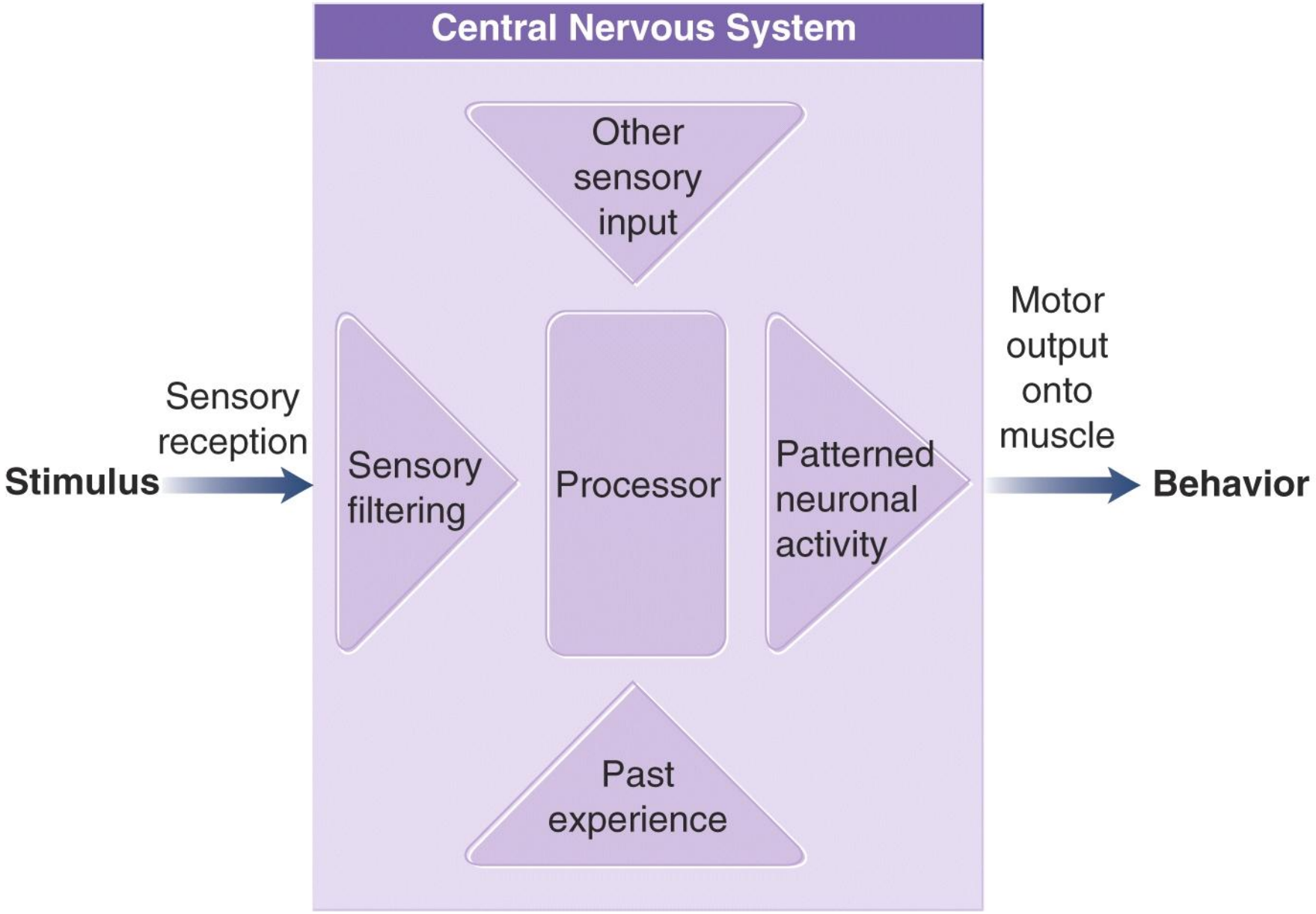
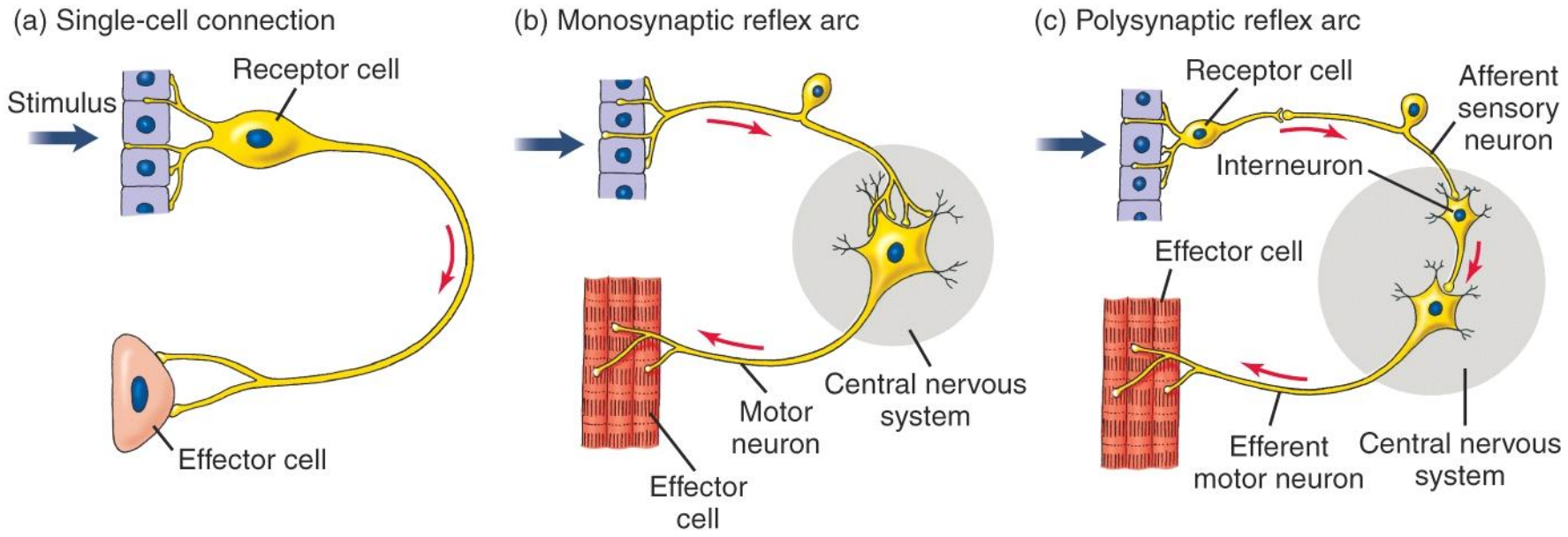
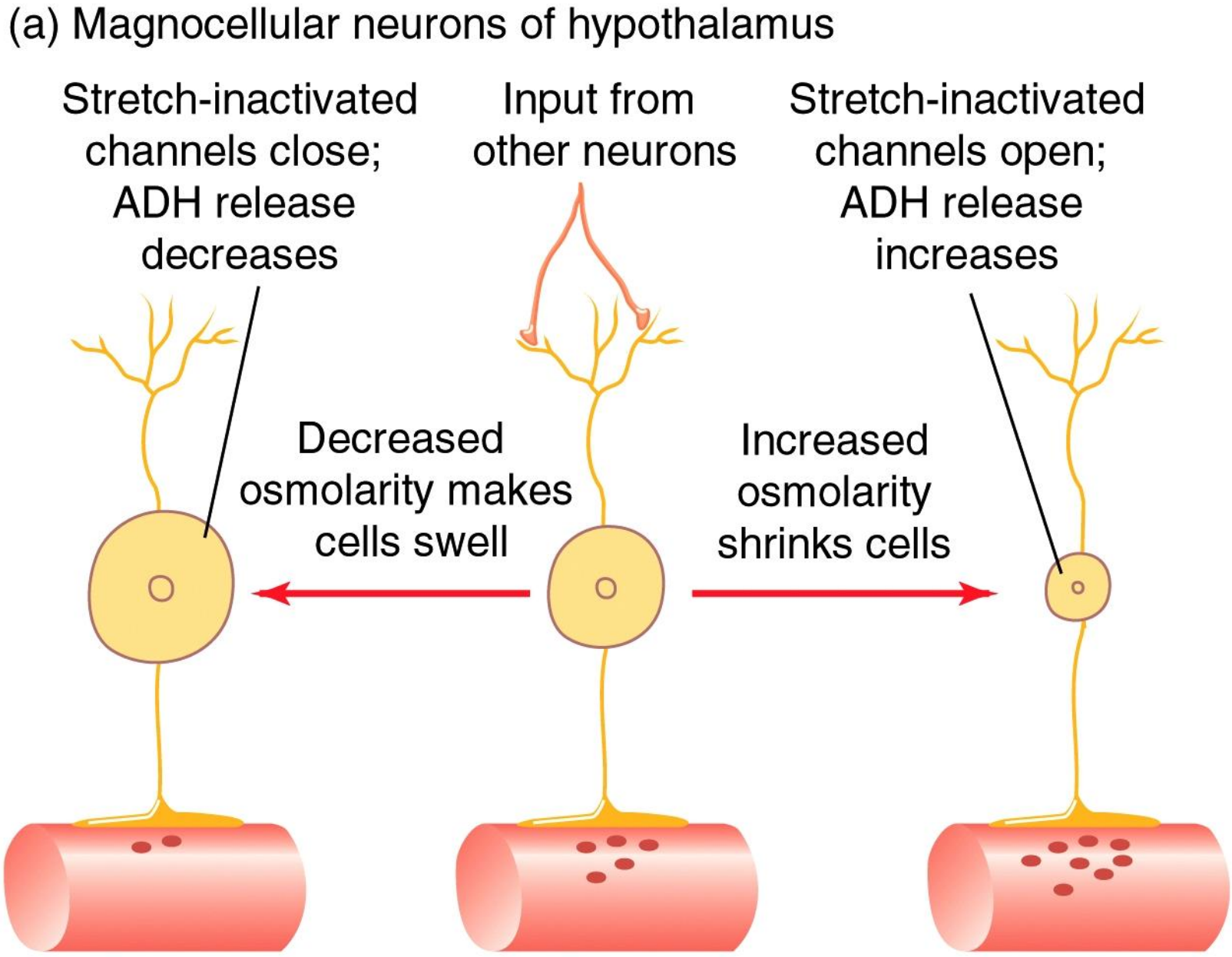
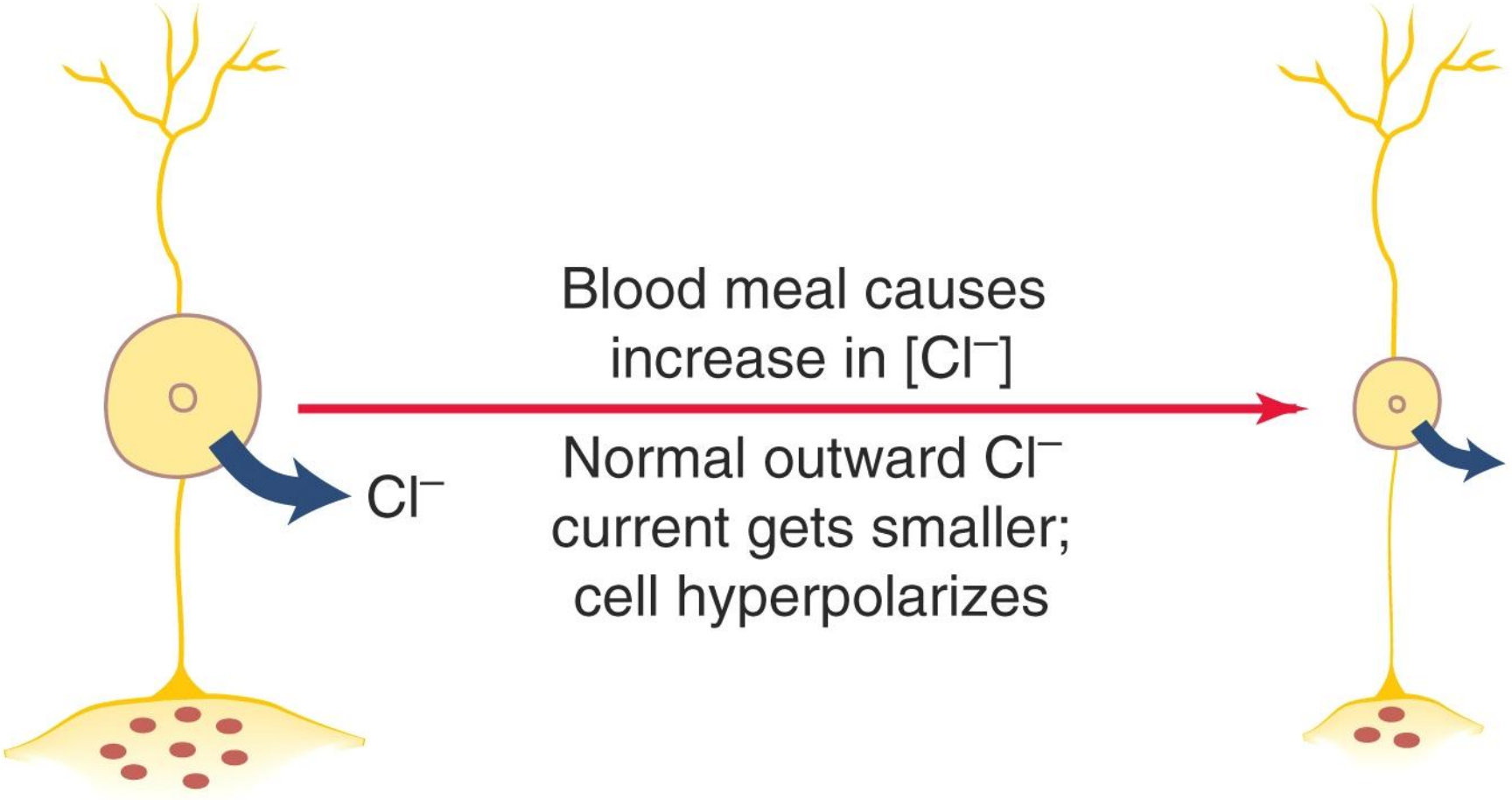

Central Nervous System
Other sensory input
Sensory reception
Stimulus
Sensory filtering
Processor
Patterned neuronal activity
Motor output onto muscle
Behavior
Past experience

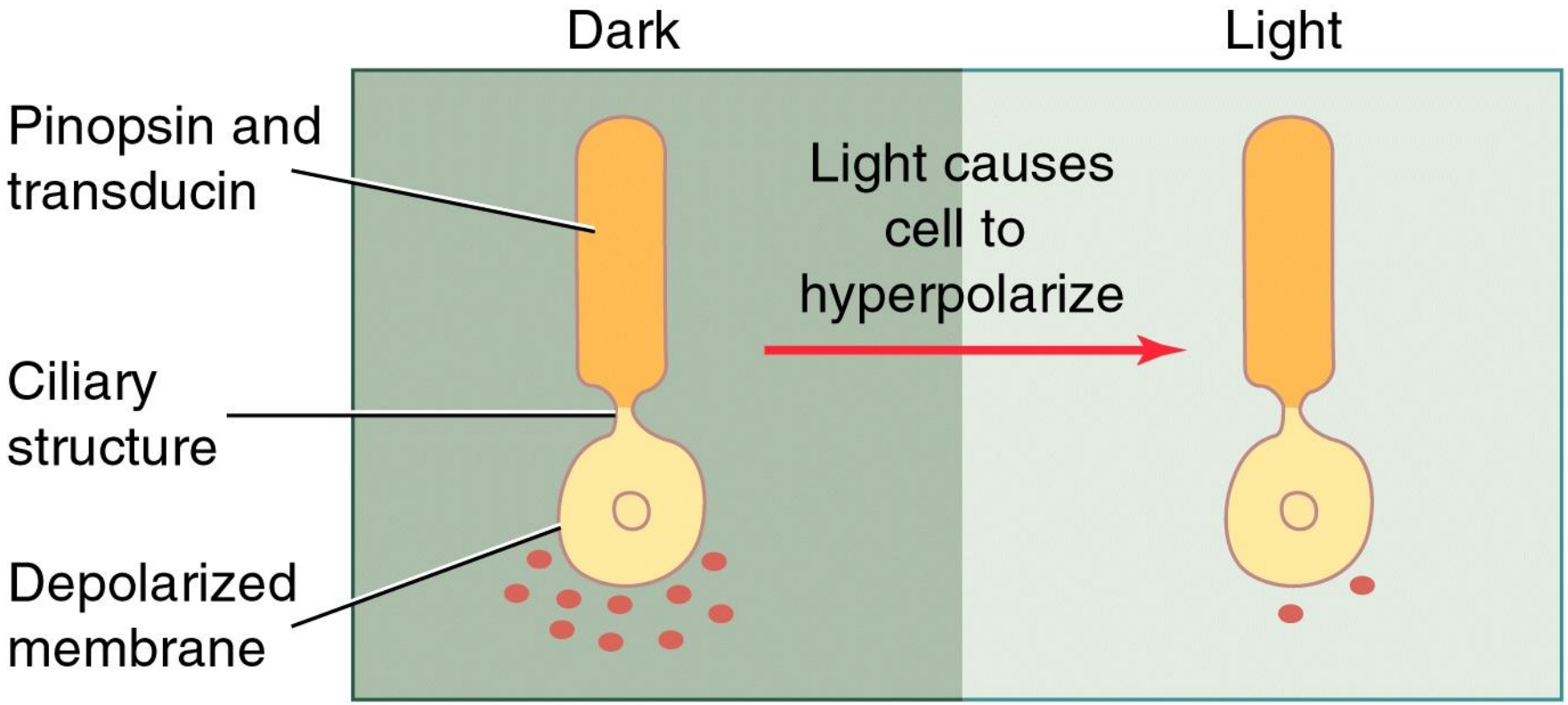

(a) Single-cell connection
Stimulus
Receptor cell
Effector cell
(b) Monosynaptic reflex arc
Central nervous system
Motor neuron
Effector cell
(c) Polysynaptic reflex arc
Receptor cell
Afferent sensory neuron
Interneuron
Effector cell
Efferent motor neuron
Central nervous system

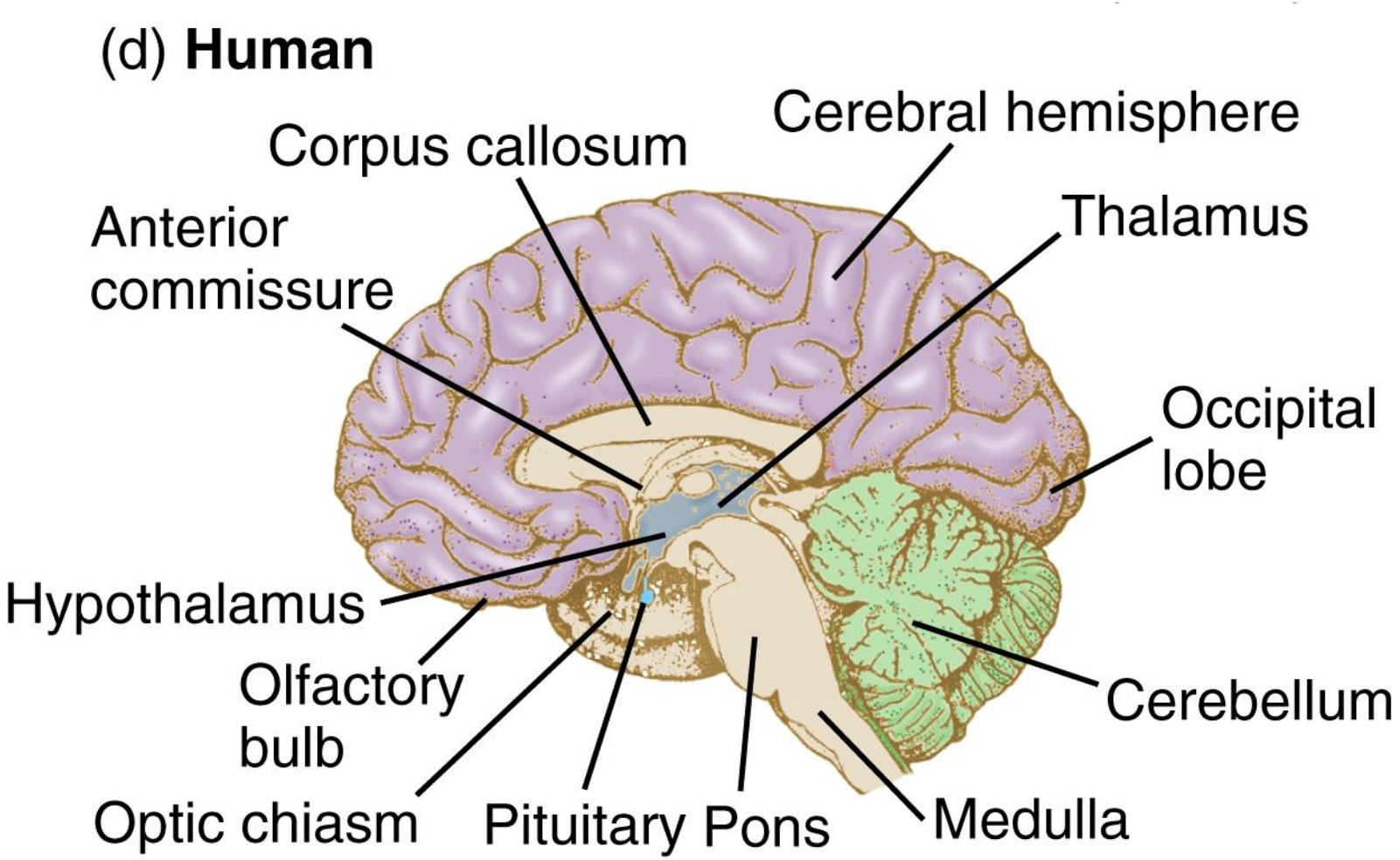

(a) Magnocellular neurons of hypothalamus
Stretch-inactivated channels close; ADH release decreases
Input from other neurons
Stretch-inactivated channels open; ADH release increases
Decreased osmolarity makes cells swell
Increased osmolarity shrinks cells

