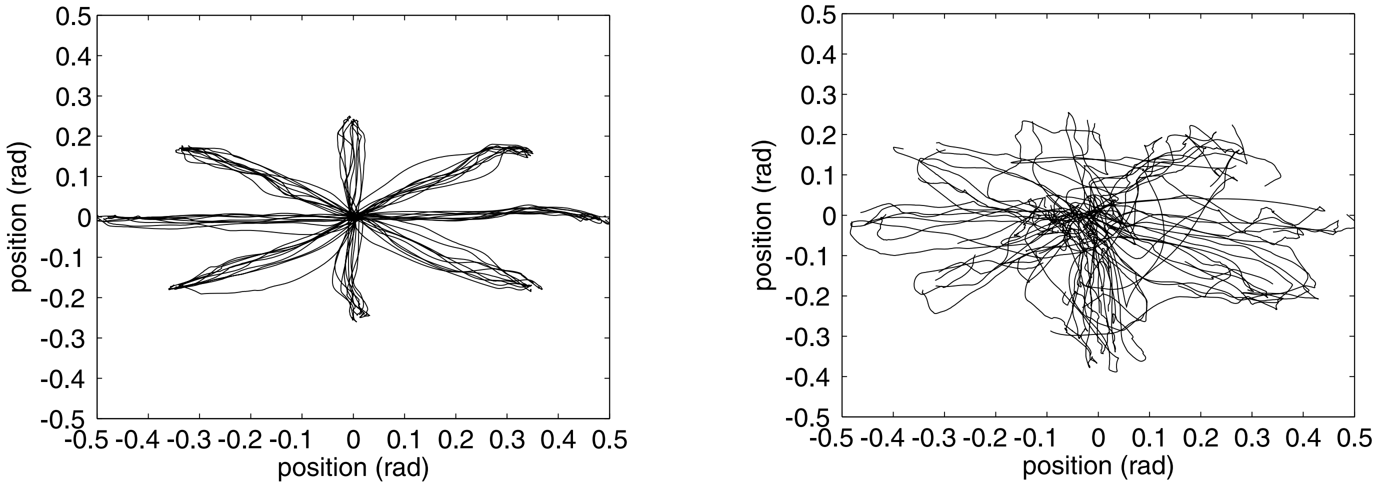


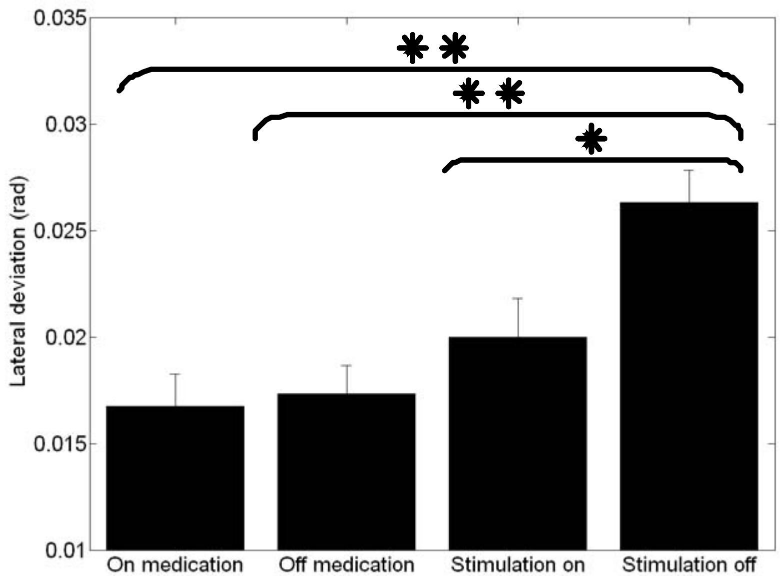
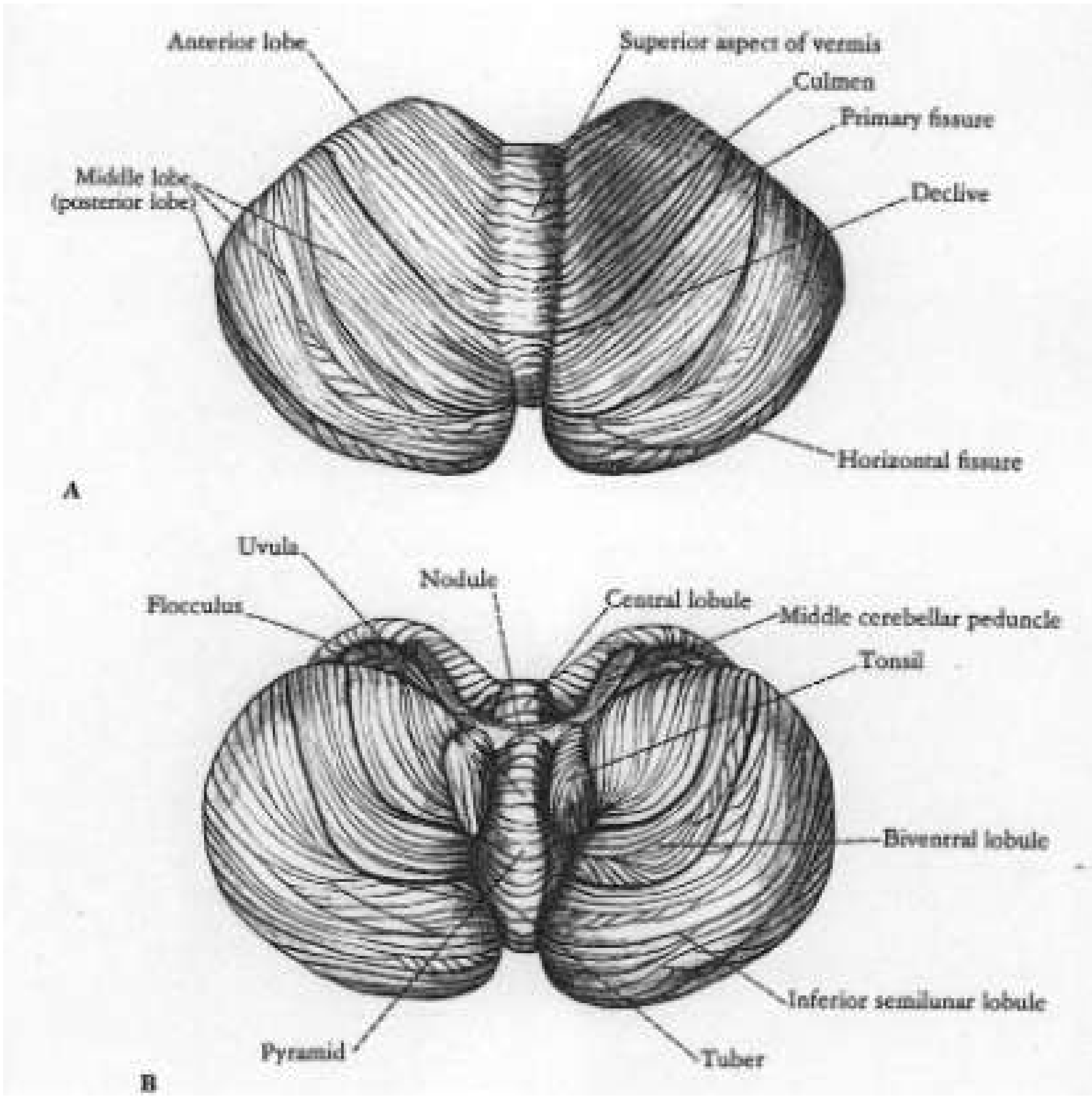