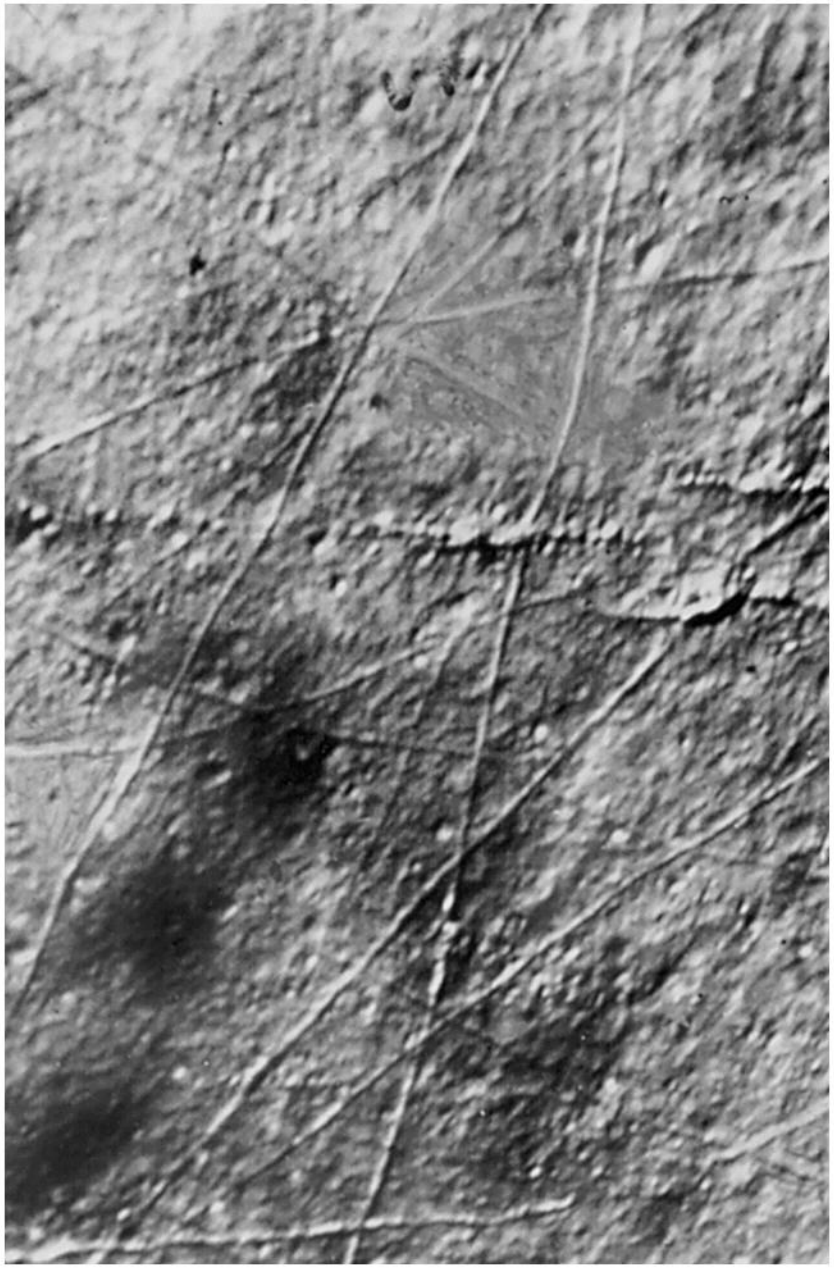
(b) Nephridial nerve cell



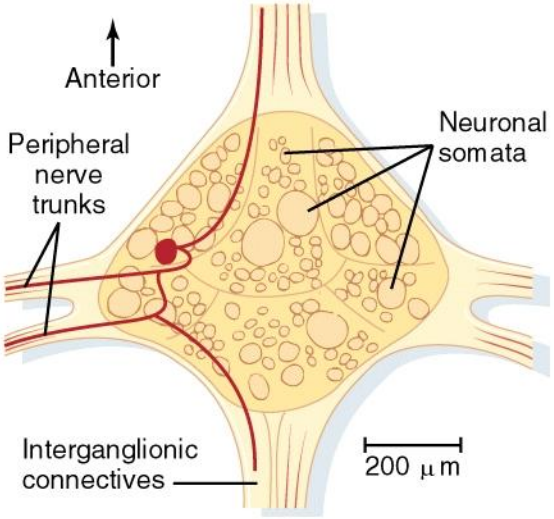
(c) Trout pinealocyte

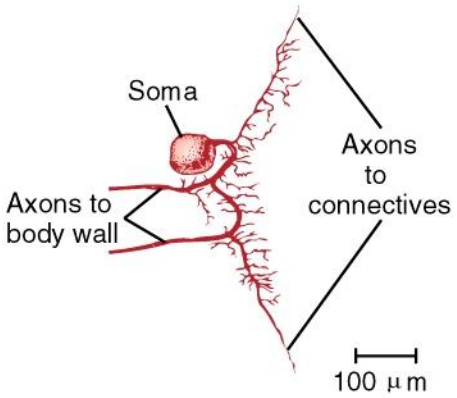



(d) Human
Cerebral hemisphere
Corpus callosum
Thalamus
Anterior commissure
Occipital lobe
Hypothalamus
Olfactory bulb
Cerebellum
Optic chiasm
Pituitary
Pons
Medulla

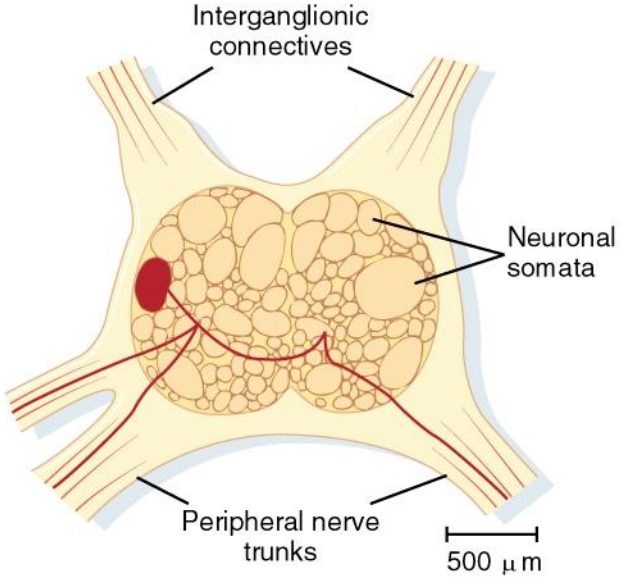


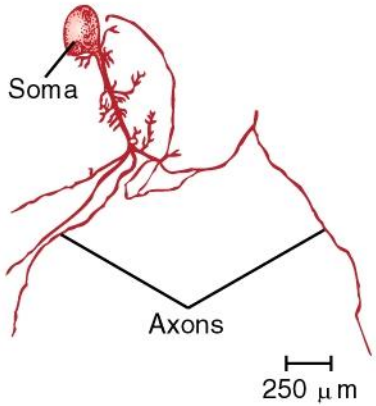
(a) Segmental ganglion of *Hirudo*



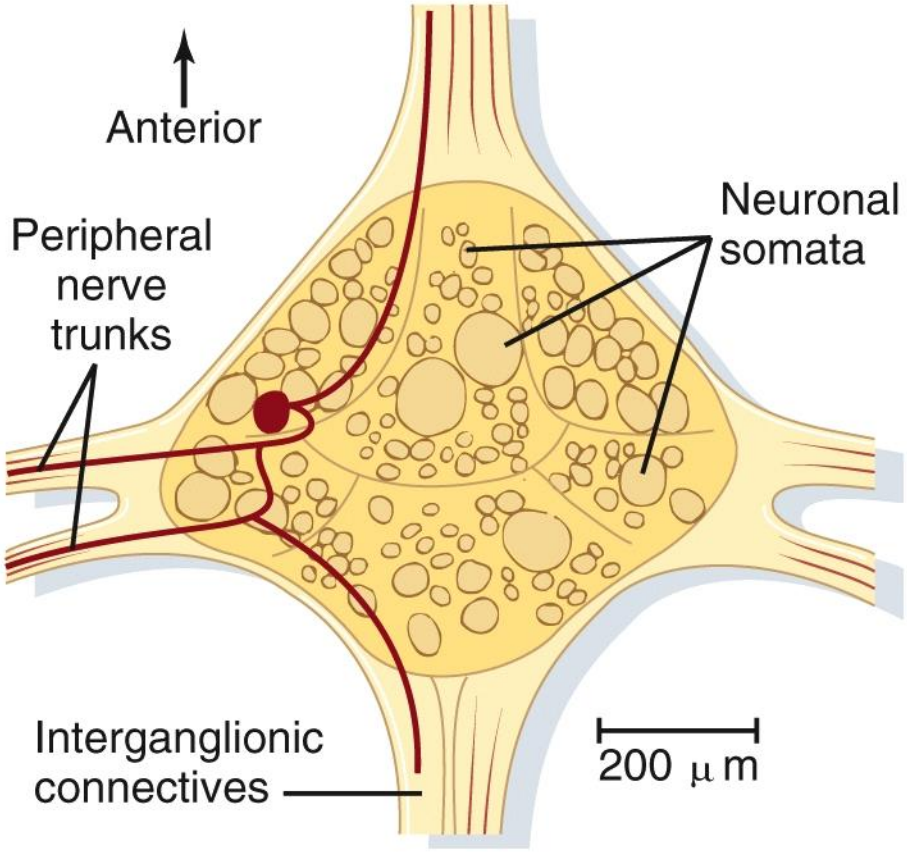


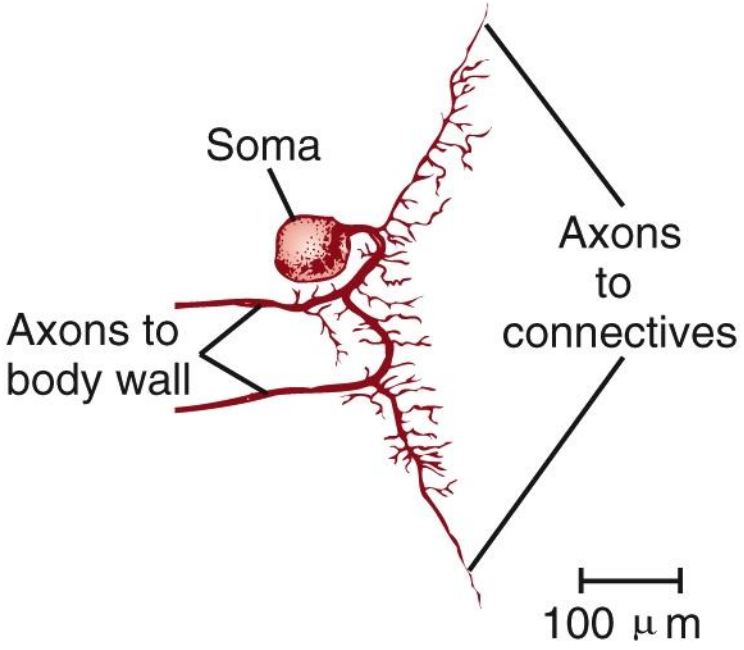
(b) Abdominal ganglion of *Aplysia*



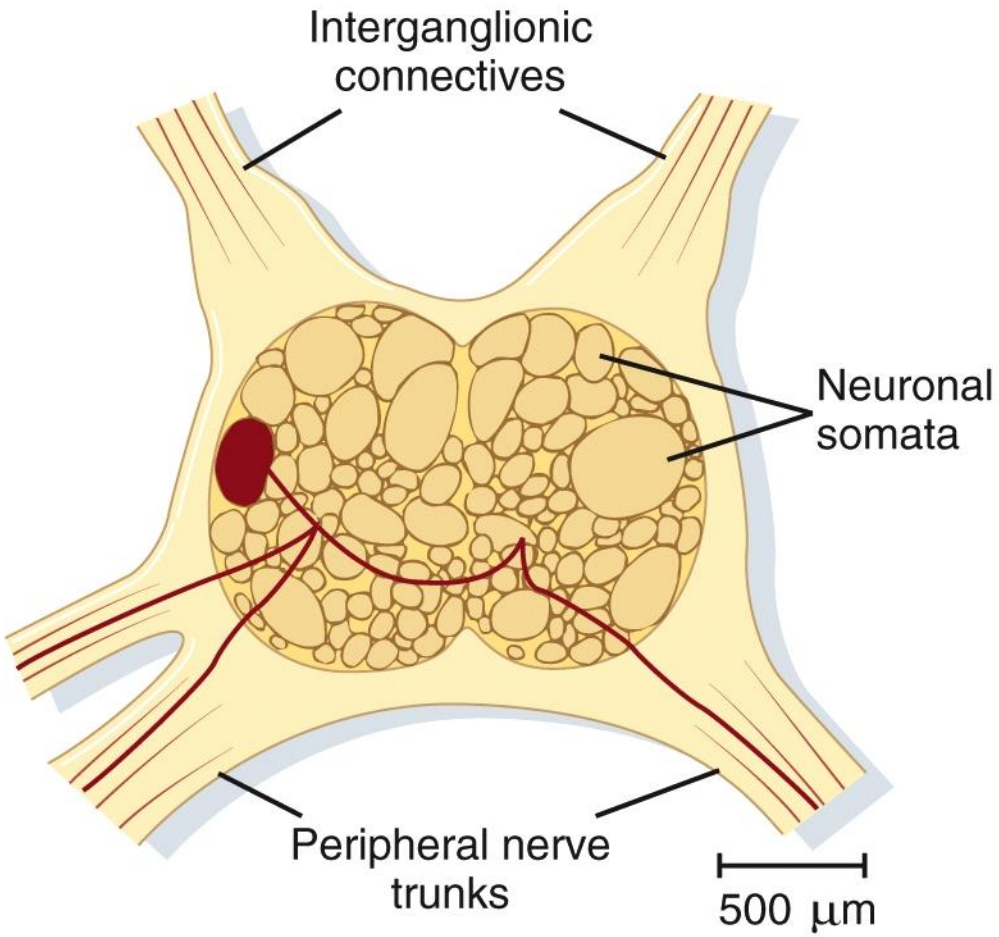


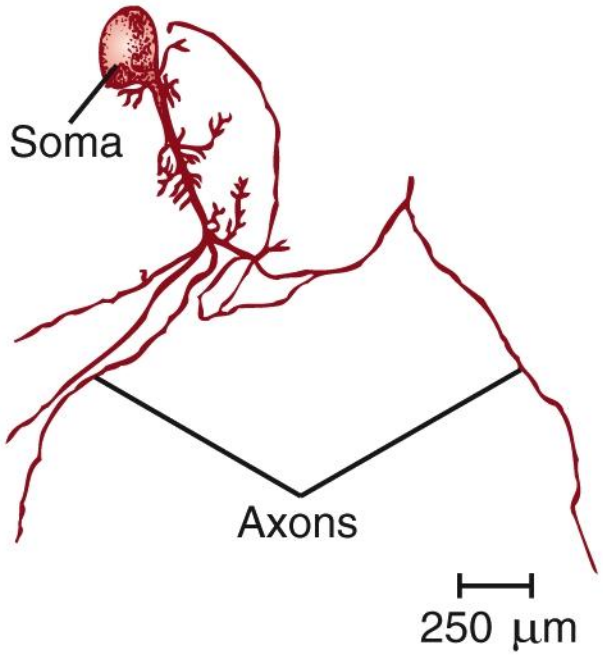
(a) Segmental ganglion of *Hirudo*

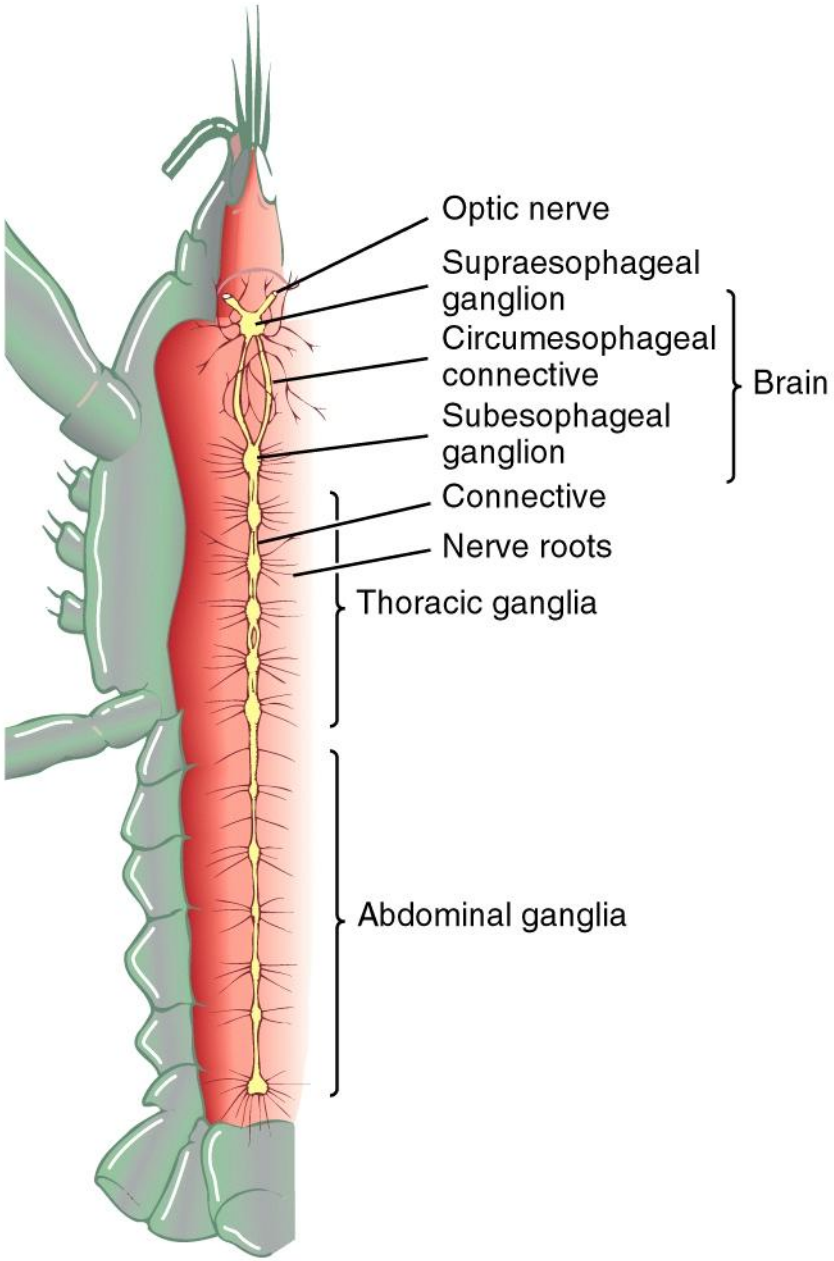




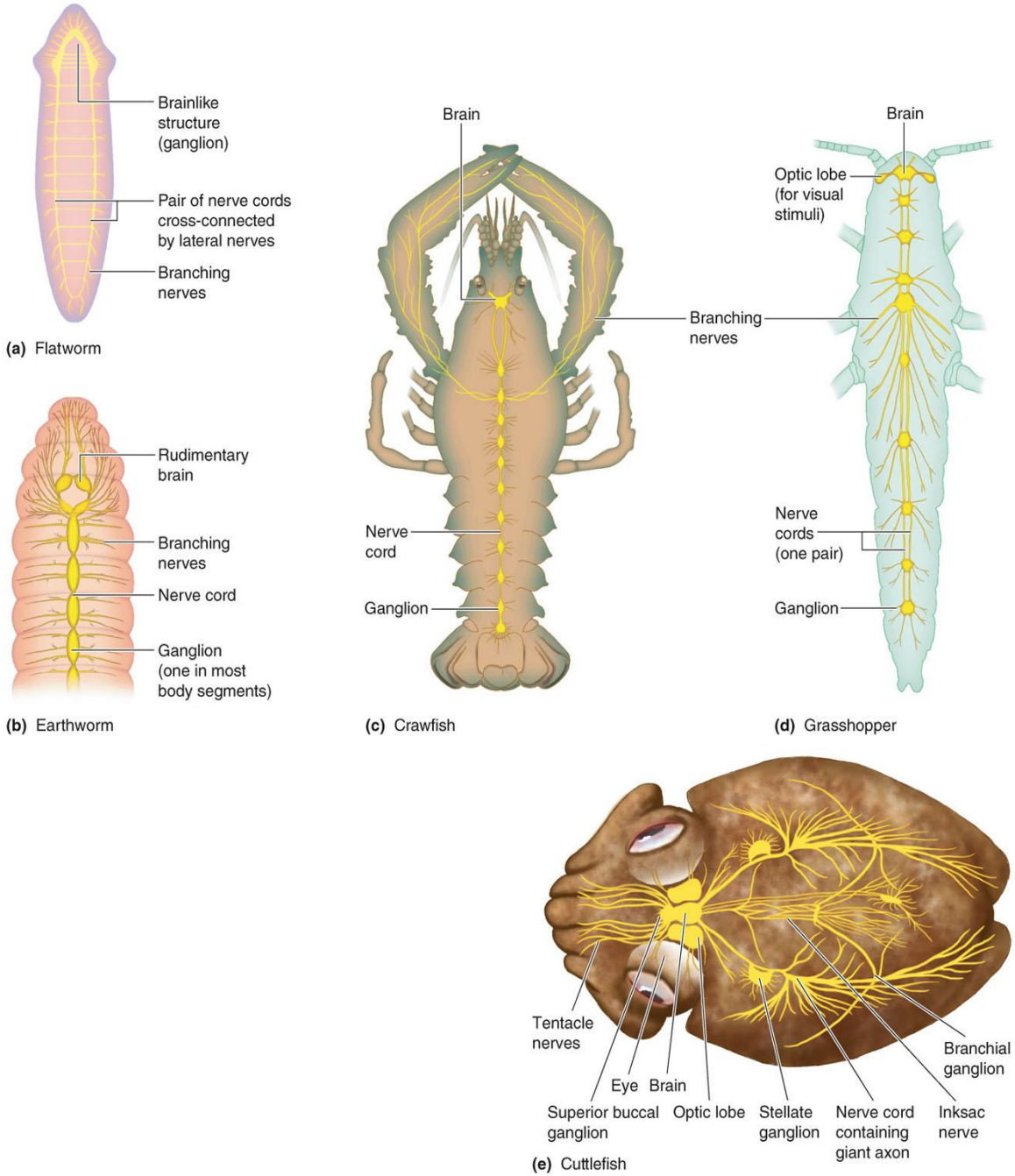
(b) Abdominal ganglion of *Aplysia*

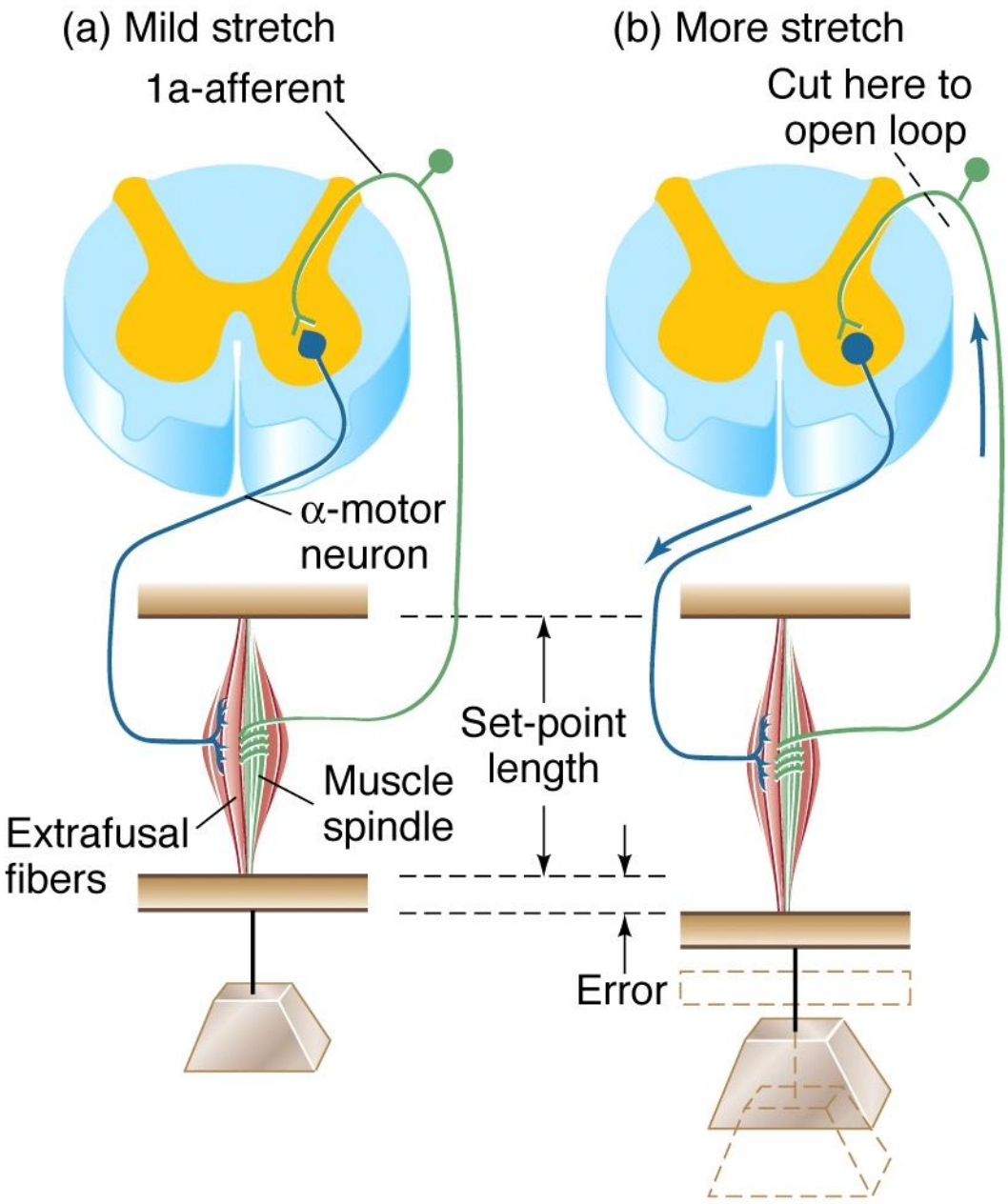


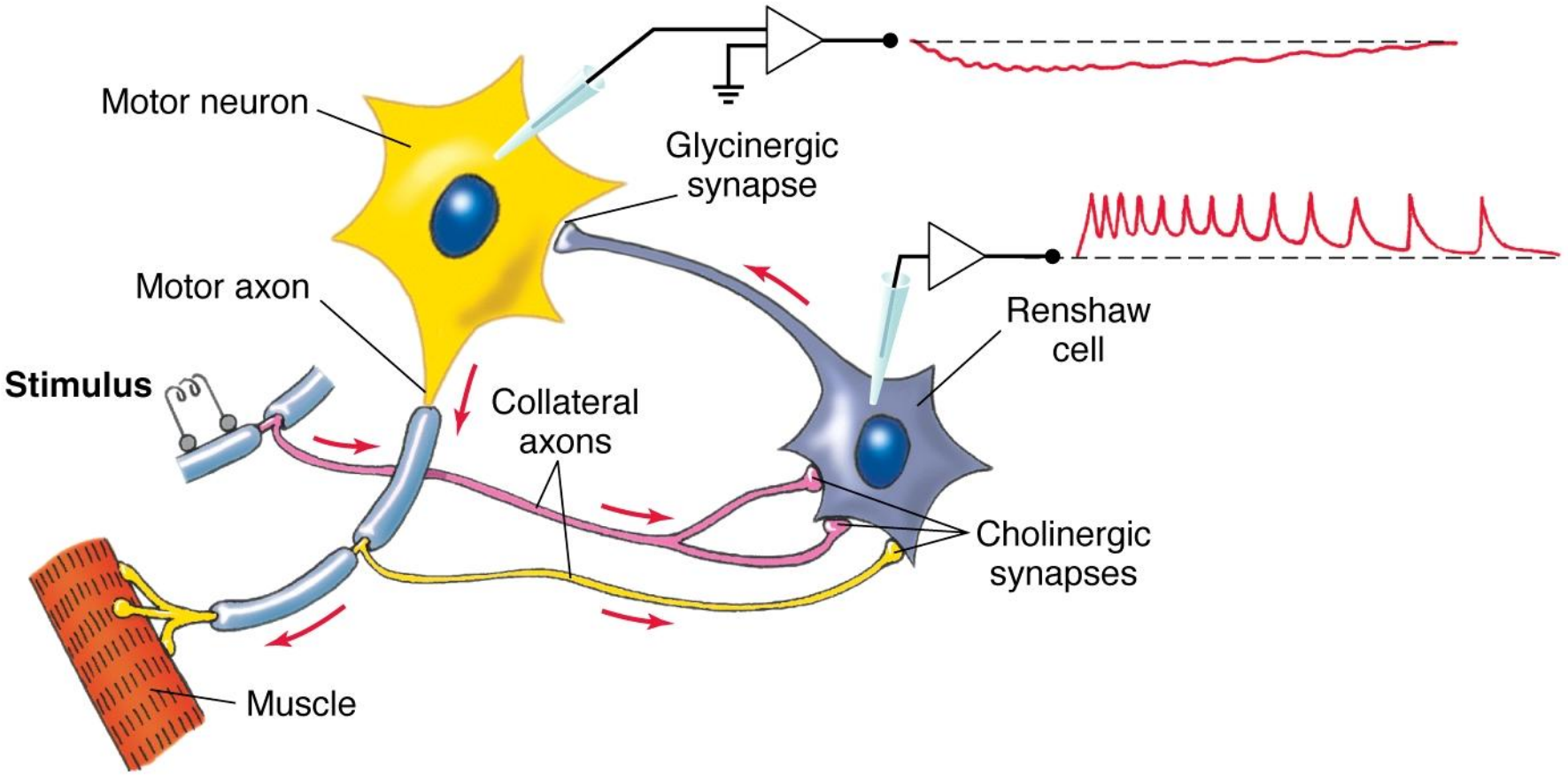


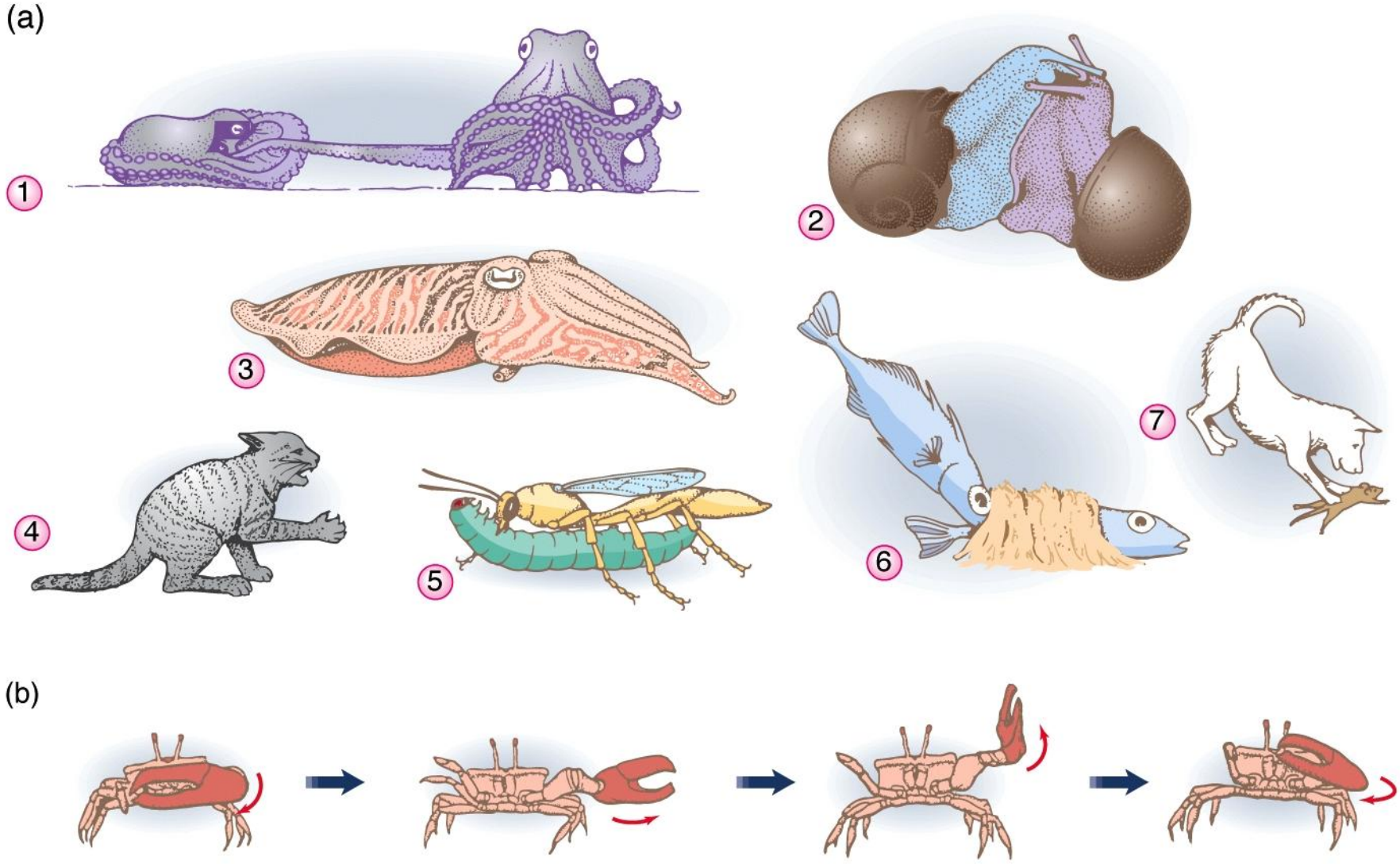

Optic nerve
Supraesophageal ganglion
Circumesophageal connective
Subesophageal ganglion
Brain
Connective
Nerve roots
Thoracic ganglia
Abdominal ganglia

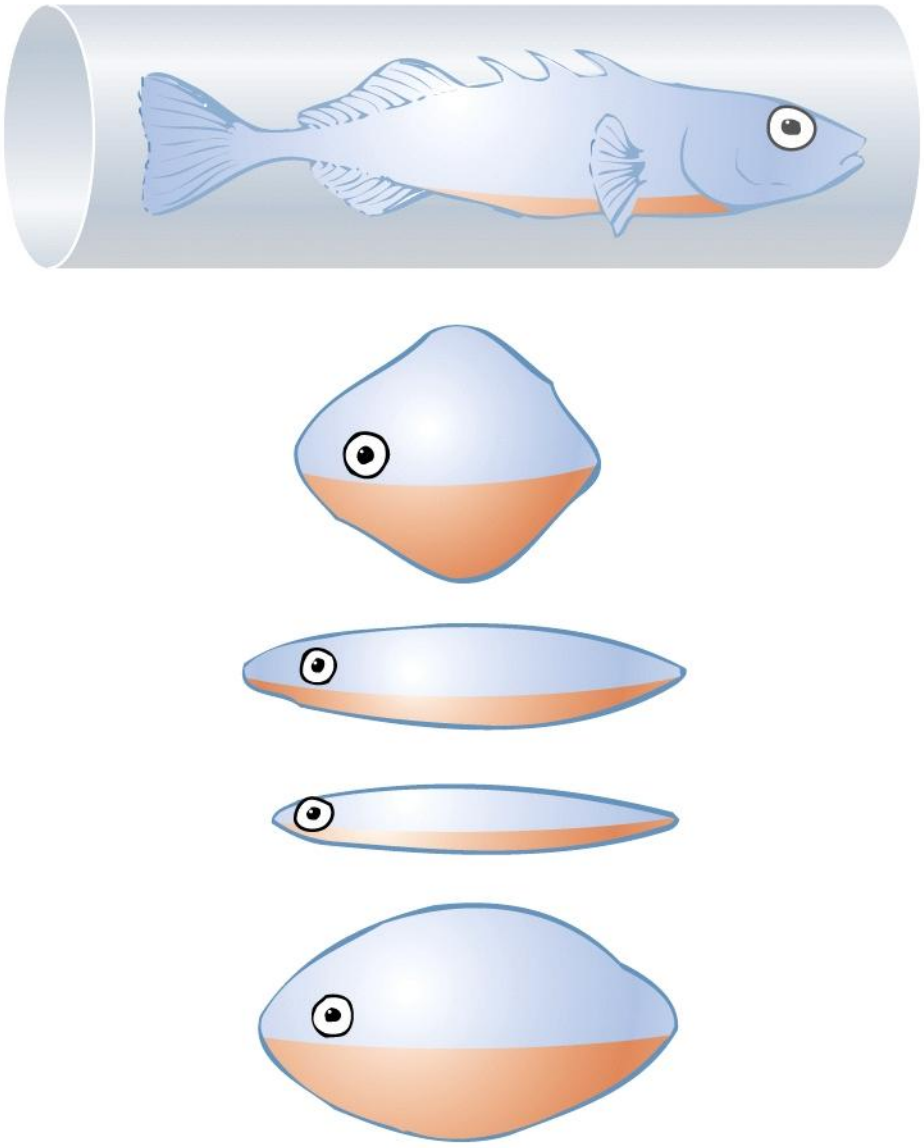
- **Segmented animals** have a chain of segmental ganglia
  - Ganglia are larger in **arthropods**
  - One ganglion for each thoracic and abdominal body segment
  - **Decentralized** brain function
- Evolutionary trend toward **enlarged anterior region** of the CNS (**cephalization**)
  - The **most advanced brains** are found in **cephalopod mollusks** and **vertebrates**
  - Ganglia are enlarged and organized into **lobes**


Brainlike structure (ganglion)
Pair of nerve cords cross-connected by lateral nerves
Branching nerves
(a) Flatworm
Rudimentary brain
Branching nerves
Nerve cord
Ganglion (one in most body segments)
(b) Earthworm
Brain
Branching nerves
Nerve cord
Ganglion
(c) Crawfish
Brain
Optic lobe (for visual stimuli)
Nerve cords (one pair)
Ganglion
(d) Grasshopper
Tentacle nerves
Eye
Brain
Superior buccal ganglion
Optic lobe
Stellate ganglion
Nerve cord containing giant axon
Inksac nerve
Branchial ganglion
(e) Cuttlefish

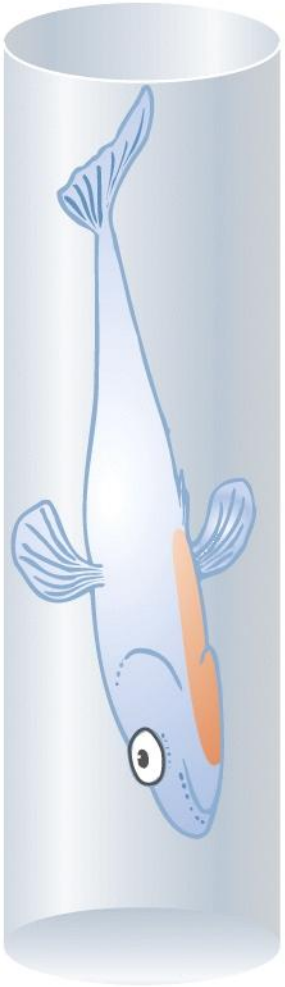

(a) Mild stretch
(b) More stretch
1a-afferent
Cut here to open loop
α-motor neuron
Set-point length
Muscle spindle
Extrafusal fibers
Error


Motor neuron
Glycinergic synapse
Motor axon
Renshaw cell
Stimulus
Collateral axons
Cholinergic synapses
Muscle

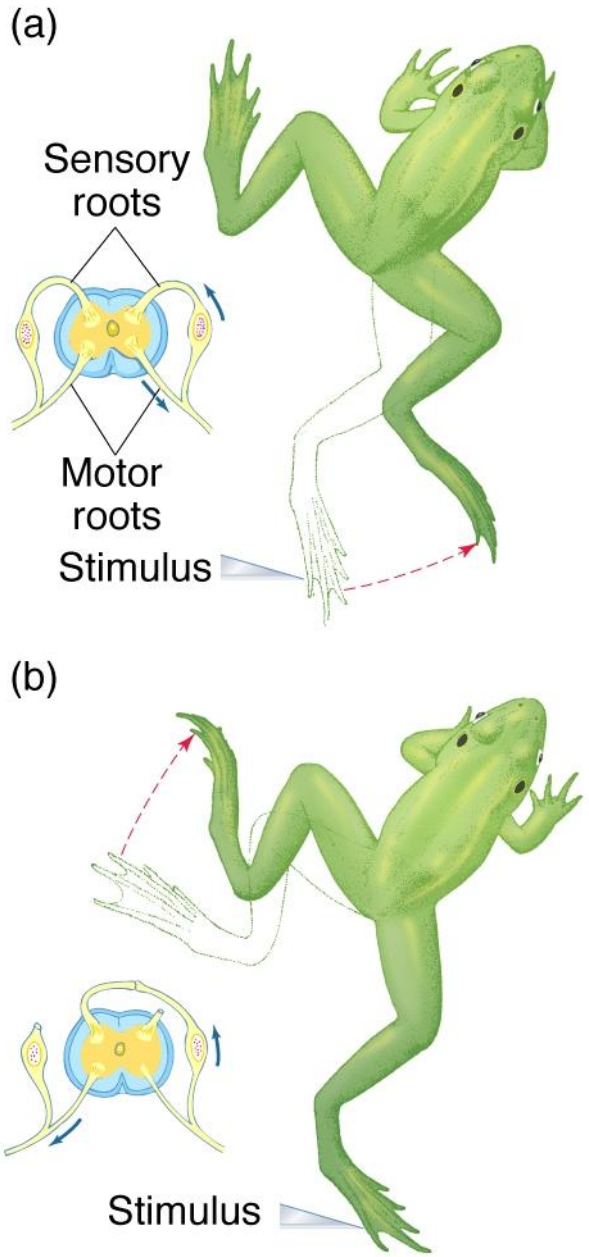

(a)
1
2
3
4
5
6
7
(b)