Figure 6. Mean values of lateral deviation across experimental groups and conditions. Whisker bars represent standard errors. A significant difference exists between the mean of the subjects tested 'off stimulation' and the other three group means (* = $p<0.05$; ** = $p<0.01$).

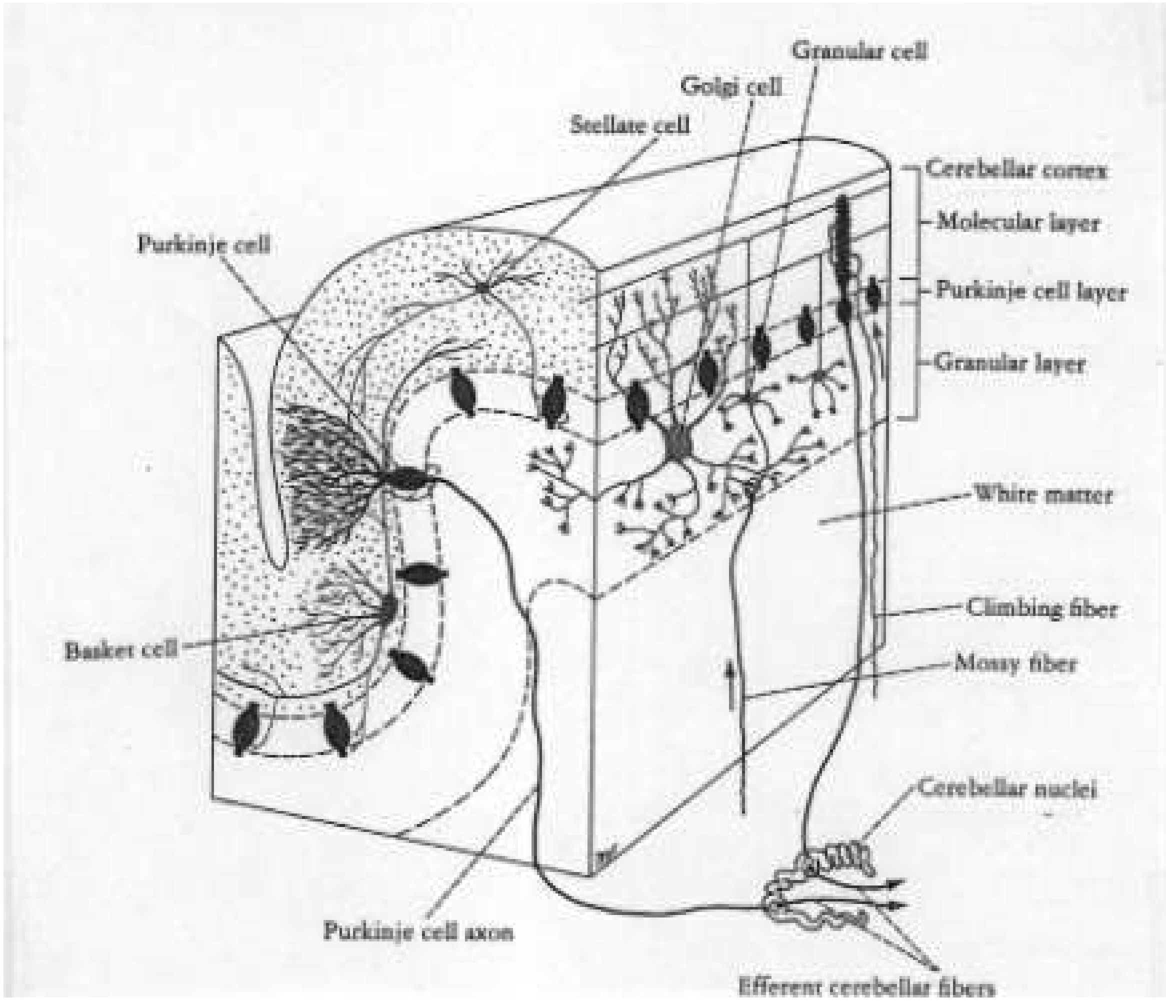
CEREBELLUM

1. A remarkably regular structure
2. No direct motor outputs
3. Ipsilateral control
4. More neurons than the rest of the brain
5. Motor Learning?
6. Coordination of Movements?
7. Skill Refinement?