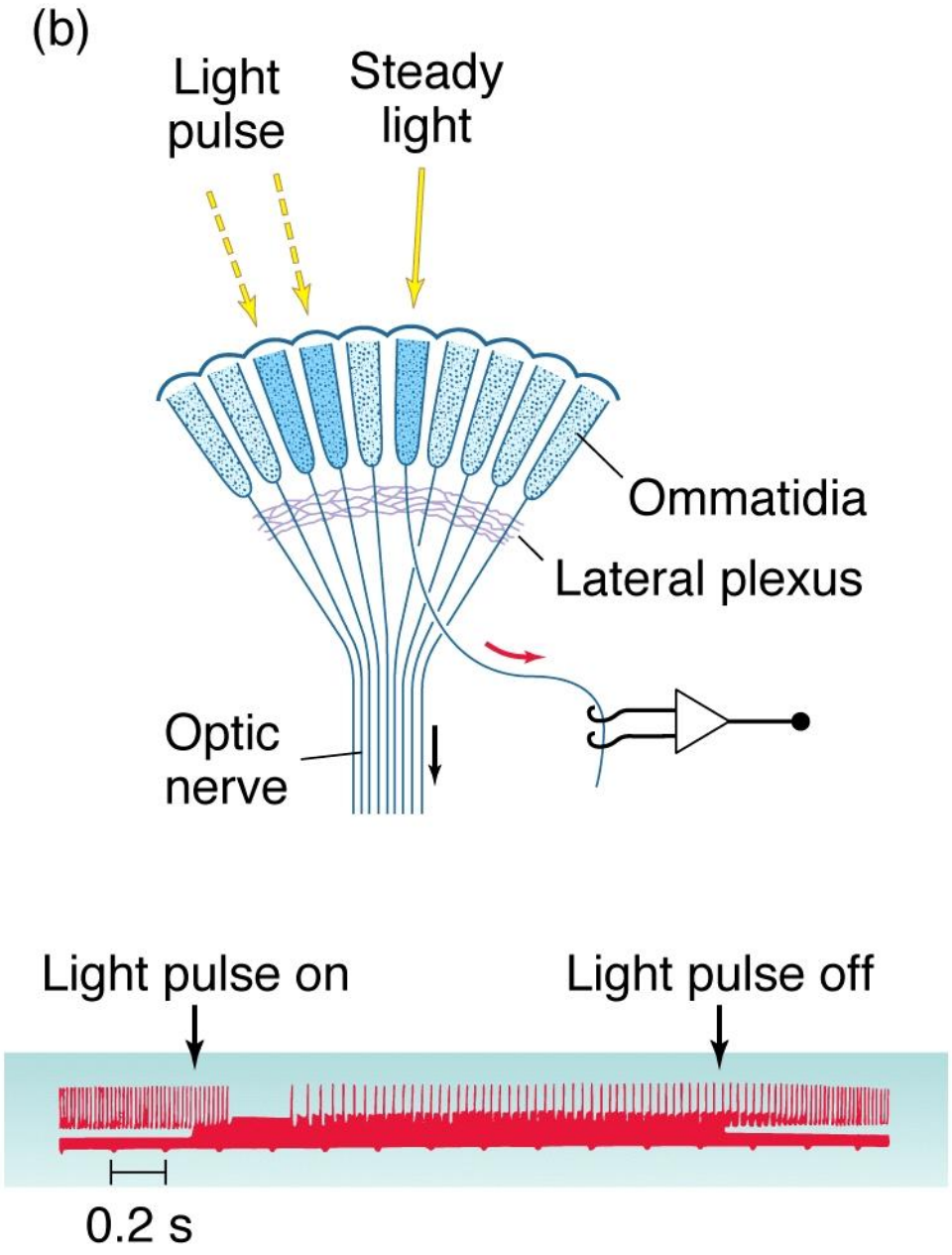


(a) Effective stimuli

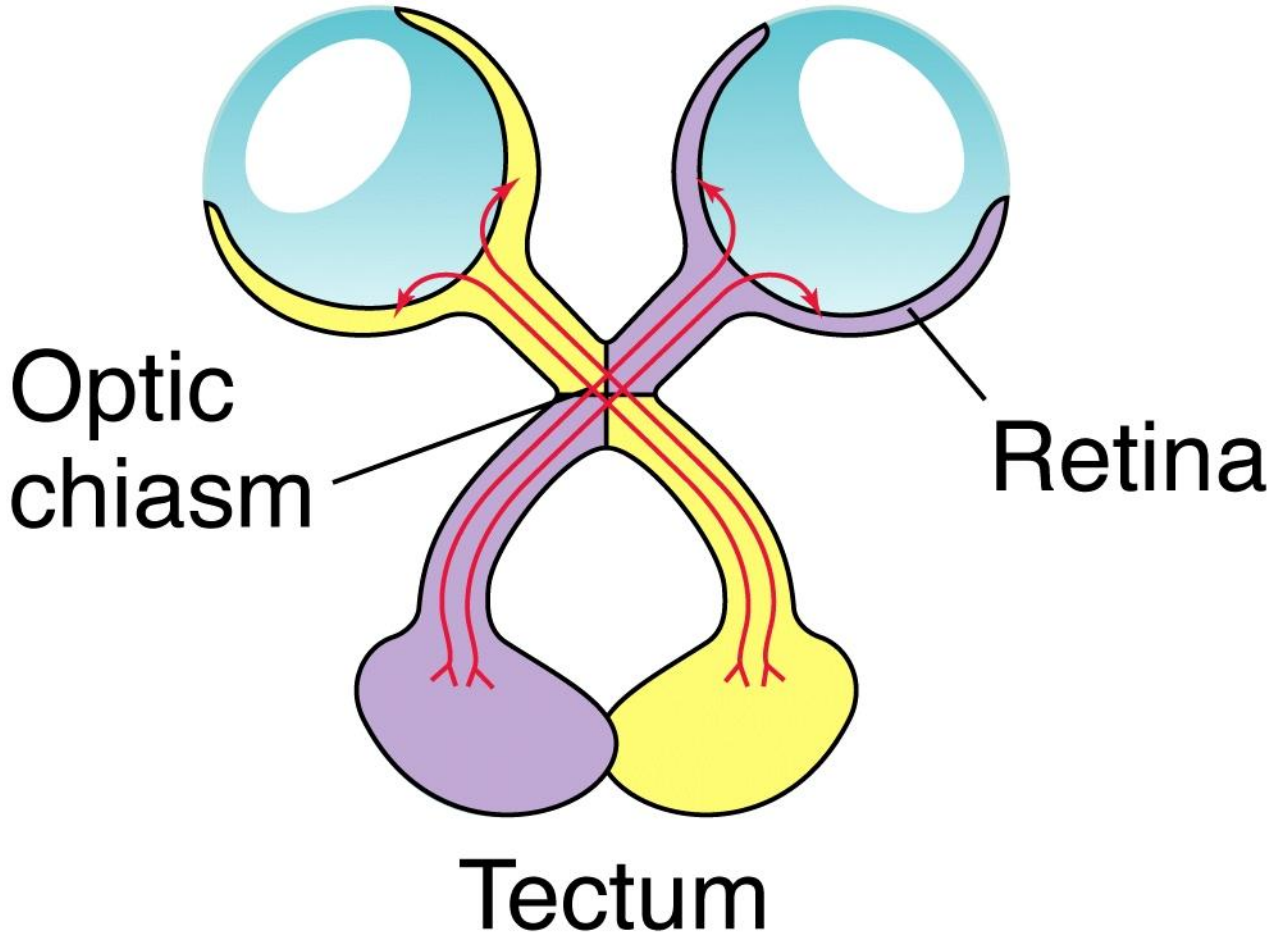


(b) No response

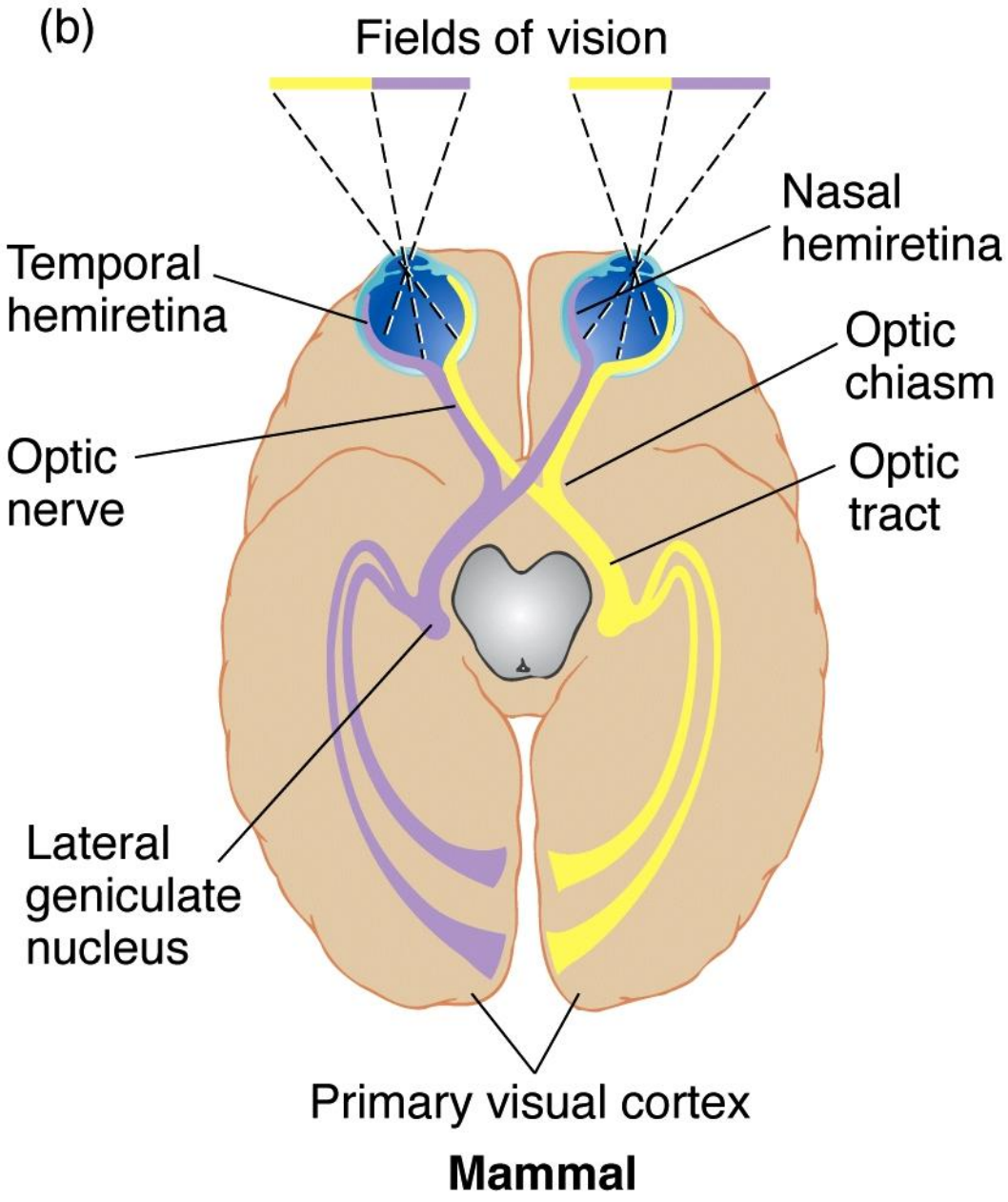

(a)
Sensory roots
Motor roots
Stimulus
(b)
Stimulus

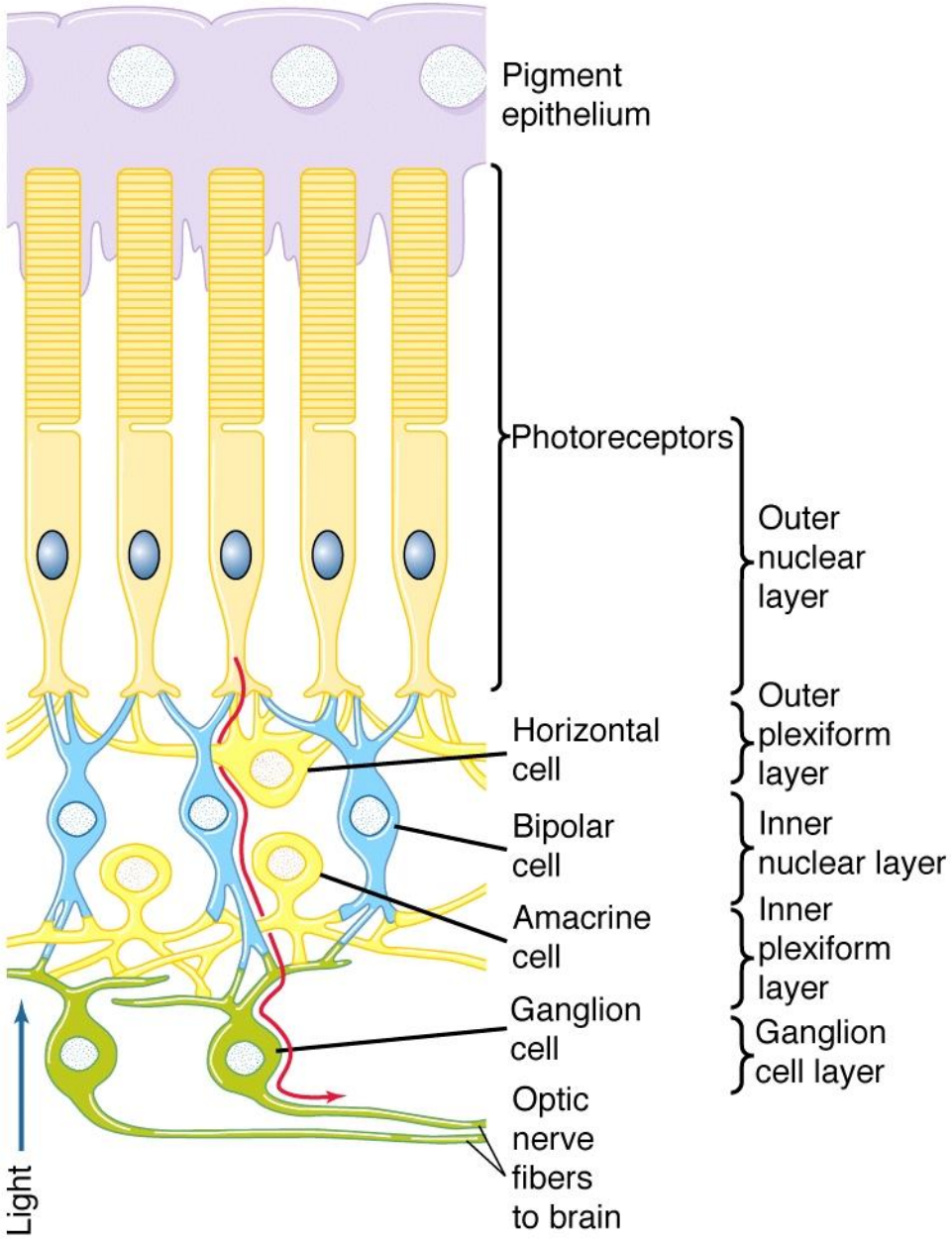

(b)
Light pulse
Steady light
Ommatidia
Lateral plexus
Optic nerve
Light pulse on
Light pulse off
0.2 s

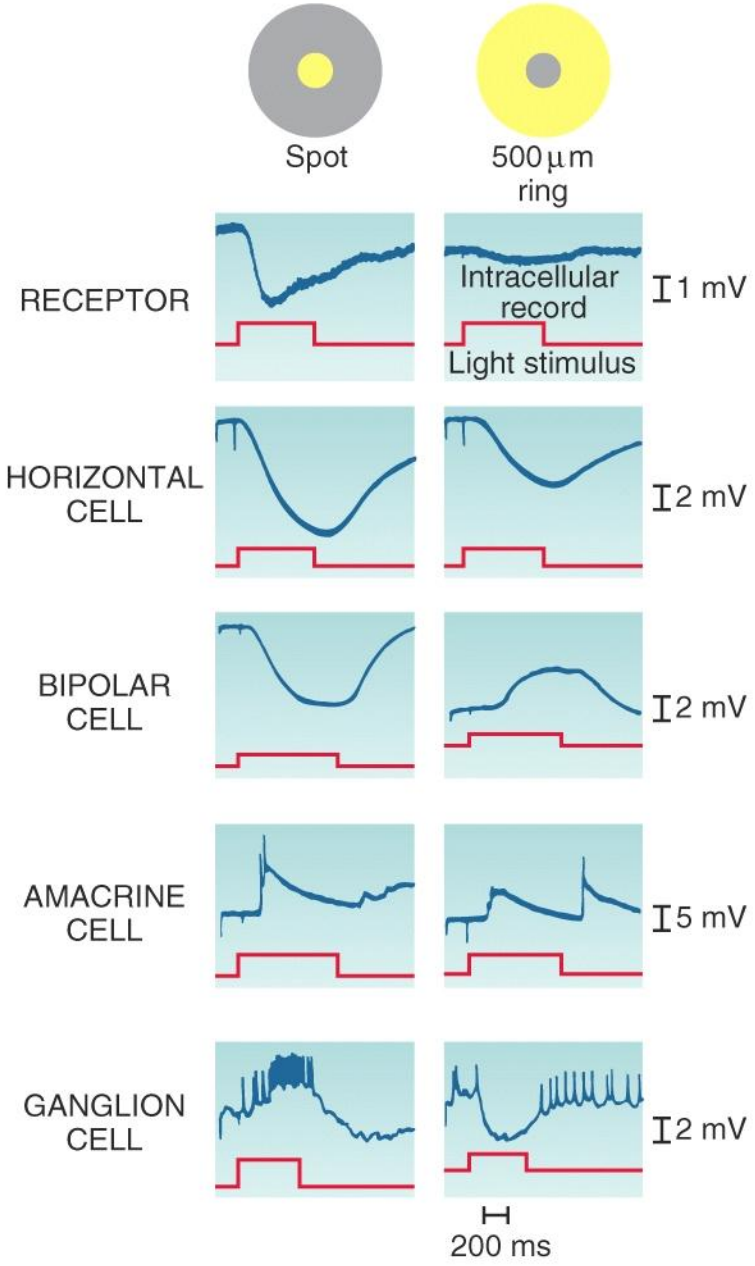
(a)

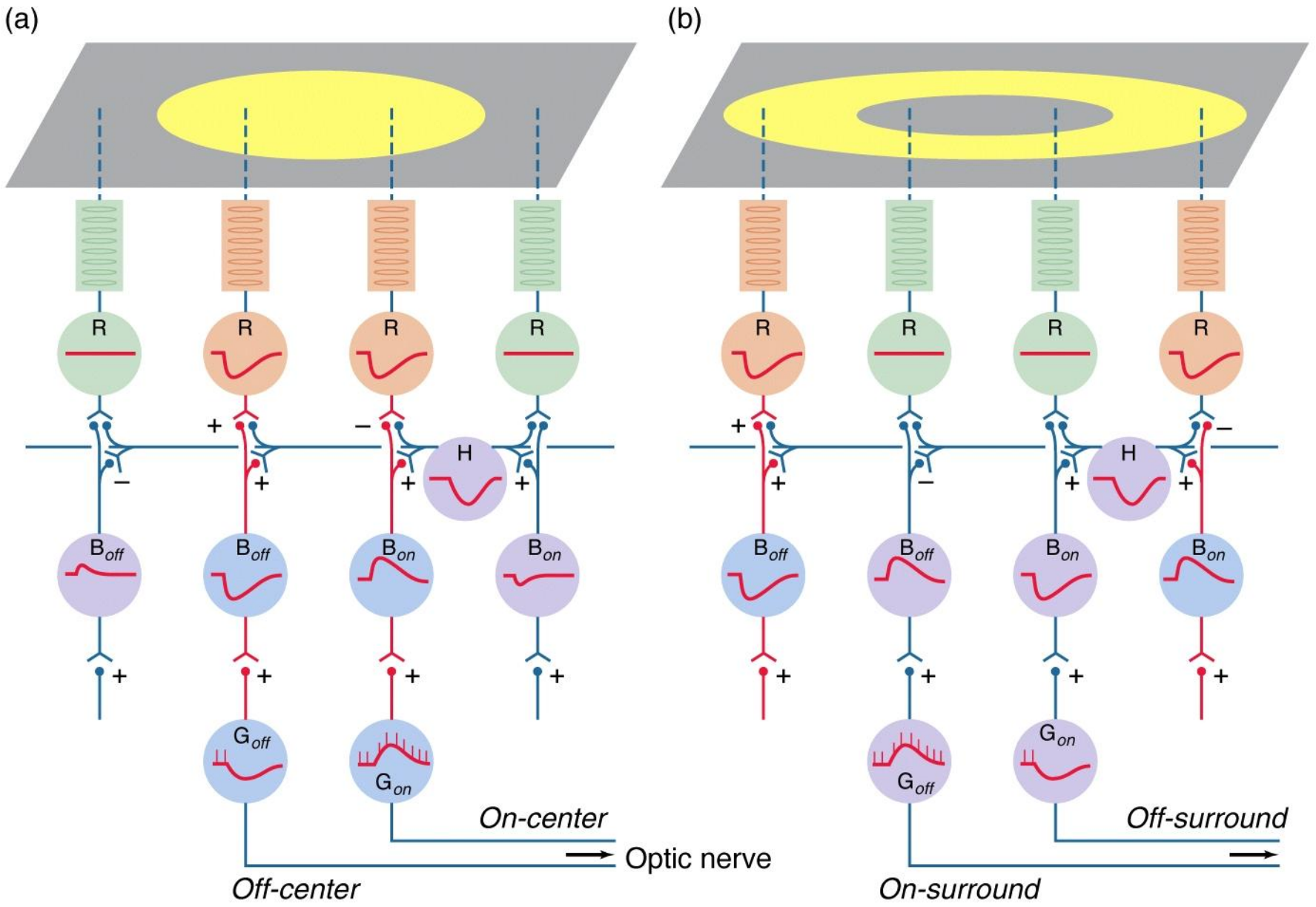


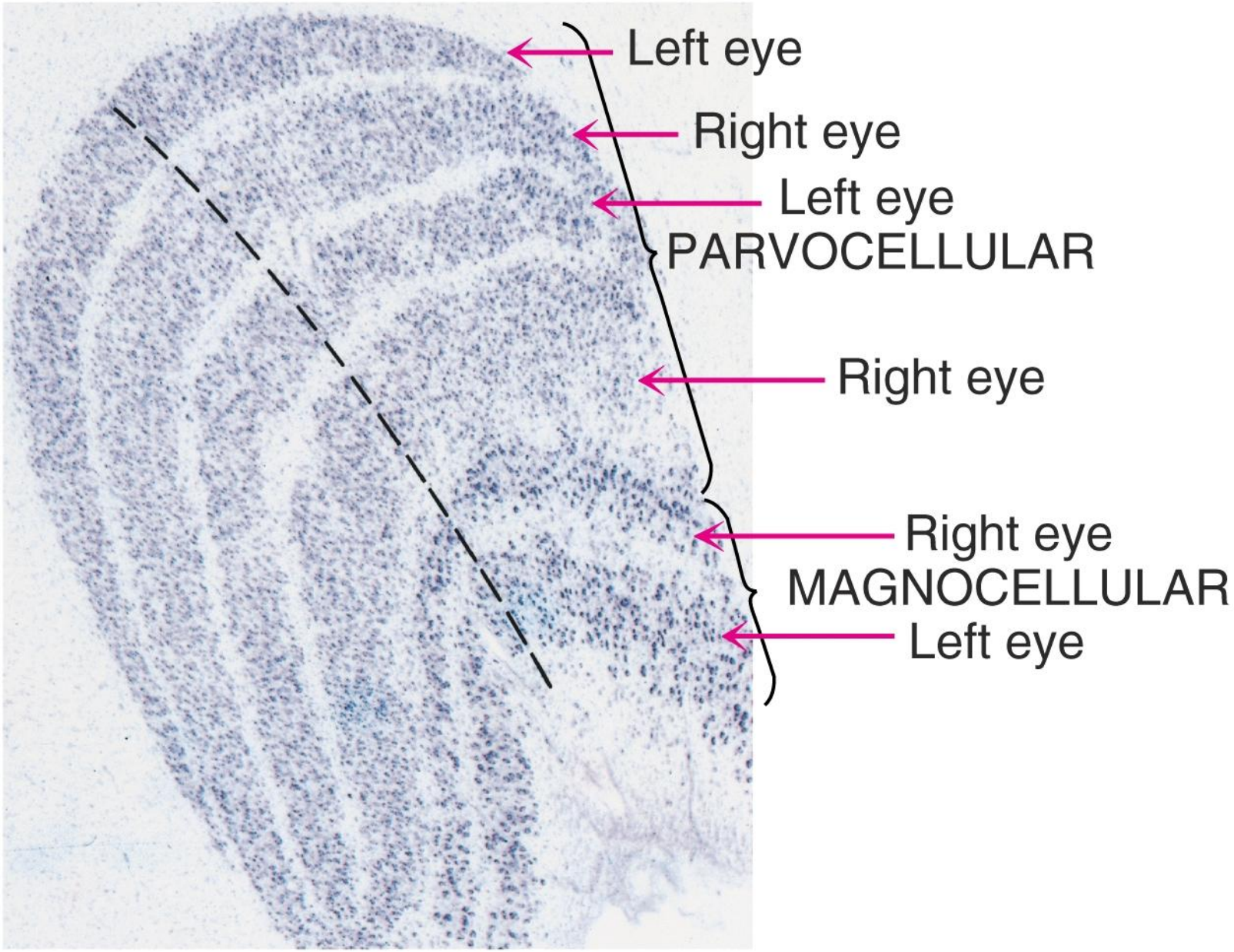
Amphibian

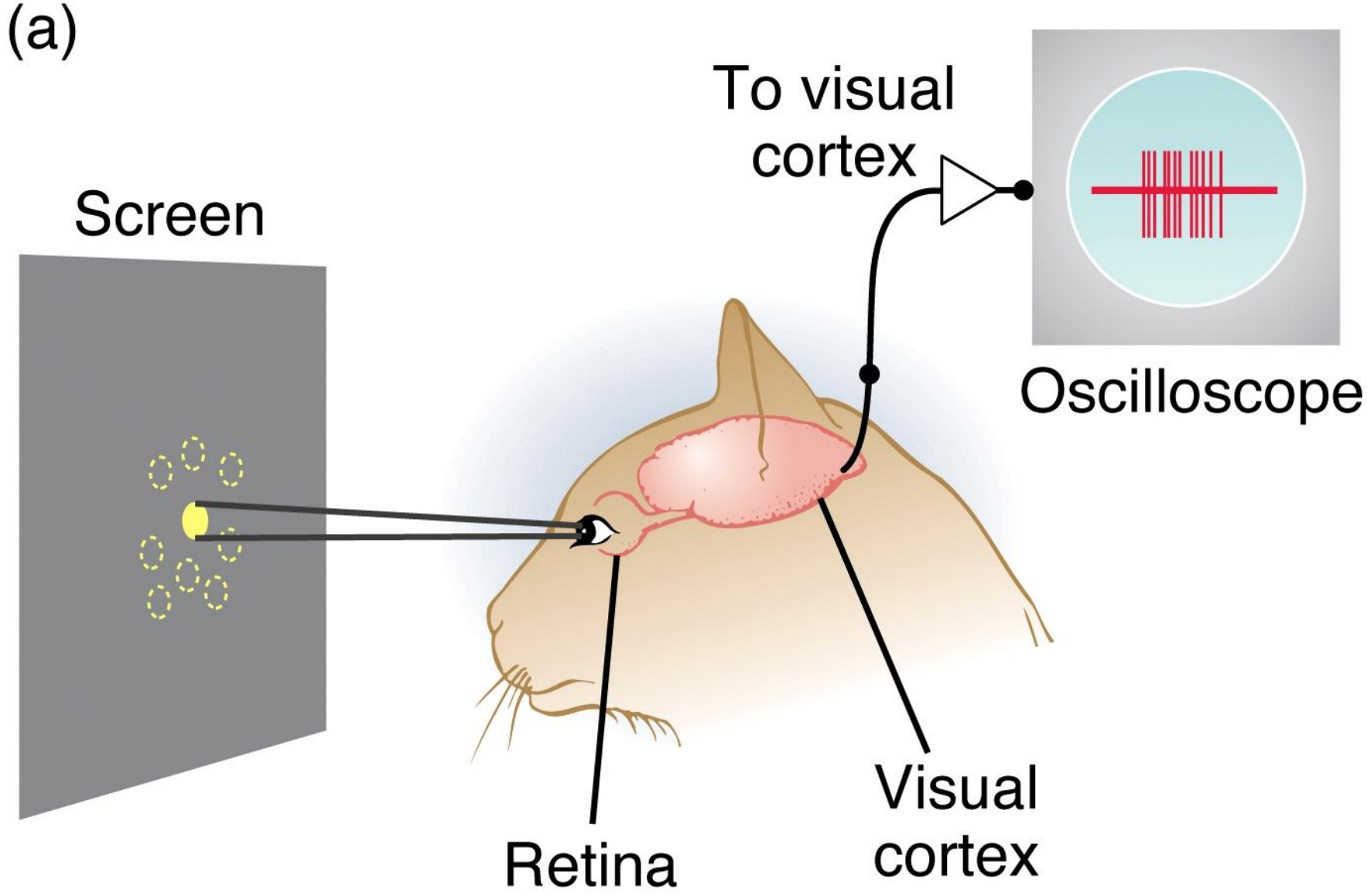

(b)
Fields of vision
Nasal hemiretina
Temporal hemiretina
Optic chiasm
Optic nerve
Optic tract
Lateral geniculate nucleus
Primary visual cortex
Mammal