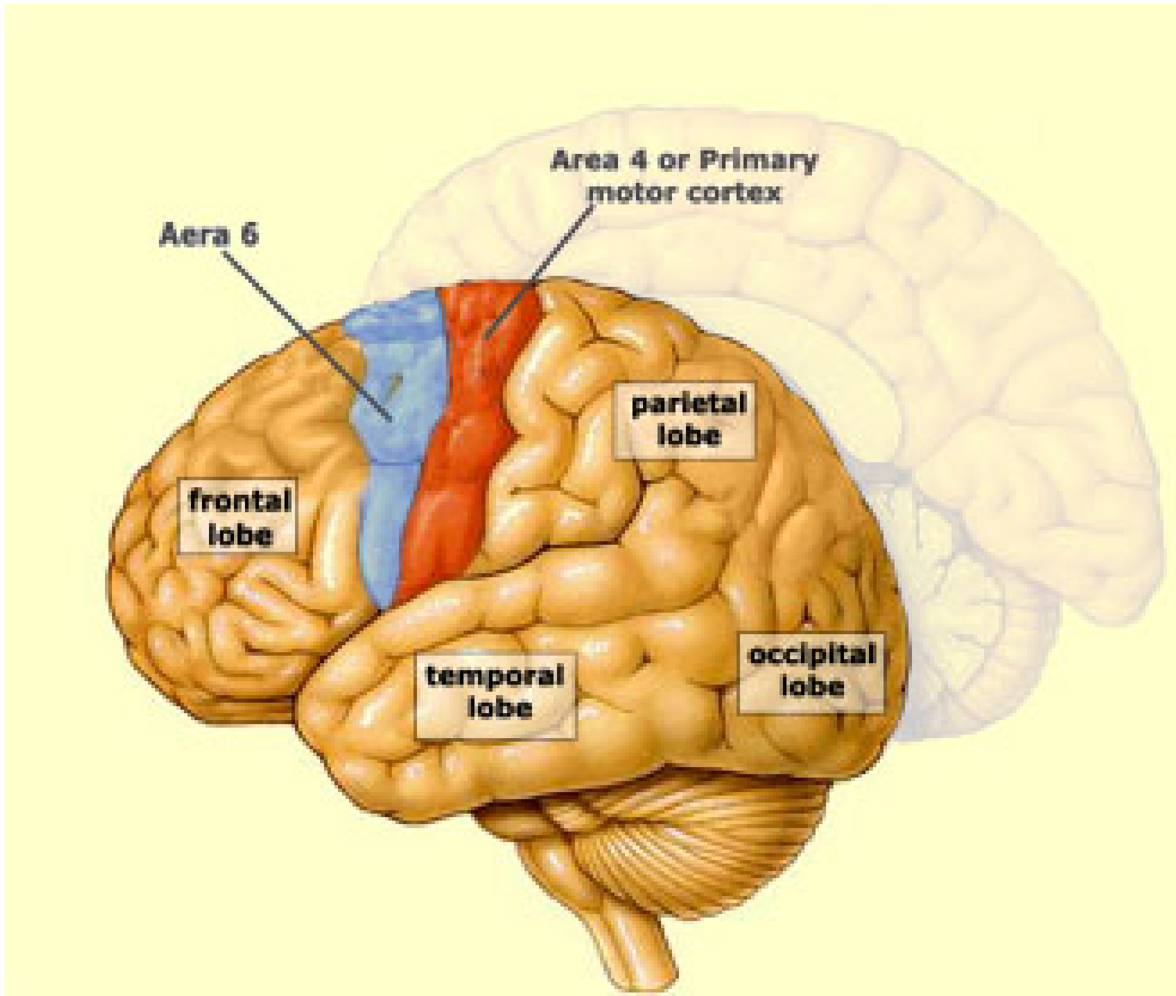
CEREBELLAR ANATOMY



CEREBELLAR NEUROANATOMY

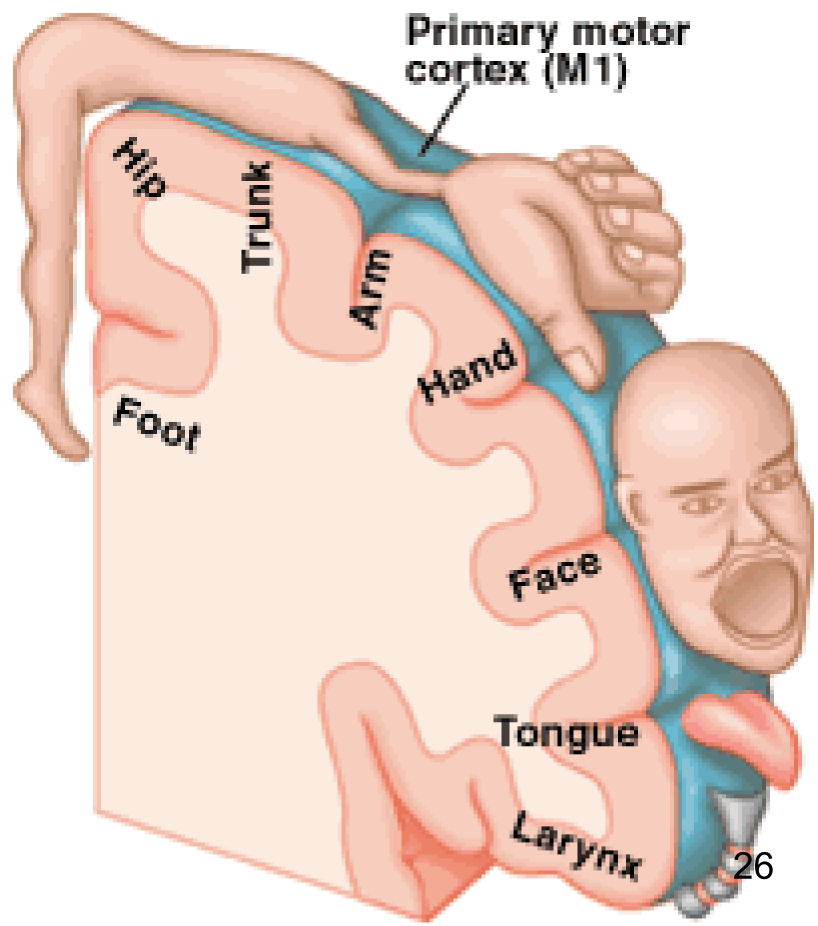


PRIMARY MOTOR CORTEX



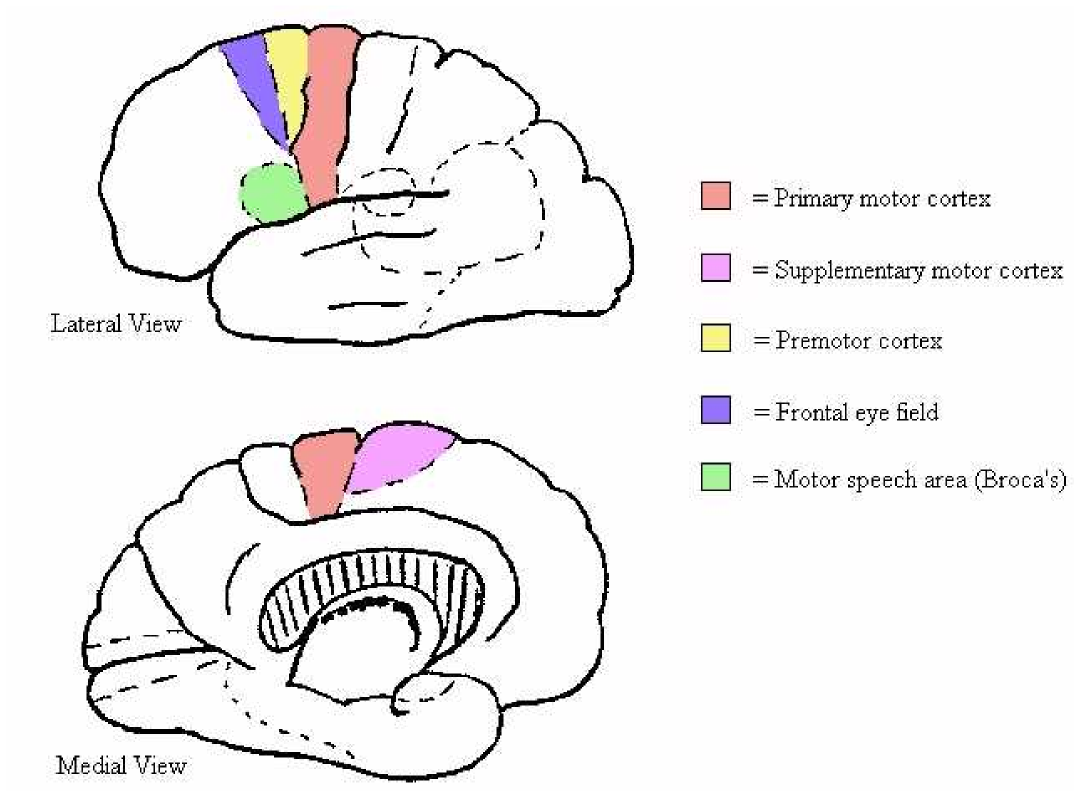
PRIMARY MOTOR CORTEX (cont.)

1. Main Cortical Motor Controller
2. Contralateral control
3. Somatotopic map
4. Controls Muscles
5. Target for Neuroprostheses



SUPPLEMENTARY MOTOR CORTEX

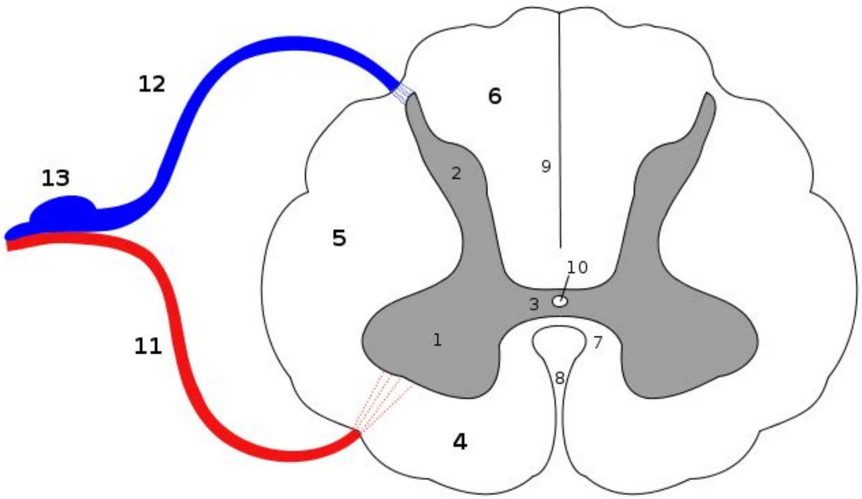
1. Sequencing of complex movements or motor programs
2. Inputs from Basal Ganglia



PREMOTOR CORTEX

1. Reciprocally connected to primary motor cortex
2. 30% of the axons in the corticospinal tract
3. Sensory guidance of movement
4. Inputs from the cerebellum

Spinal Cord Neuroanatomy

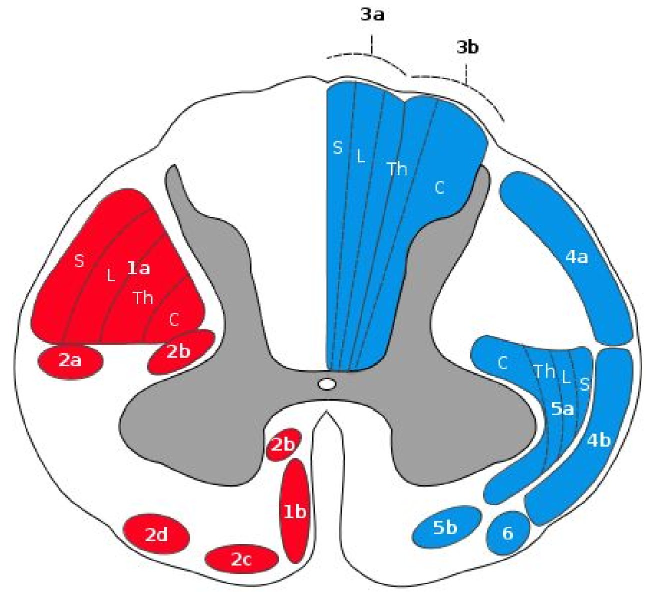


Gray matter

1. Anterior horn
2. Posterior horn
3. Gray commisure

White matter

4. Anterior funiculus
5. Lateral funiculus
6. Posterior funiculus
7. Anterior commisure
8. Anterior median fissure
9. Posterior median sulcus
10. Central canal
11. Anterior root
12. Posterior root
13. Dorsal root ganglion



Motor and decending (efferent) pathways (left, red)

1. Pyramidal Tracts
1a. Lateral corticospinal tract
1b. Anterior corticospinal tract

2. Extrapyramidal Tracts
2a. Rubrospinal tract
2b. Reticulospinal tract
2c. Vestibulospinal tract
2d. Olivospinal tract

Somatotopy Abbreviations:
S: Sacral, **L:** Lumbar
Th: Thoracic, **C:** Cervical

Sensory and ascending (afferent) pathways (right, blue)