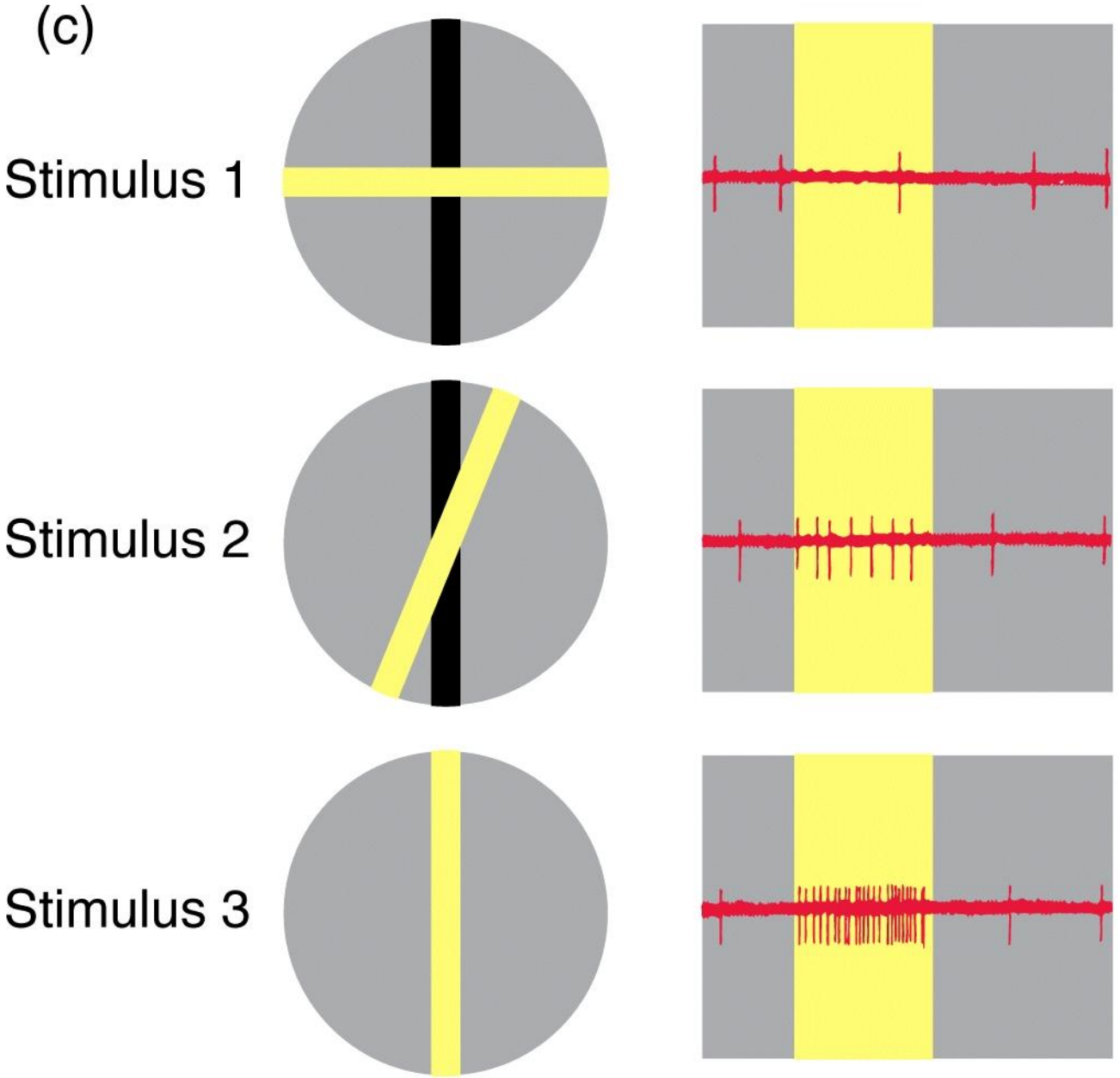

Pigment epithelium
Photoreceptors
Outer nuclear layer
Outer plexiform layer
Horizontal cell
Bipolar cell
Inner nuclear layer
Amacrine cell
Inner plexiform layer
Ganglion cell
Ganglion cell layer
Optic nerve fibers to brain
Light

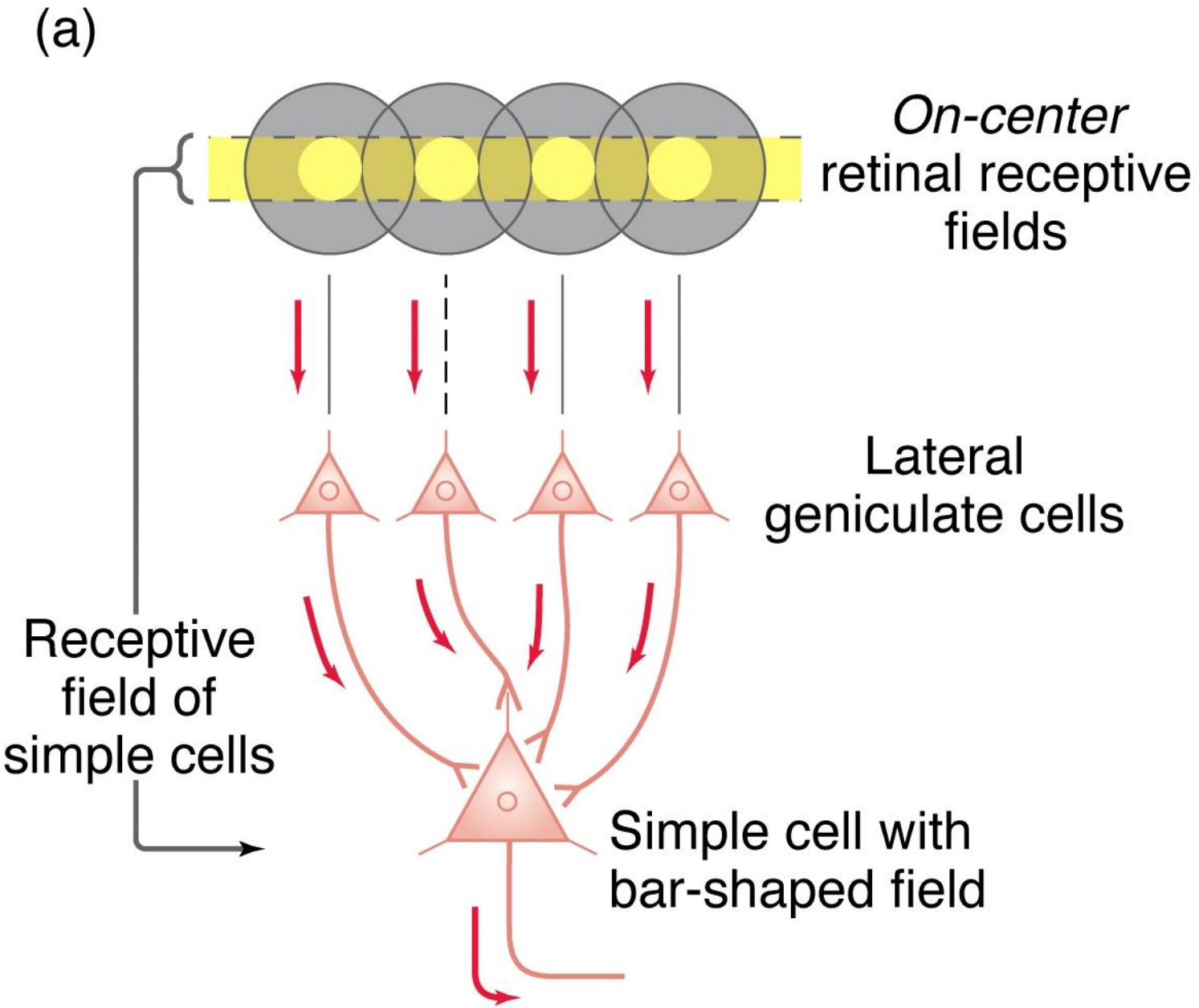

Spot
500 µm ring
RECEPTOR
Intracellular record
Light stimulus
1 mV
HORIZONTAL CELL
2 mV
BIPOLAR CELL
2 mV
AMACRINE CELL
5 mV
GANGLION CELL
2 mV
200 ms

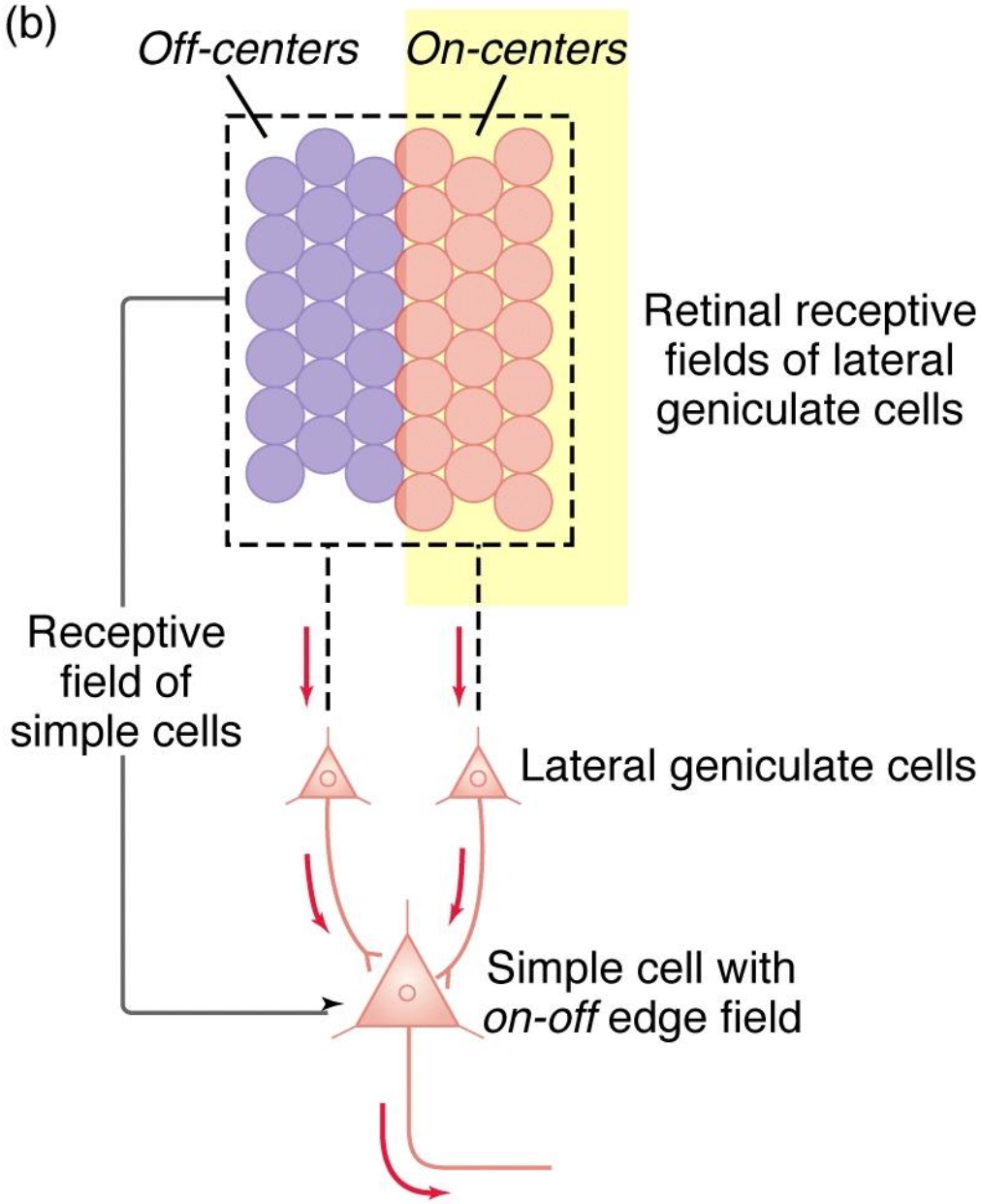

(a)
(b)
R
H
B_{off}
B_{on}
G_{off}
G_{on}
On-center
Optic nerve
Off-center
Off-surround
On-surround

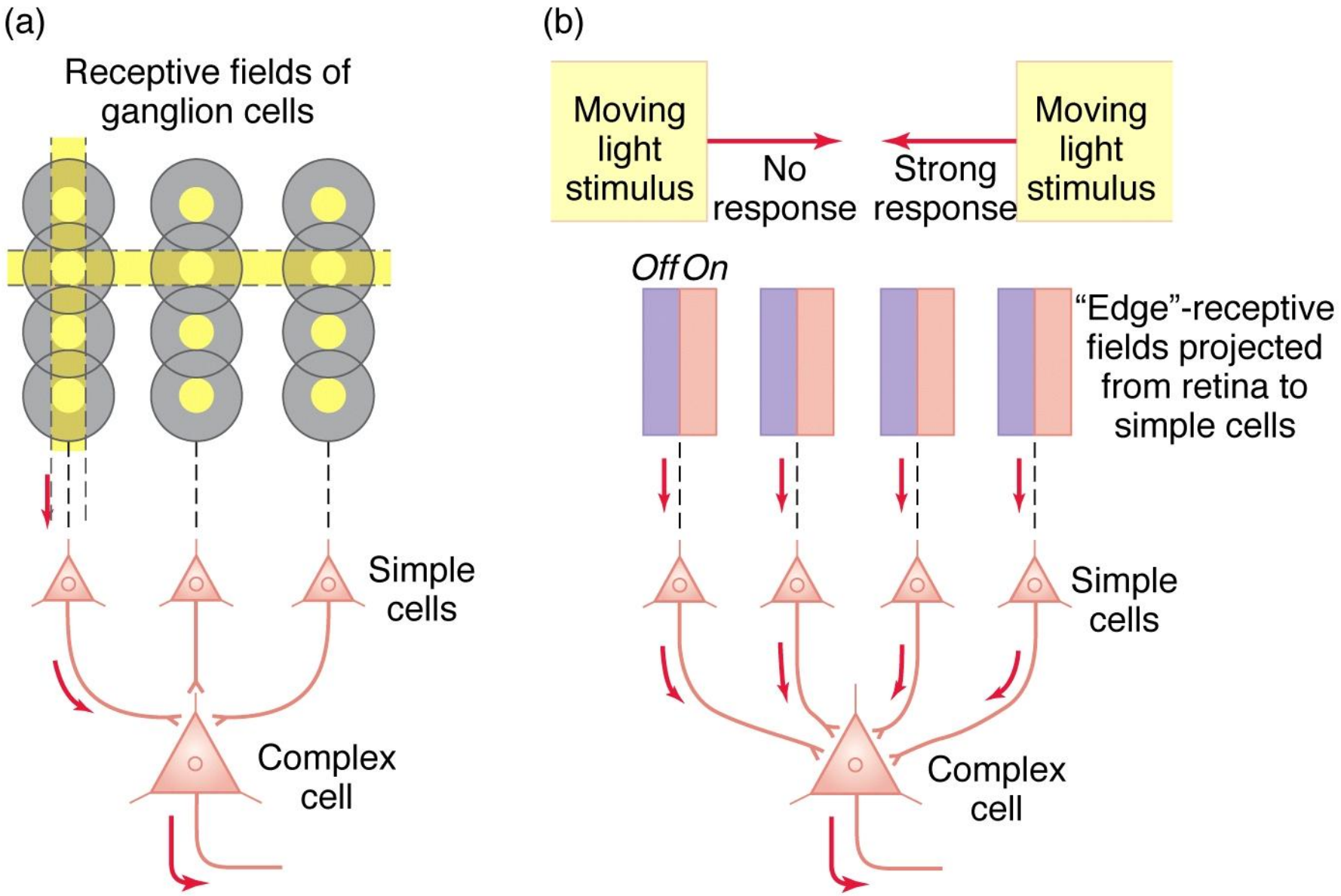

Left eye
Right eye
Left eye
PARVOCELLULAR
Right eye
Right eye
MAGNOCELLULAR
Left eye

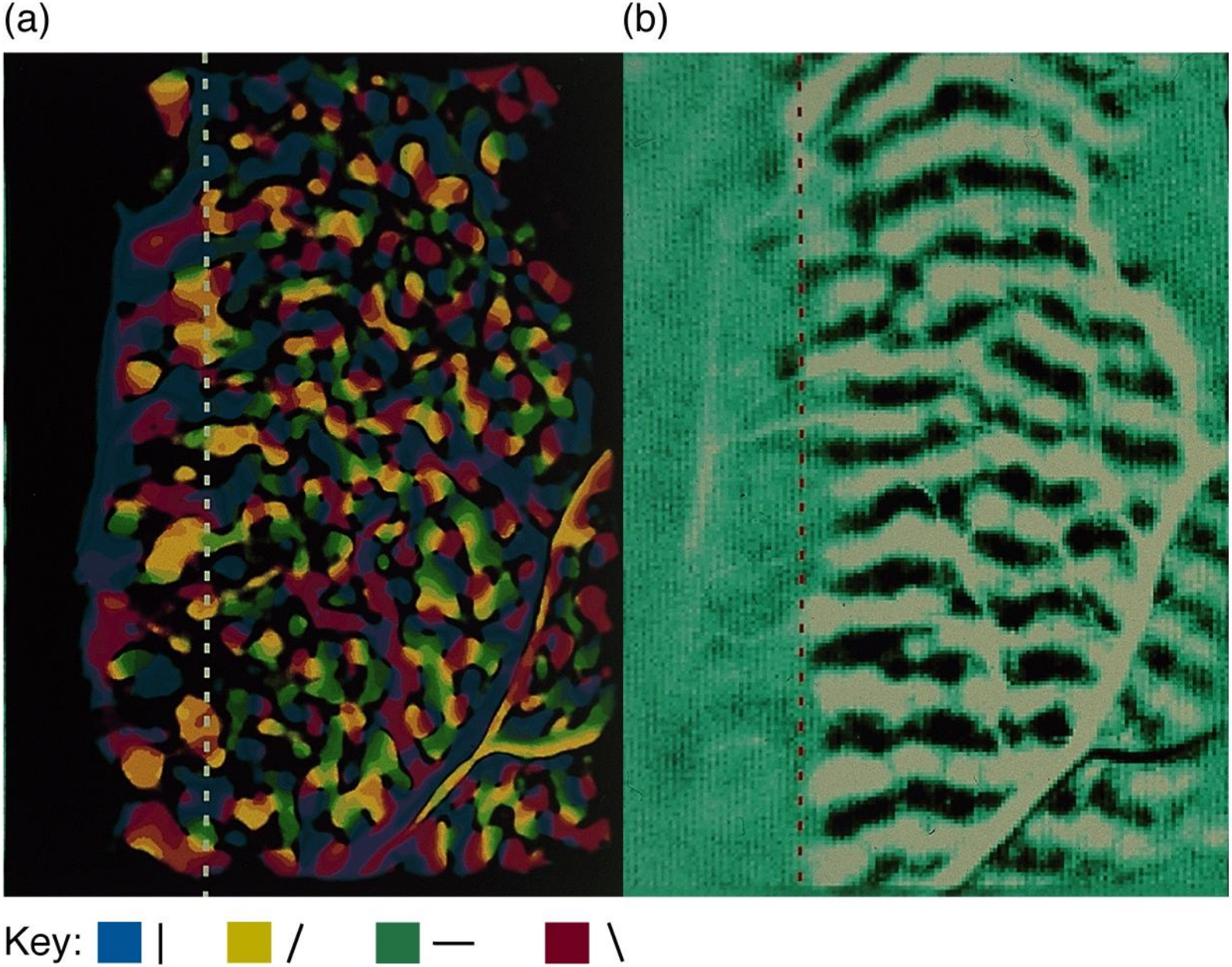

(a)
To visual cortex
Screen
Oscilloscope
Retina
Visual cortex

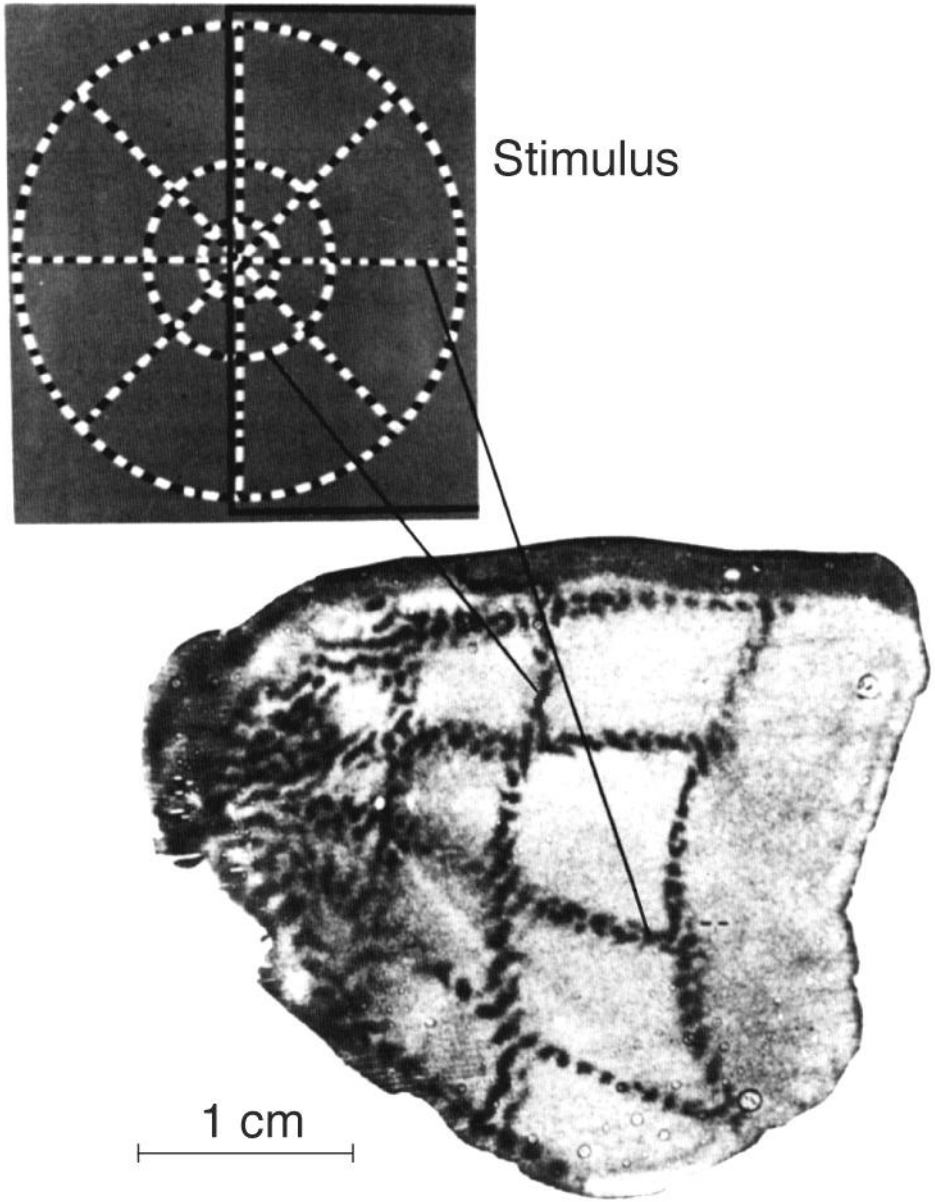

(c)
Stimulus 1
Stimulus 2
Stimulus 3

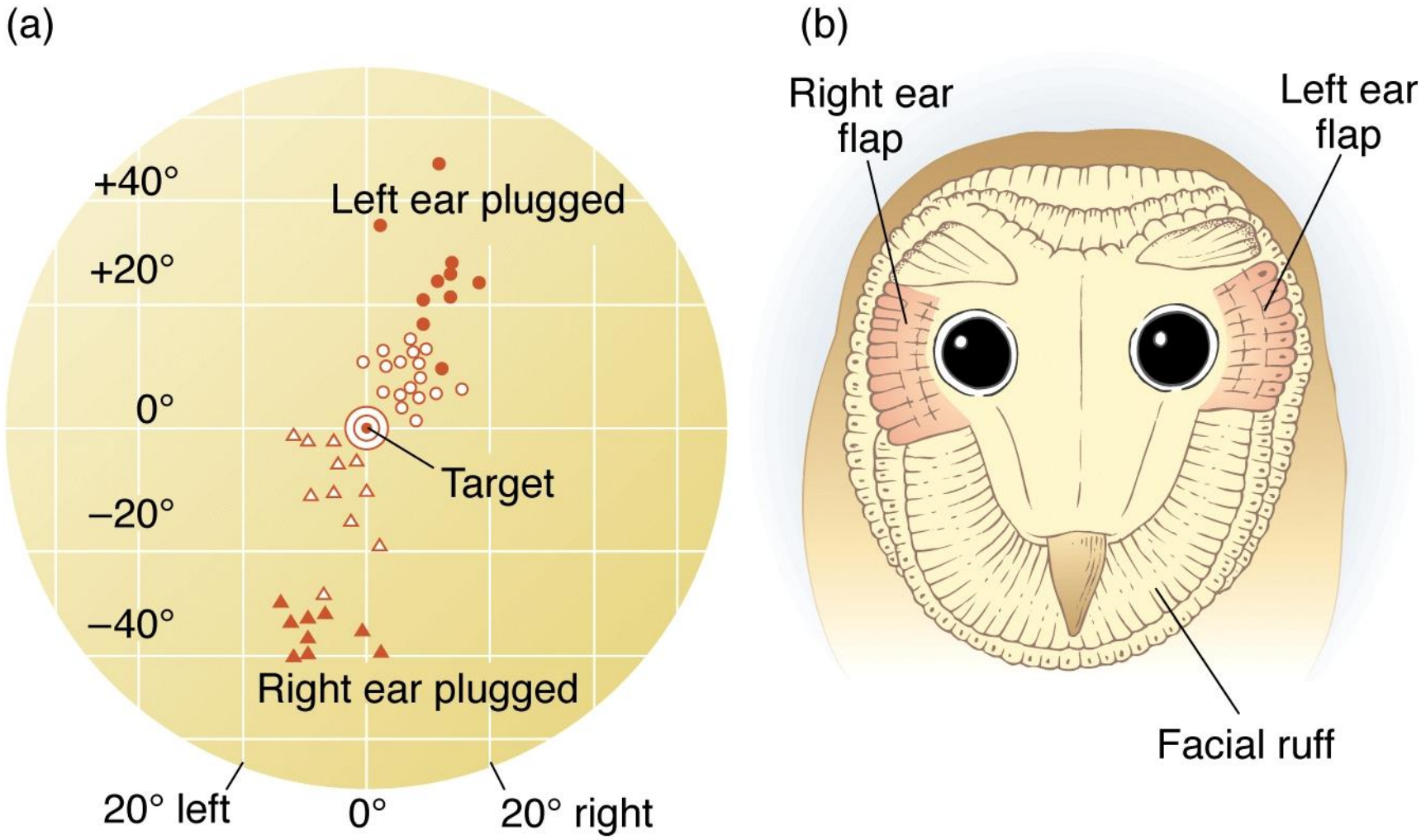

(a)
On-center
retinal receptive
fields
Lateral
geniculate cells
Receptive
field of
simple cells
Simple cell with
bar-shaped field


(b)
Off-centers
On-centers
Retinal receptive fields of lateral geniculate cells
Receptive field of simple cells
Lateral geniculate cells
Simple cell with on-off edge field

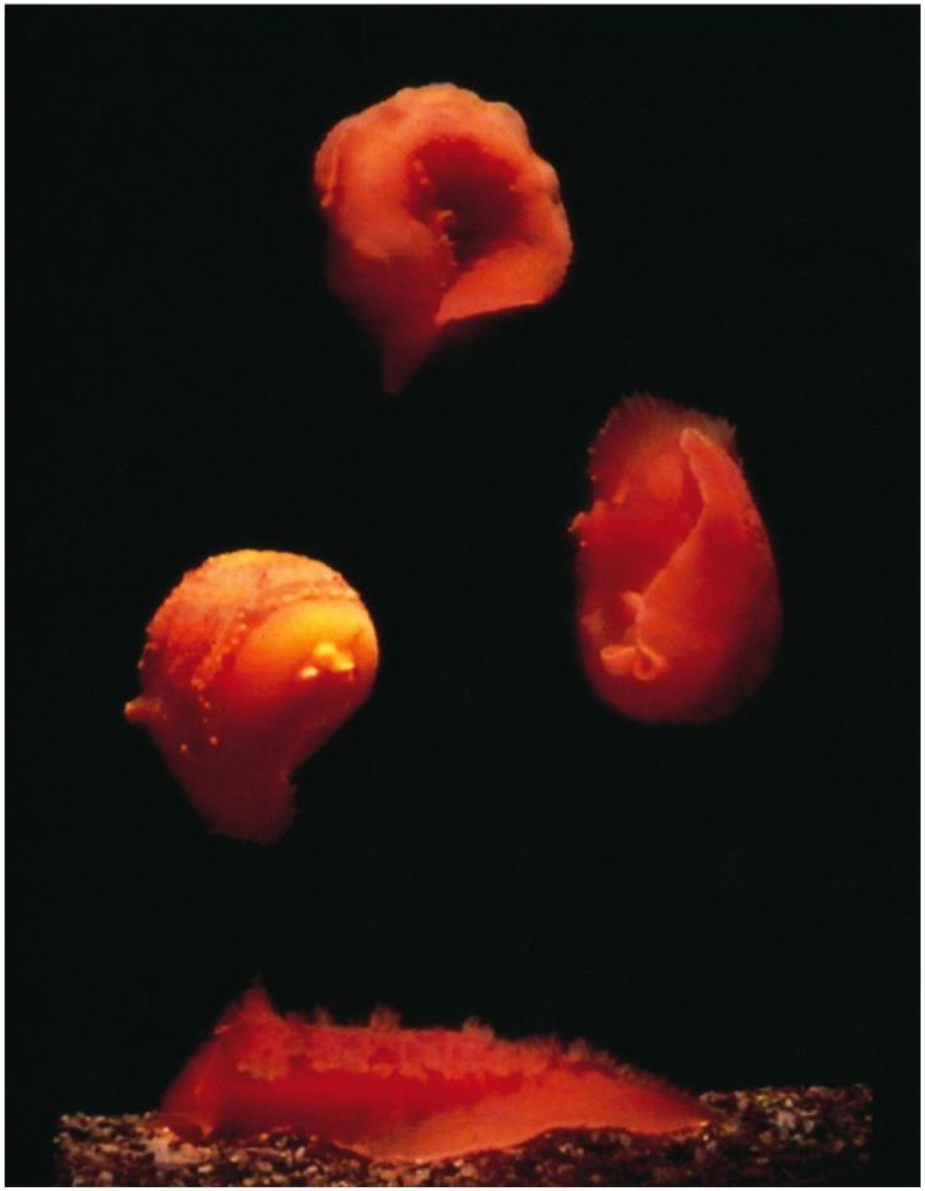

(a)
Receptive fields of ganglion cells
Simple cells
Complex cell
(b)
Moving light stimulus
No response
Strong response
Moving light stimulus
Off On
"Edge"-receptive fields projected from retina to simple cells
Simple cells
Complex cell

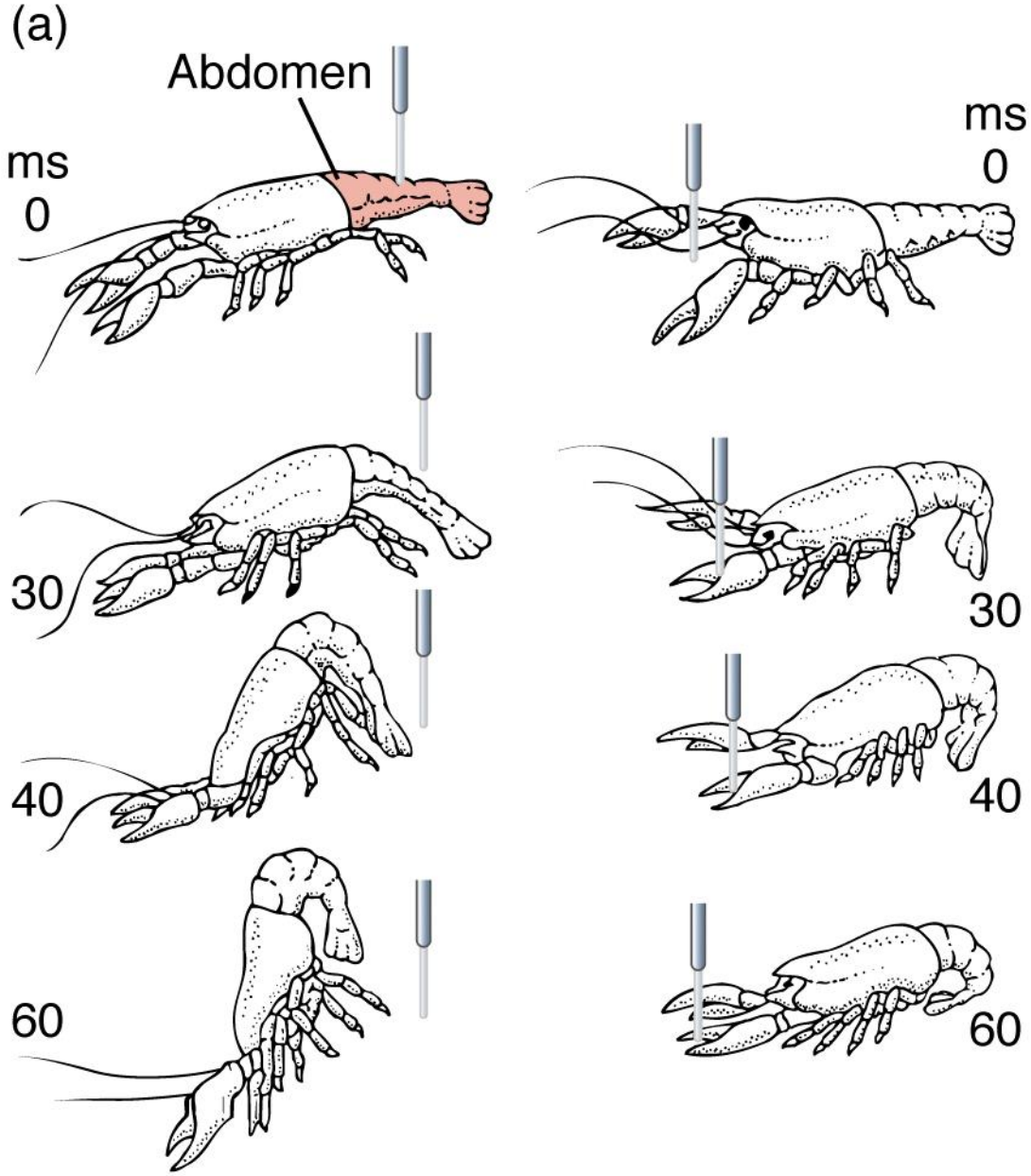

(a)
(b)
Key: | / — \

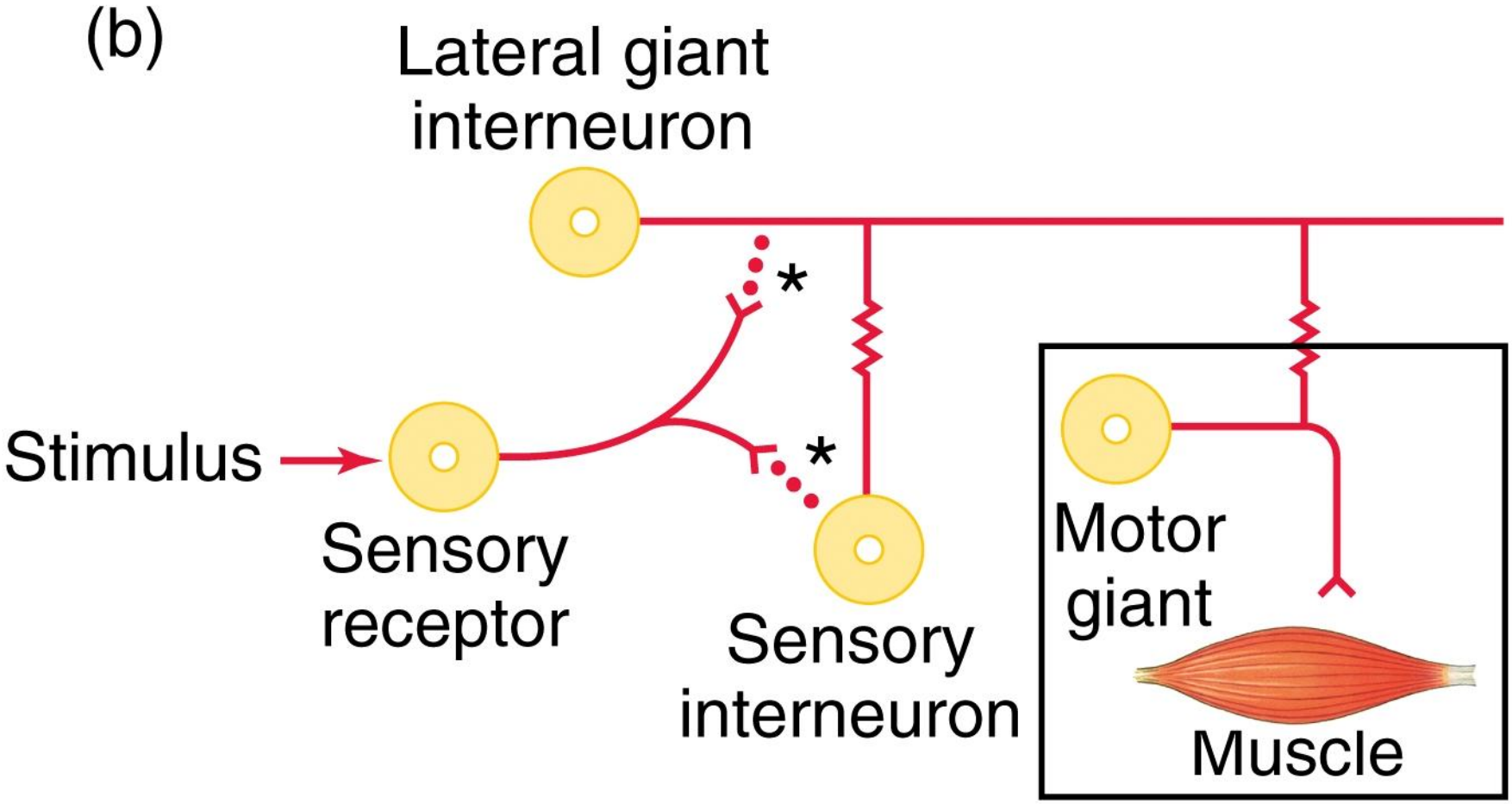

Stimulus
1 cm

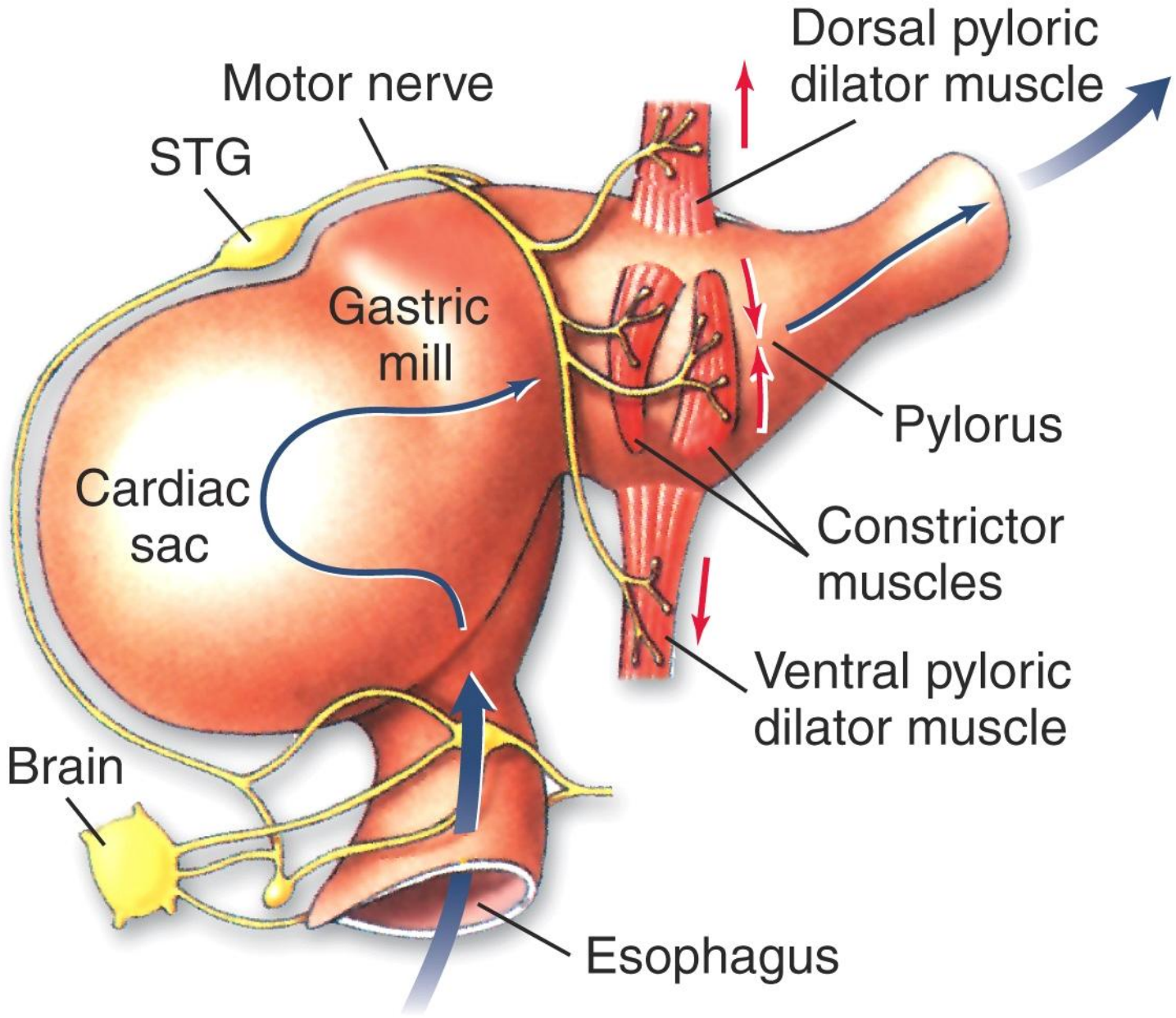

(a)
+40°
+20°
0°
–20°
–40°
Left ear plugged
Target
Right ear plugged
20° left
0°
20° right
(b)
Right ear flap
Left ear flap
Facial ruff

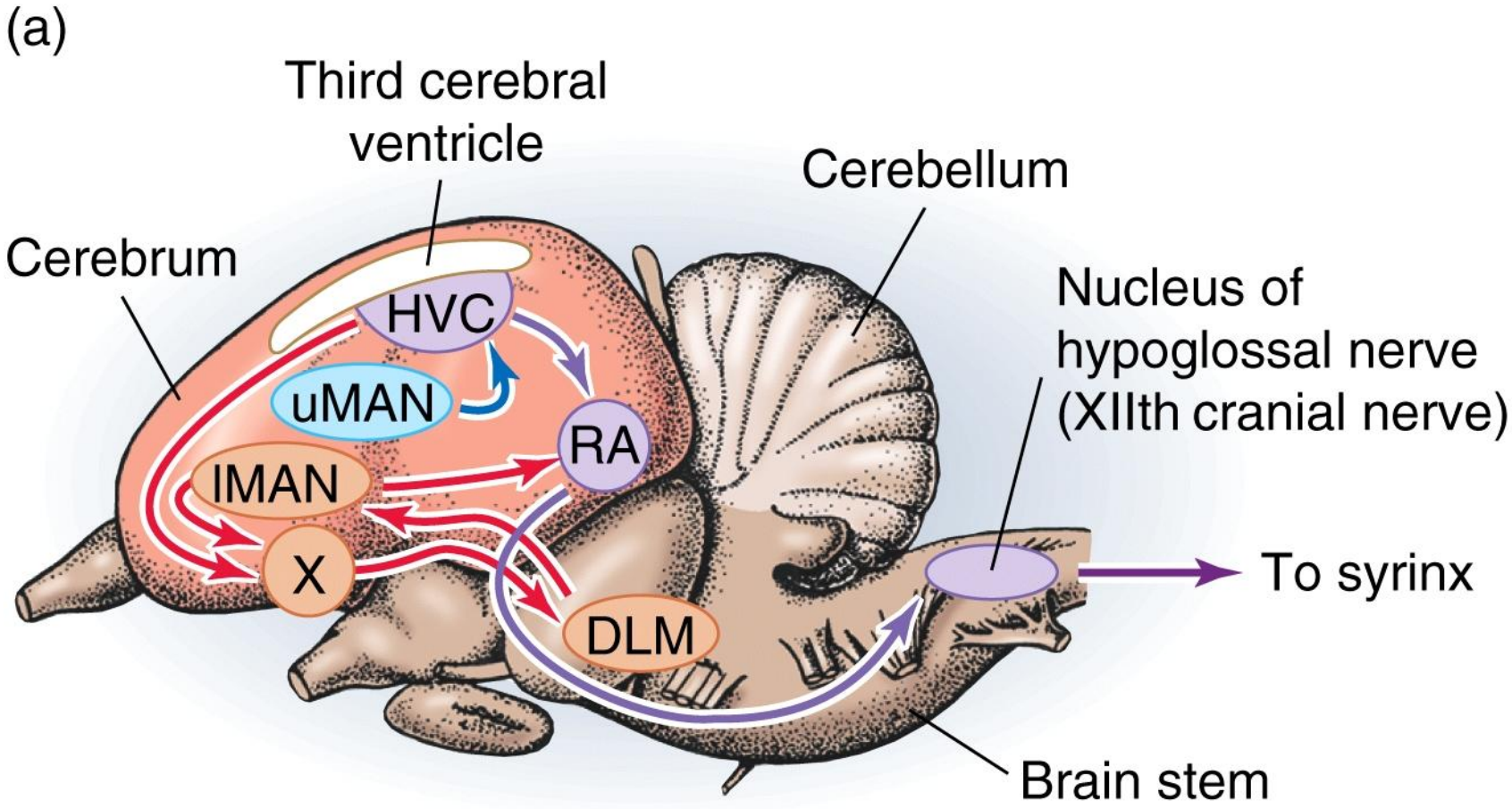
(a)