3. Dorsal Column Medial Lemniscus System
3a. Gracile fasciculus
3b. Cuneate fasciculus

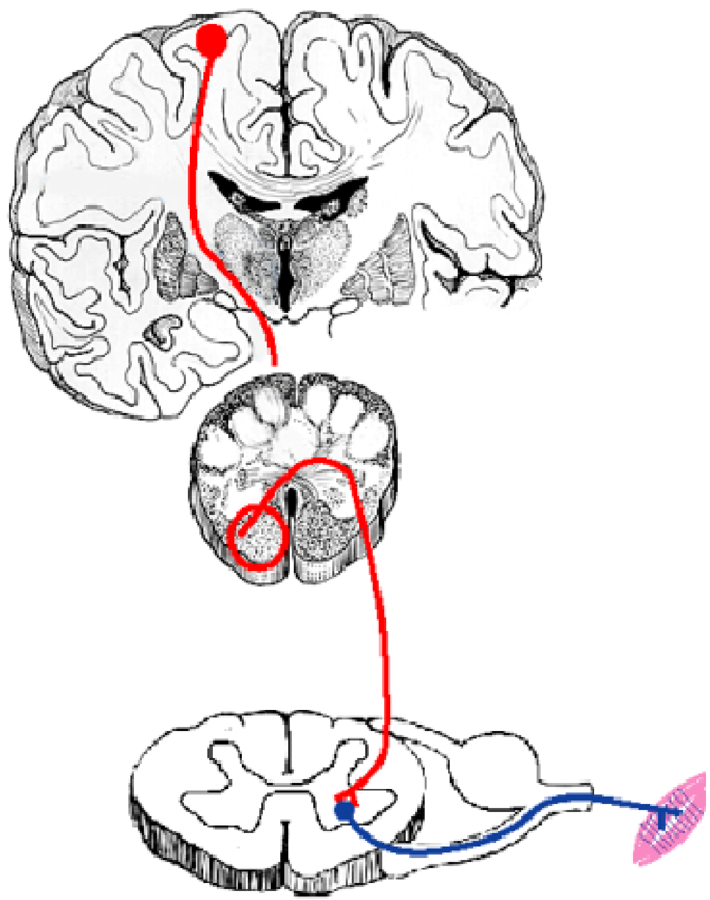
4. Spinocerebellar Tracts
4a. Posterior spinocerebellar tract
4b. Anterior spinocerebellar tract

5. Anterolateral System
5a. Lateral spinothalamic tract
5b. Anterior spinothalamic tract

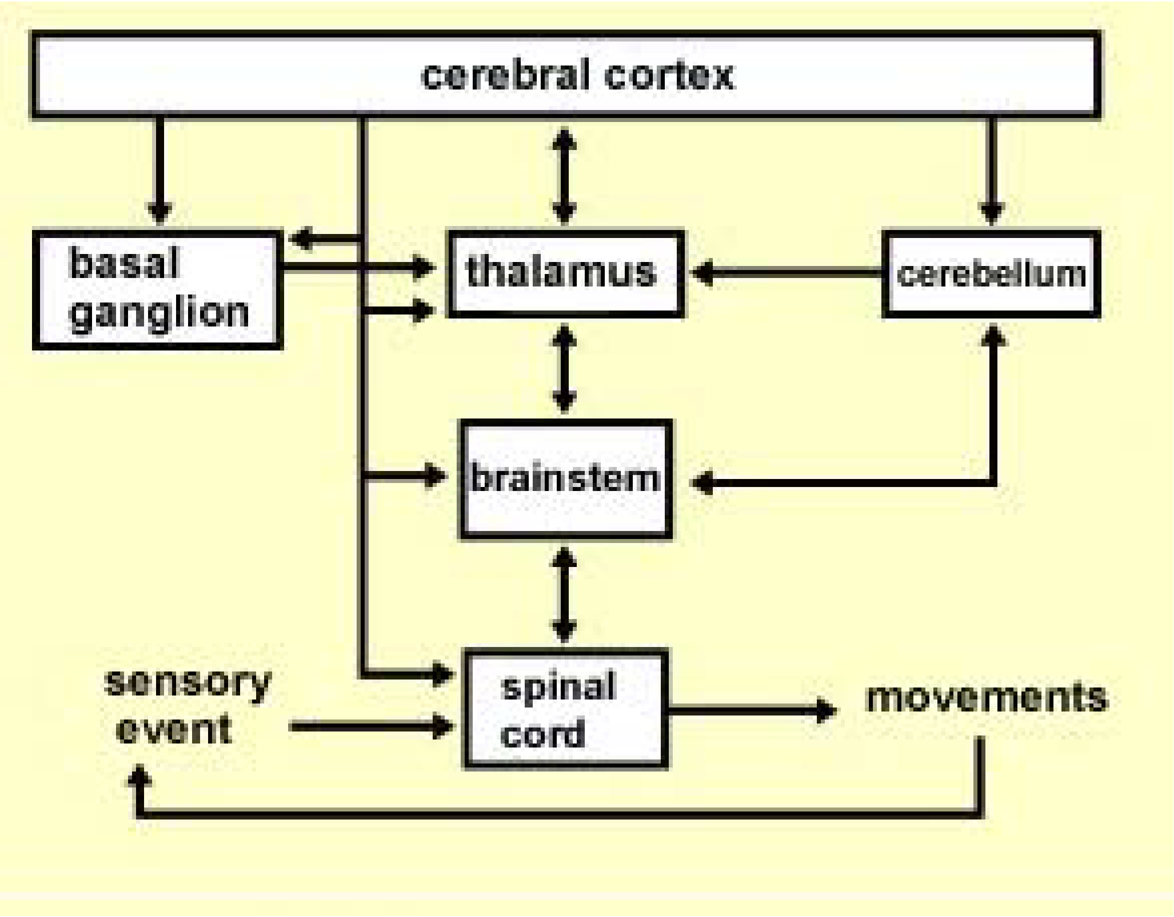
6. Spino-olivary fibers

Corticospinal Tract

- Bundle of axons of single neurons
- Originates from layer V of motor cortex
- Cell bodies are in the motor cortex
- Axons travel down to the spinal cord
- 80%: cross over in the medulla oblongata →lateral corticospinal tract of contralateral side
- 10%: no cross-over → the lateral corticospinal tract (ipsilateral side)
- 10%: no cross-over at the medulla oblongata, but at the spinal cord.
- Synapses to neurons in the ventral horn (mostly onto interneurons)

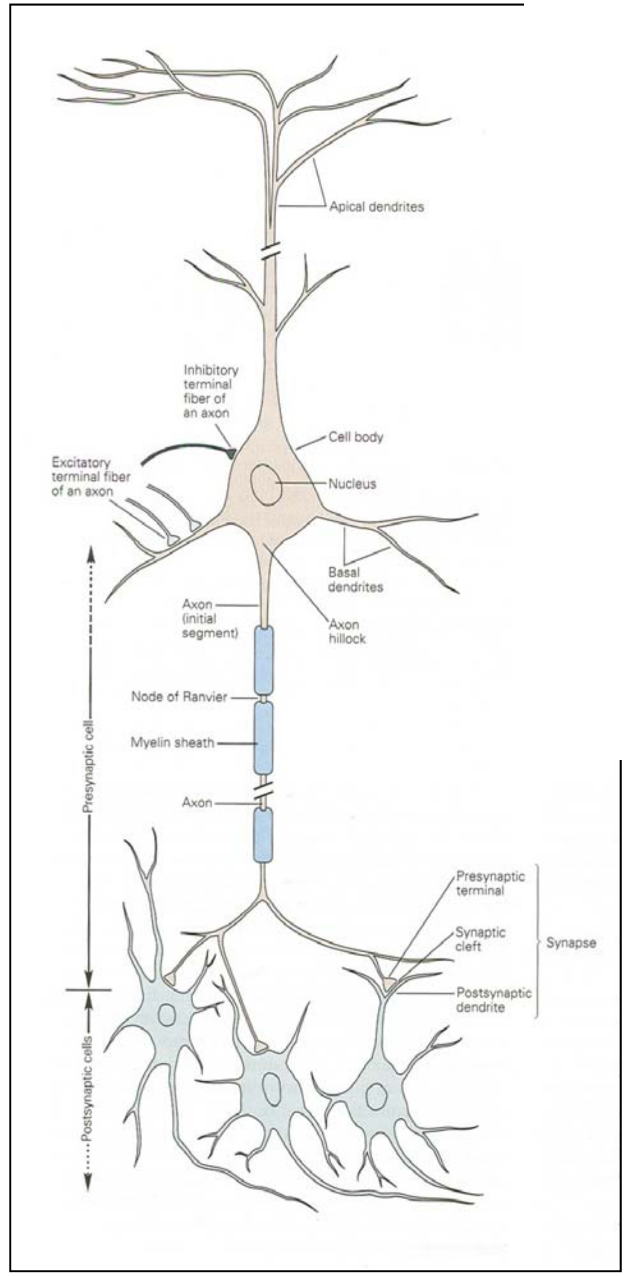


MOTOR CIRCUITS



Neurons

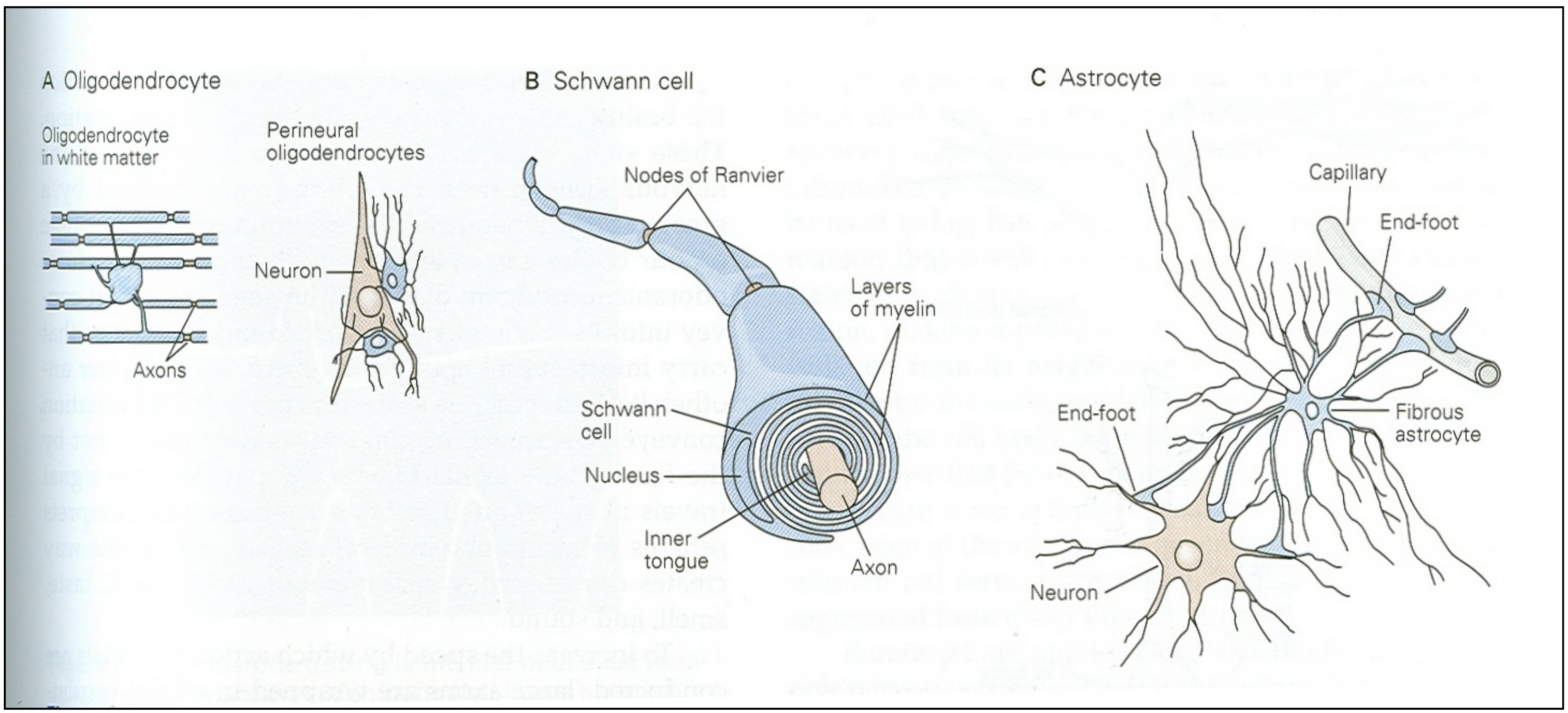
- Two major cell types: neurons & glial cells
  - Neuron doctrine: "neurons do the talking"
- Neuron morphology (i.e. shape) is highly variable. Main features:
  - Cell body ~50 μm
  - Input: dendrites (usually many)
    - Number highly variable, average ~1000 per neuron
  - Output: axon (usually 1)
    - Length ~ meters
    - Diameter ~0.2-20 μm
    - Often wrapped in *myelin* to speed information transmission