(a)
Abdomen
ms
0
ms
0
30
30
40
40
60
60


(b)
Lateral giant interneuron
*
*
Stimulus
Sensory receptor
Sensory interneuron
Motor giant
Muscle

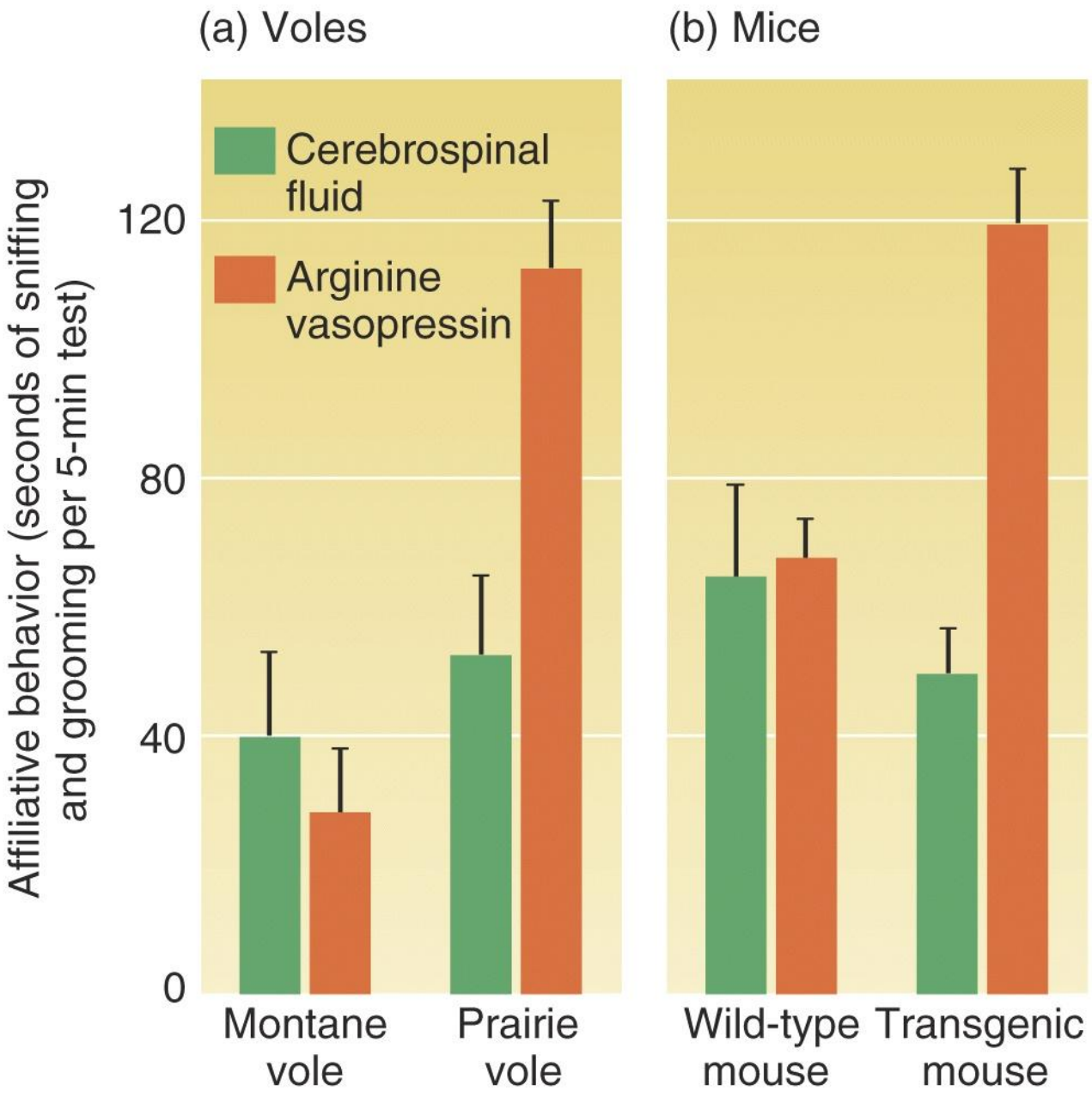

Dorsal pyloric
dilator muscle
Motor nerve
STG
Gastric
mill
Pylorus
Cardiac
sac
Constrictor
muscles
Ventral pyloric
dilator muscle
Brain
Esophagus

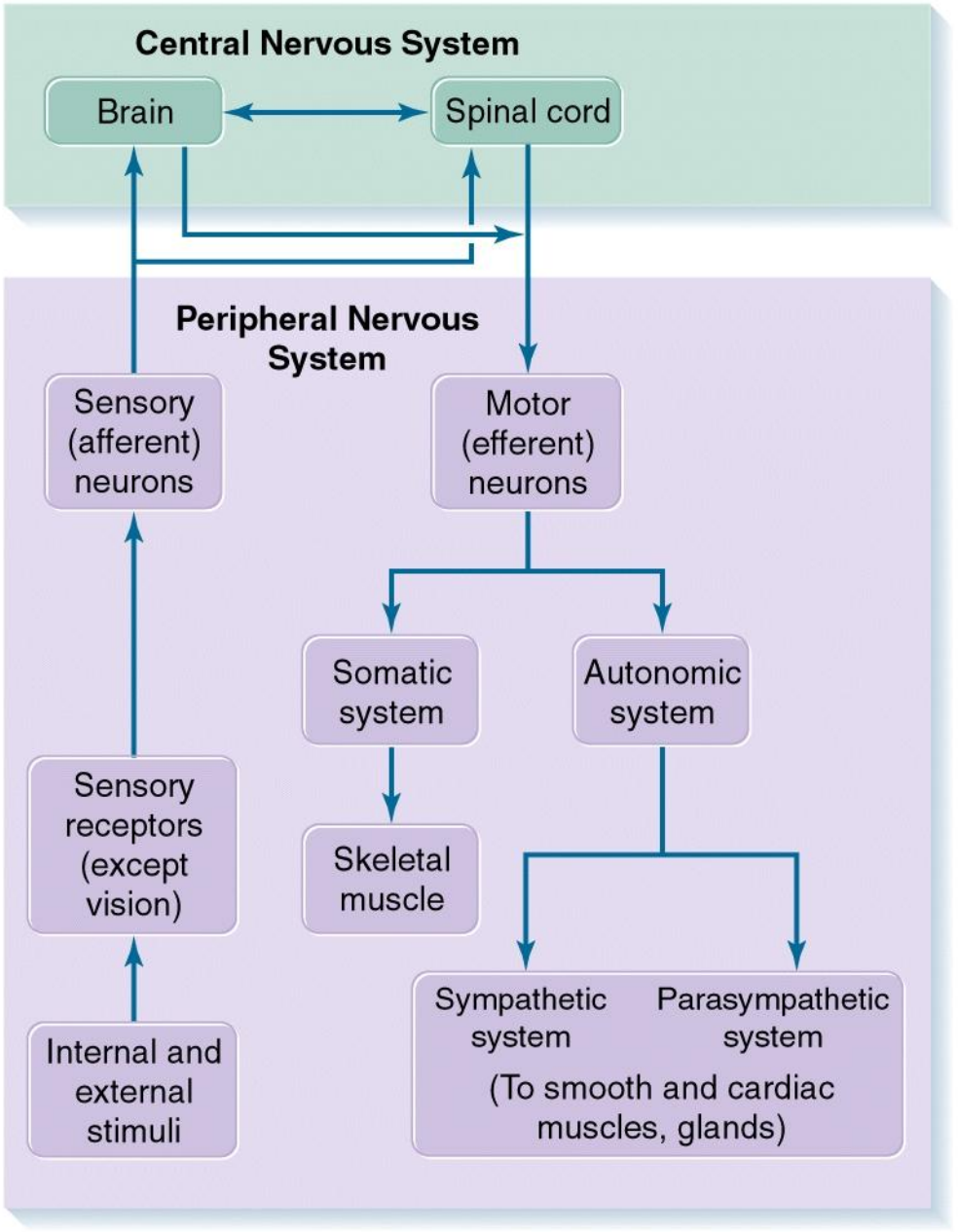

(a)
Third cerebral ventricle
Cerebellum
Cerebrum
HVC
uMAN
RA
IMAN
X
DLM
Nucleus of hypoglossal nerve (XIIth cranial nerve)
To syrinx
Brain stem

(c)

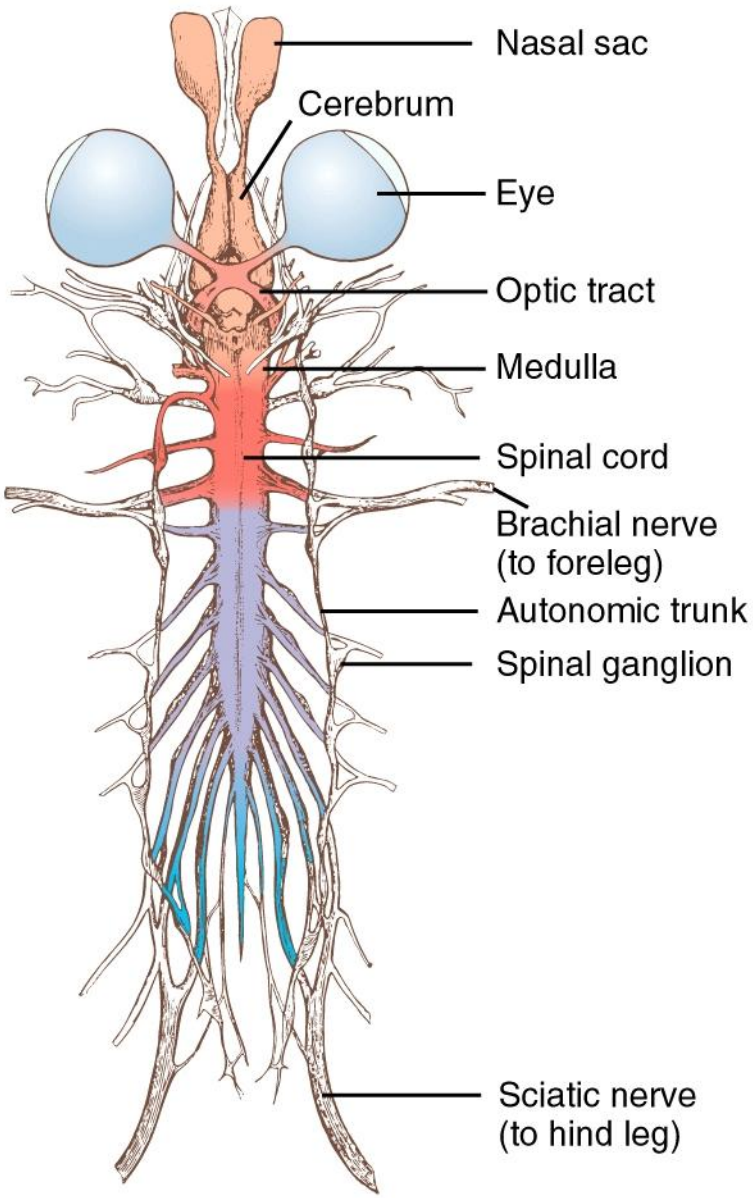
Female zebra finches

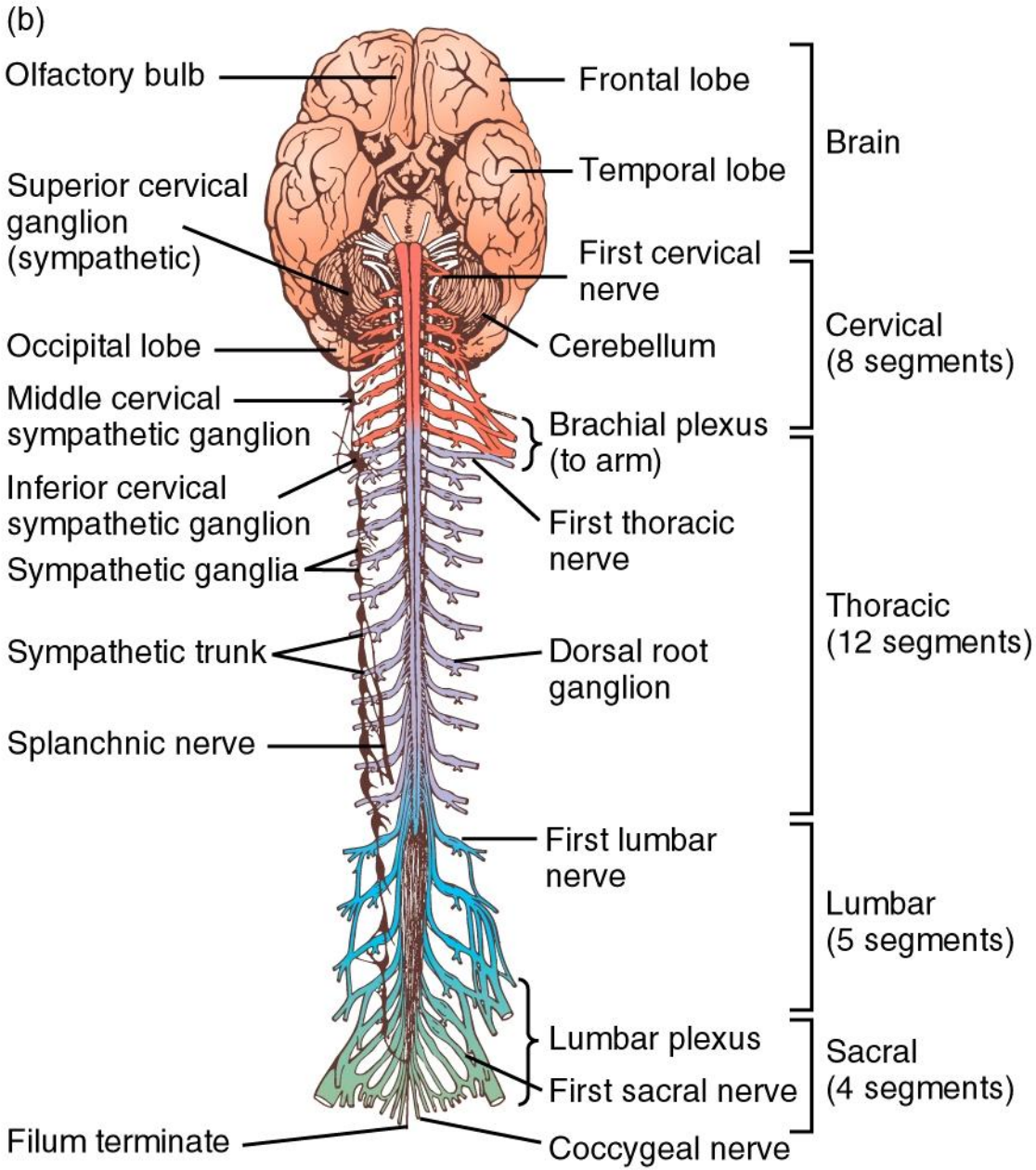
	1	2	3	4
Early treatment	DHT	DHT	Estradiol	Estradiol
Adult treatment	None	DHT	None	DHT
Size of HVC and RA increased following treatment ?	✓ Yes	? Uncertain	✓✓ Greatly enlarged	✓✓ Greatly enlarged
Song?	× No	× No	Some song	Singing

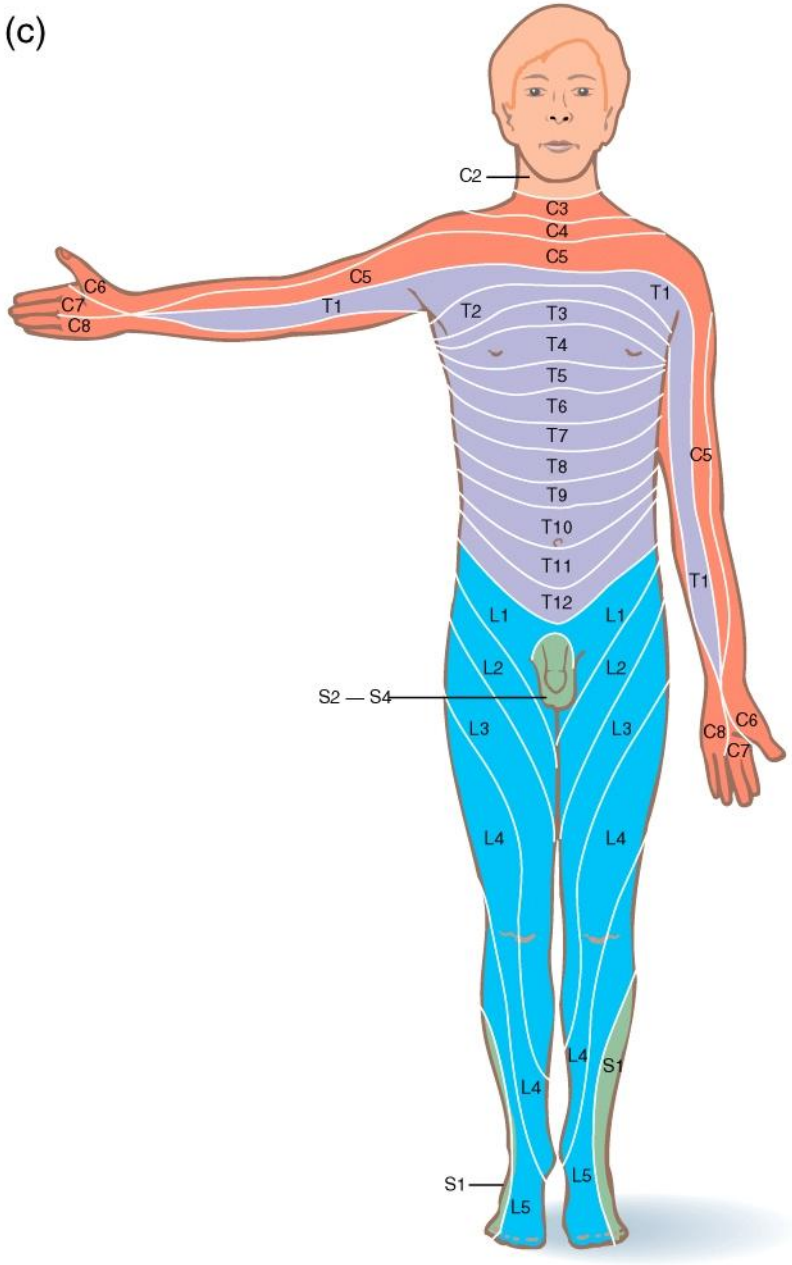

(a) Voles
(b) Mice
Cerebrospinal fluid
Arginine vasopressin
Affiliative behavior (seconds of sniffing and grooming per 5-min test)
120
80
40
0
Montane vole
Prairie vole
Wild-type mouse
Transgenic mouse


Central Nervous System
Brain
Spinal cord
Peripheral Nervous System
Sensory (afferent) neurons
Motor (efferent) neurons
Somatic system
Autonomic system
Sensory receptors (except vision)
Skeletal muscle
Internal and external stimuli
Sympathetic system
Parasympathetic system
(To smooth and cardiac muscles, glands)

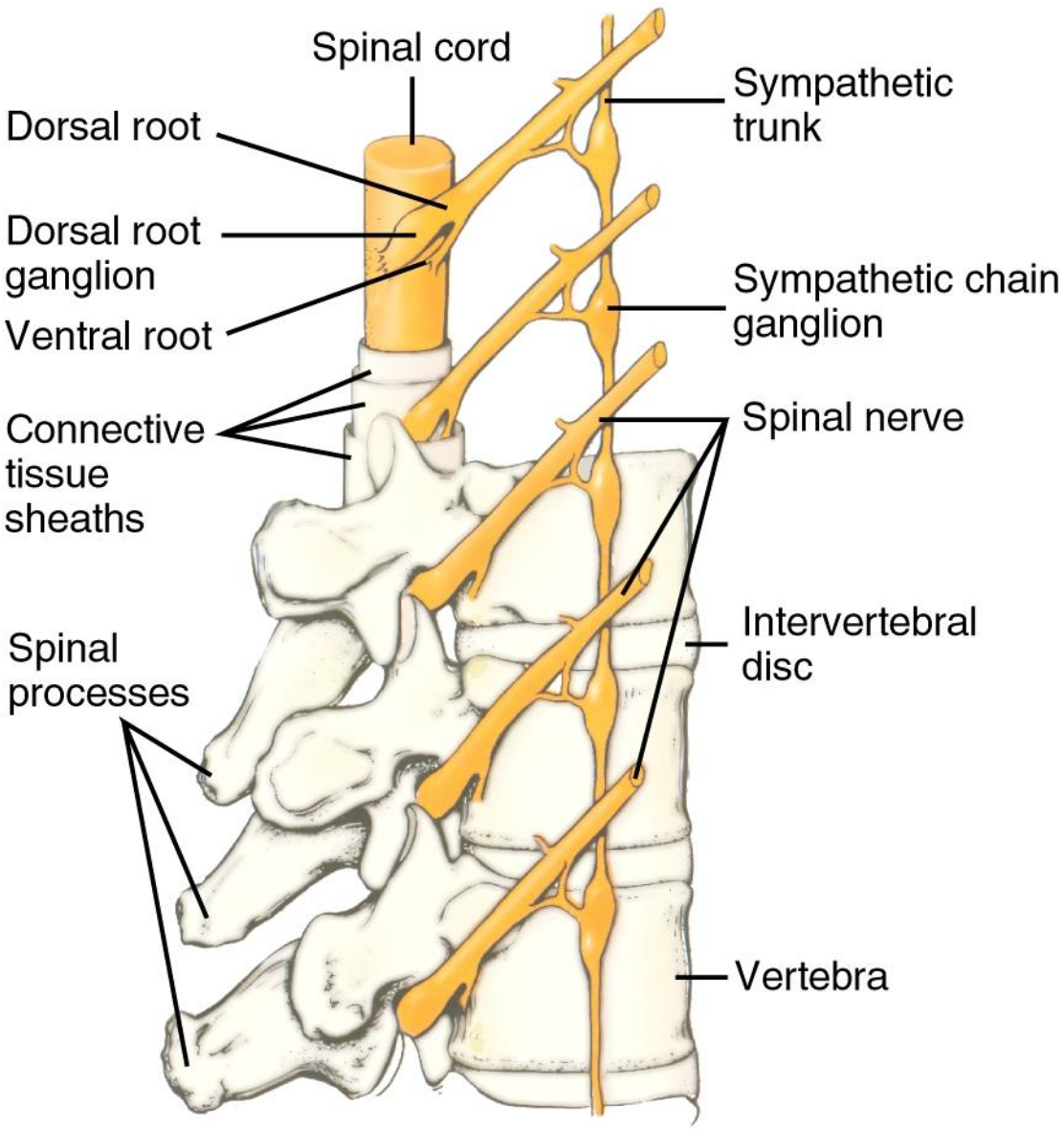
(a)