Glial cells

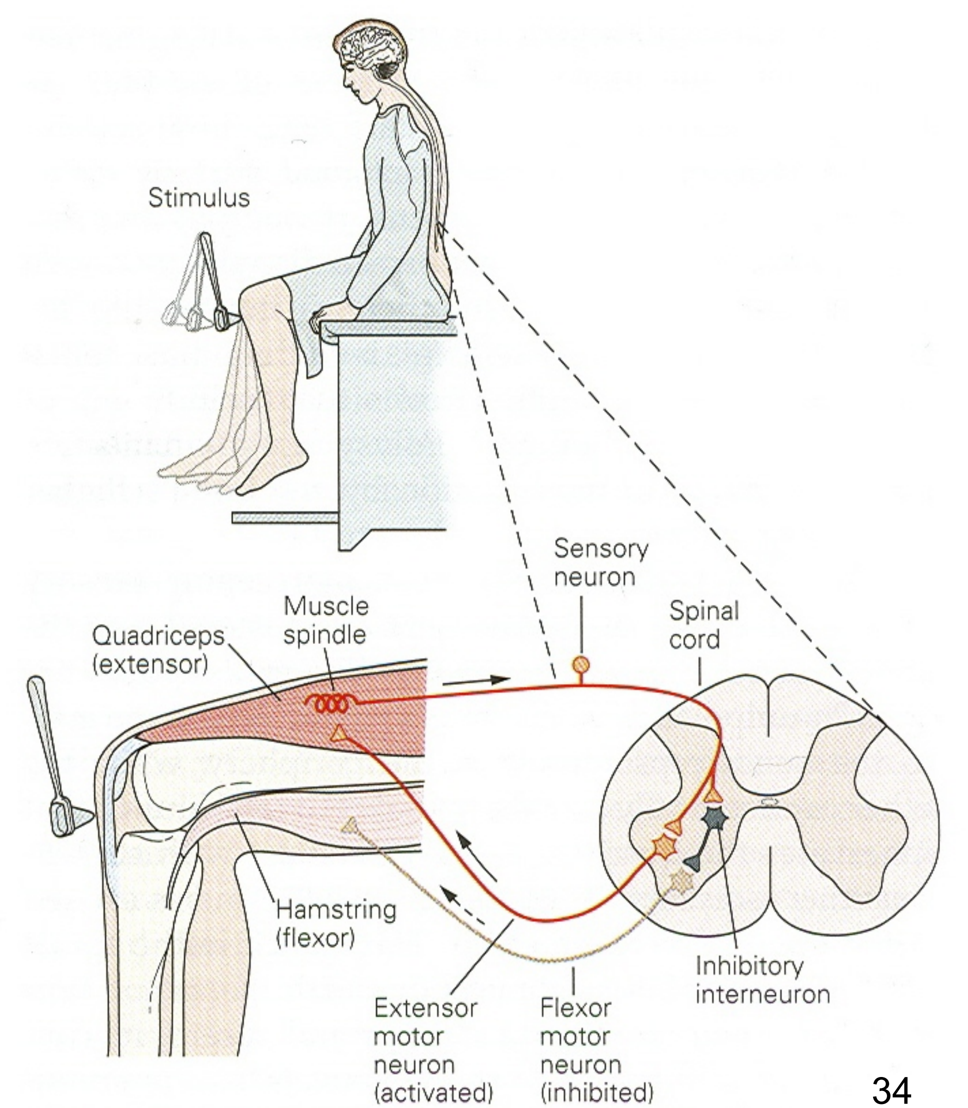
- Many different types.
- Three predominate:
  - Oligodendrocytes (centrally)
  - Schwann cells (peripherally)
  - Astrocytes

◄These provide the myelin sheath that wraps neuron axons



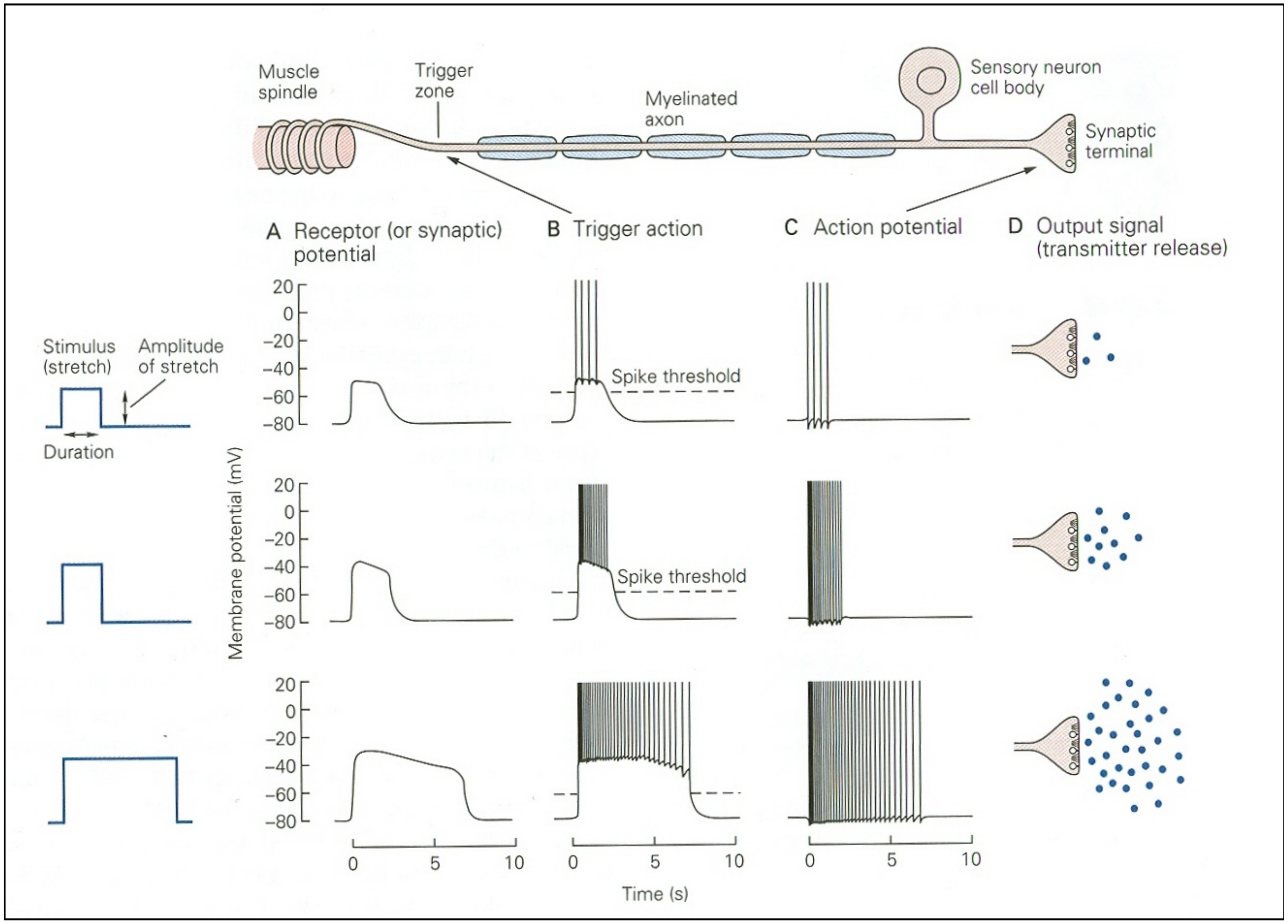
Connections determine function

- The involuntary "knee-jerk" reflex
  - a.k.a. stretch reflex
  - Sensors in the muscles (muscle spindles) excite sensory neurons
  - Sensory neurons send signals to the spinal cord
    - afferent=to
  - Motor neurons send signals from the spinal cord
    - efferent=from
  - Motor neurons excite muscle activity
    - Contraction in the muscle containing the sensor
    - Relaxation in the opposite (antagonist) muscle
    - This is achieved by an inhibitory interneuron interposed between the sensory and motor neurons

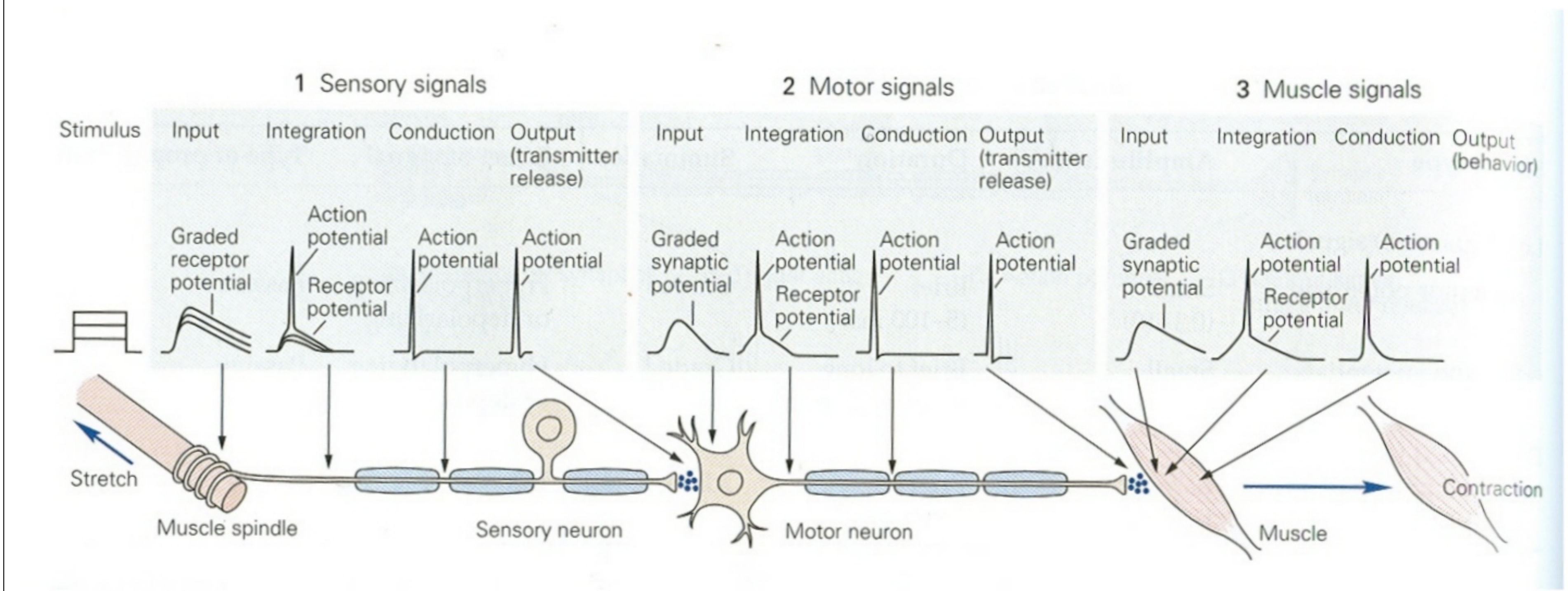


Neuron signaling

- Information is transmitted by all-or-none *action potentials*
  - Regenerated along the axon with no amplitude loss
  - Implies the signal is coded in firing frequency
- Communication with other cells occurs at *synapses*
  - Specialized places where adjacent cell membranes are closely apposed
  - Via chemical transmitters released into the synapse



Signal flow in the stretch reflex



Recap rudiments of nerve physiology

- Neurons do the CNS's information processing
- Neural inputs on dendrites, output on the axon
  - many dendritic input action-potentials required to trigger output axonal action-potentials
- Action potentials transmit information
  - actively regenerated wave of depolarization travels along the axon
  - normally transmitted only in one direction
  - all-or-none events, essentially identical for all neurons
  - frequency-coded—pulse rate codes signal strength
  - propagation speed up to 120 m/s—if myelinated
- Connections determine computation
  - what a signal does depends on where it's connected
  - consistent with highly localized CNS operations