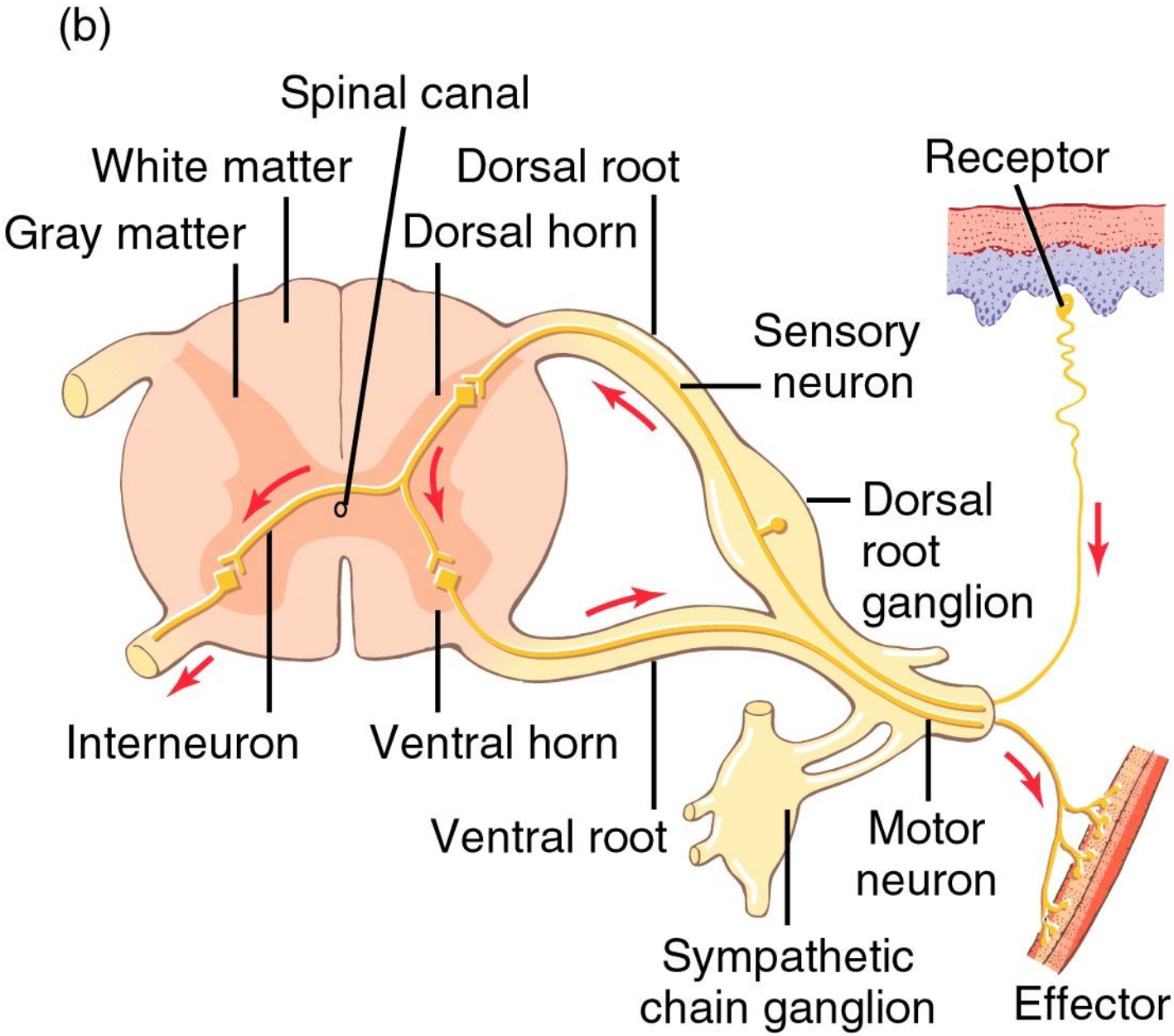

Nasal sac
Cerebrum
Eye
Optic tract
Medulla
Spinal cord
Brachial nerve
(to foreleg)
Autonomic trunk
Spinal ganglion
Sciatic nerve
(to hind leg)

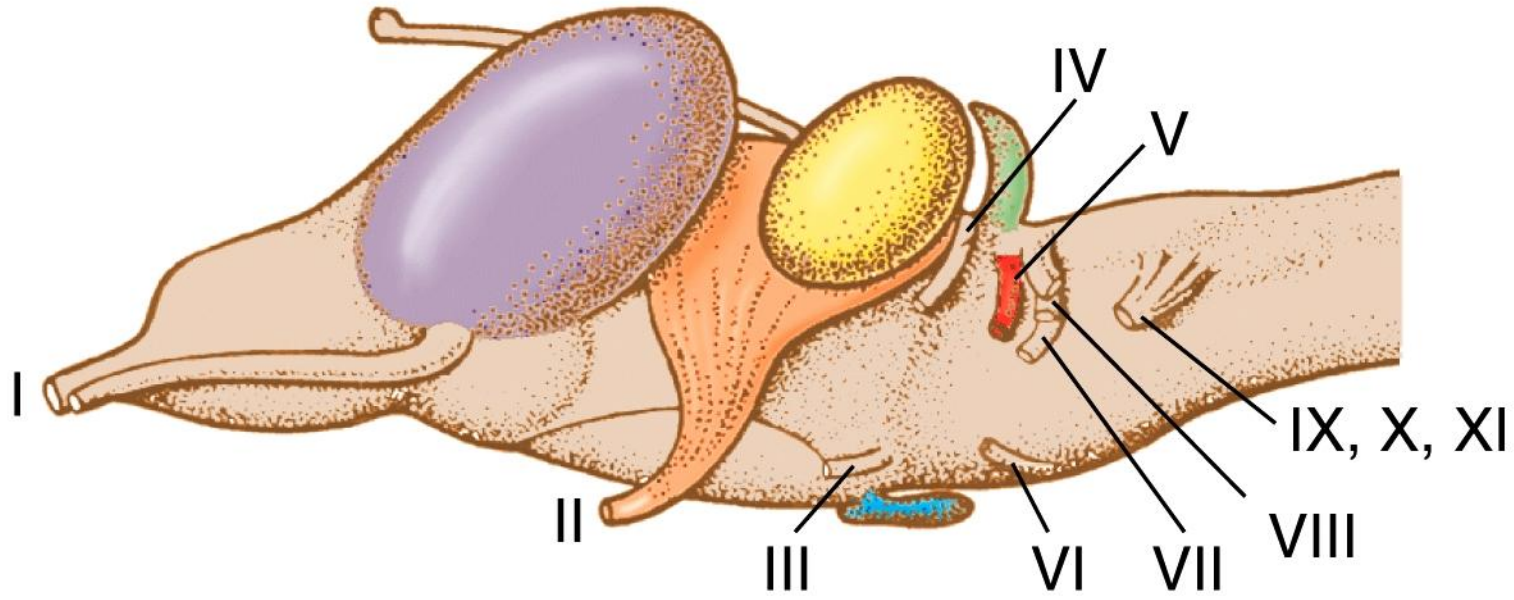

(b)
Olfactory bulb
Frontal lobe
Temporal lobe
Superior cervical ganglion (sympathetic)
First cervical nerve
Occipital lobe
Cerebellum
Middle cervical sympathetic ganglion
Brachial plexus (to arm)
Inferior cervical sympathetic ganglion
First thoracic nerve
Sympathetic ganglia
Sympathetic trunk
Dorsal root ganglion
Splanchnic nerve
First lumbar nerve
Lumbar plexus
First sacral nerve
Filum terminate
Coccygeal nerve
Brain
Cervical (8 segments)
Thoracic (12 segments)
Lumbar (5 segments)
Sacral (4 segments)


(c)
C2
C3
C4
C5
C6
C5
C7
T1
C8
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
C5
T1
L1
L1
L2
L2
S2 — S4
L3
L3
C8
C6
C7
L4
L4
L4
S1
L5
S1
L5

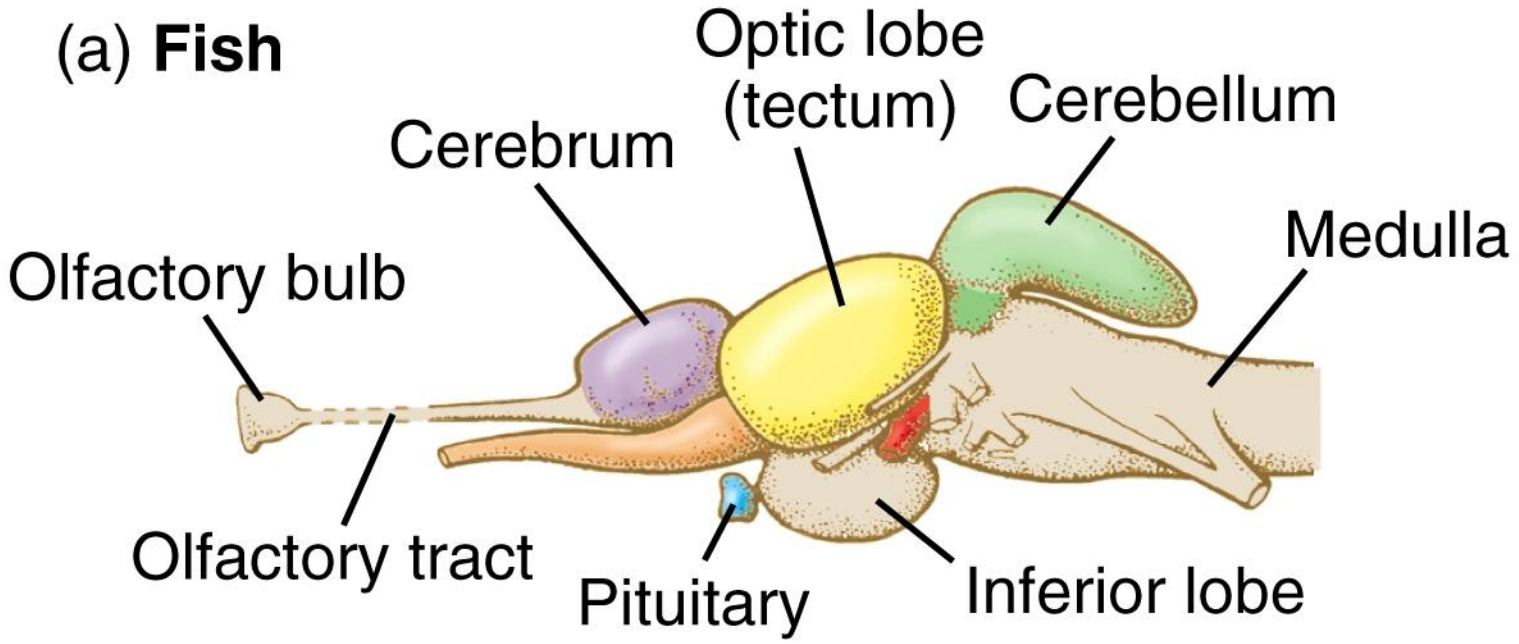
(a)

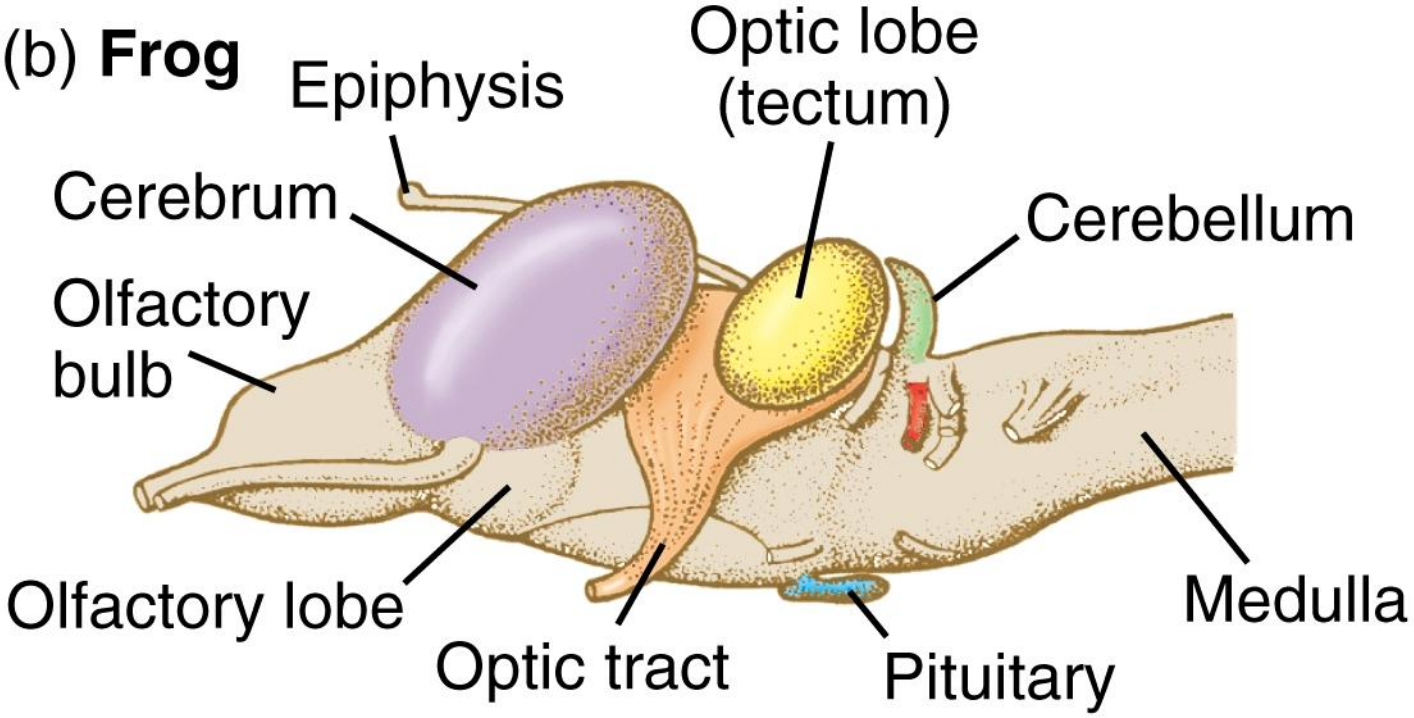

Spinal cord
Dorsal root
Dorsal root ganglion
Ventral root
Connective tissue sheaths
Spinal processes
Sympathetic trunk
Sympathetic chain ganglion
Spinal nerve
Intervertebral disc
Vertebra

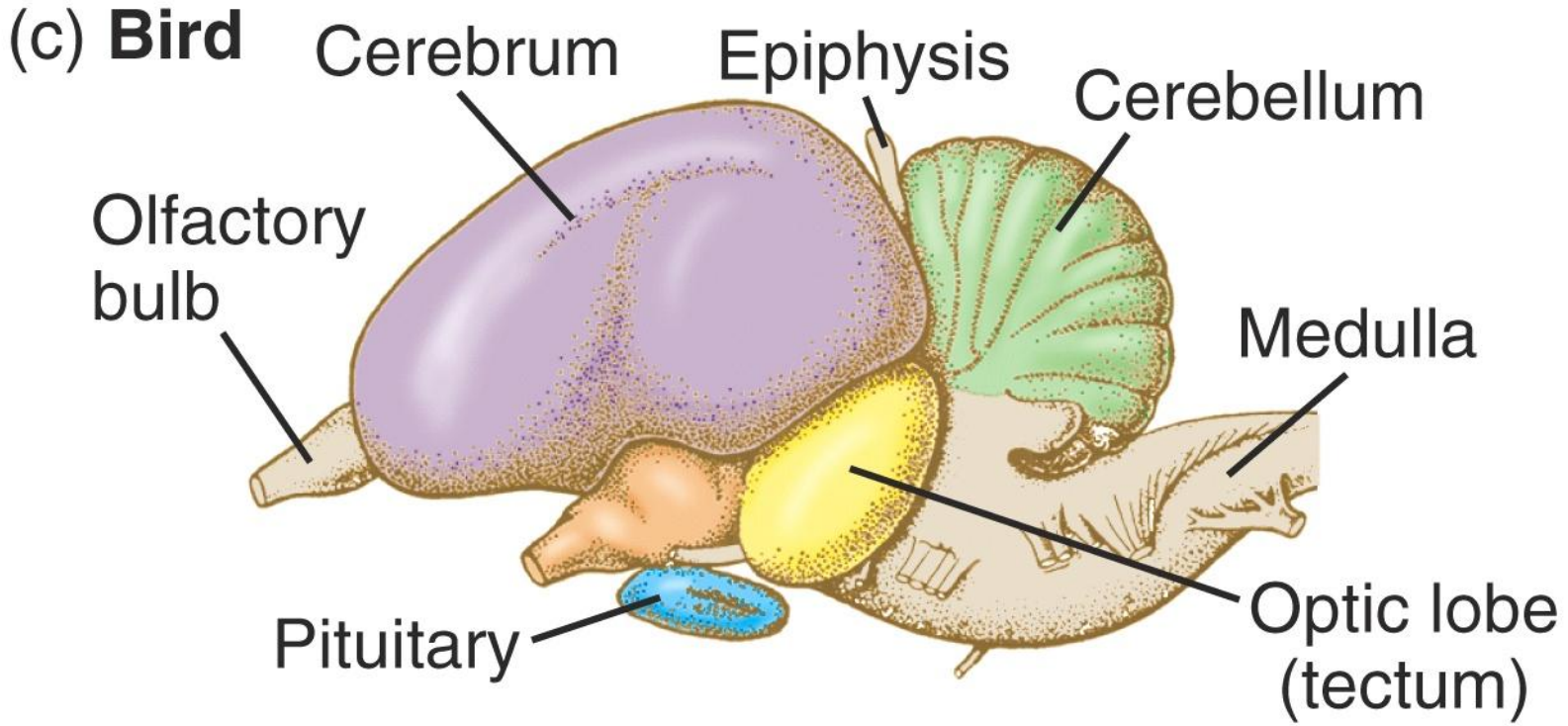

(b)
Spinal canal
White matter
Gray matter
Dorsal root
Dorsal horn
Receptor
Sensory neuron
Dorsal root ganglion
Interneuron
Ventral horn
Ventral root
Motor neuron
Sympathetic chain ganglion
Effector

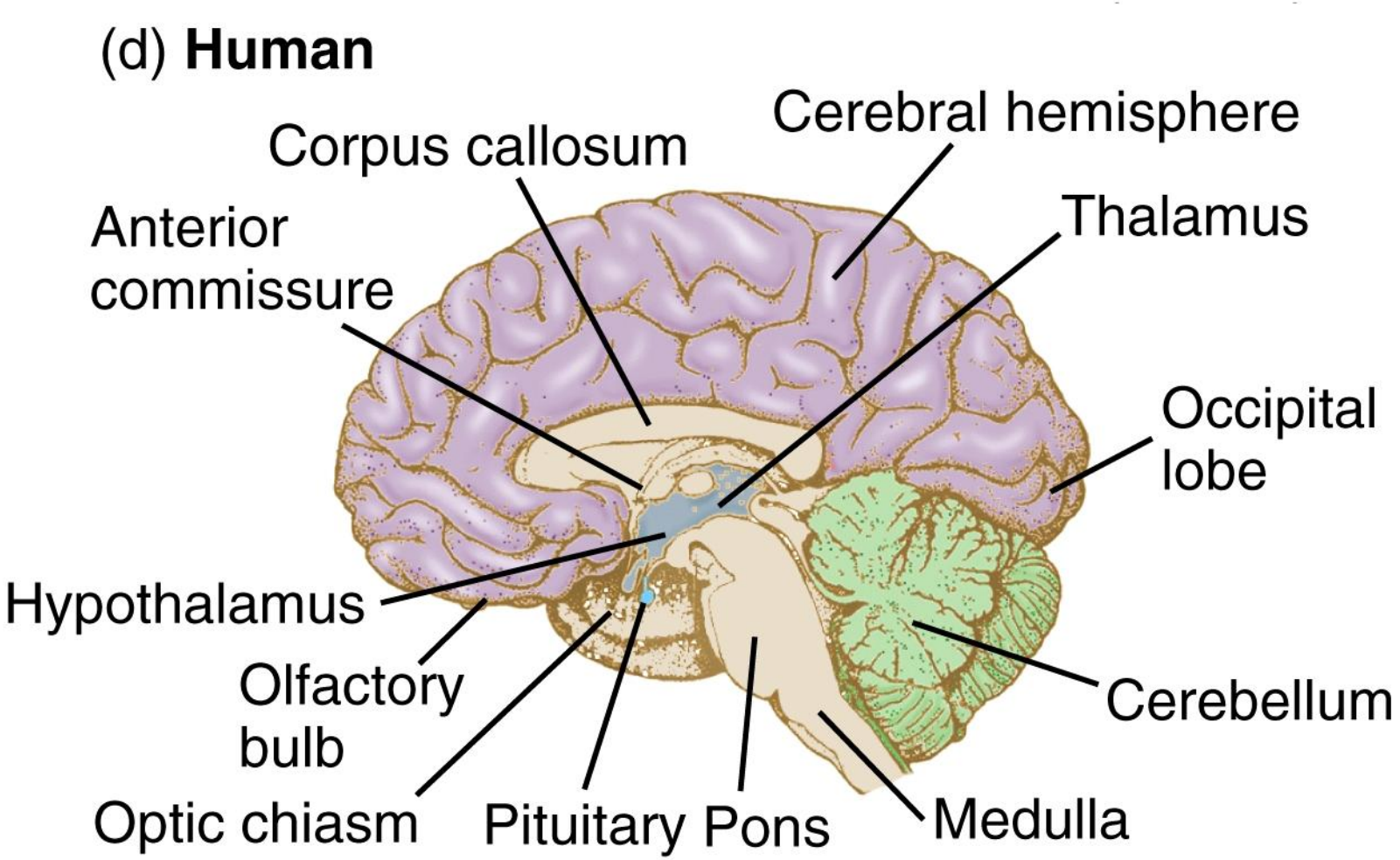


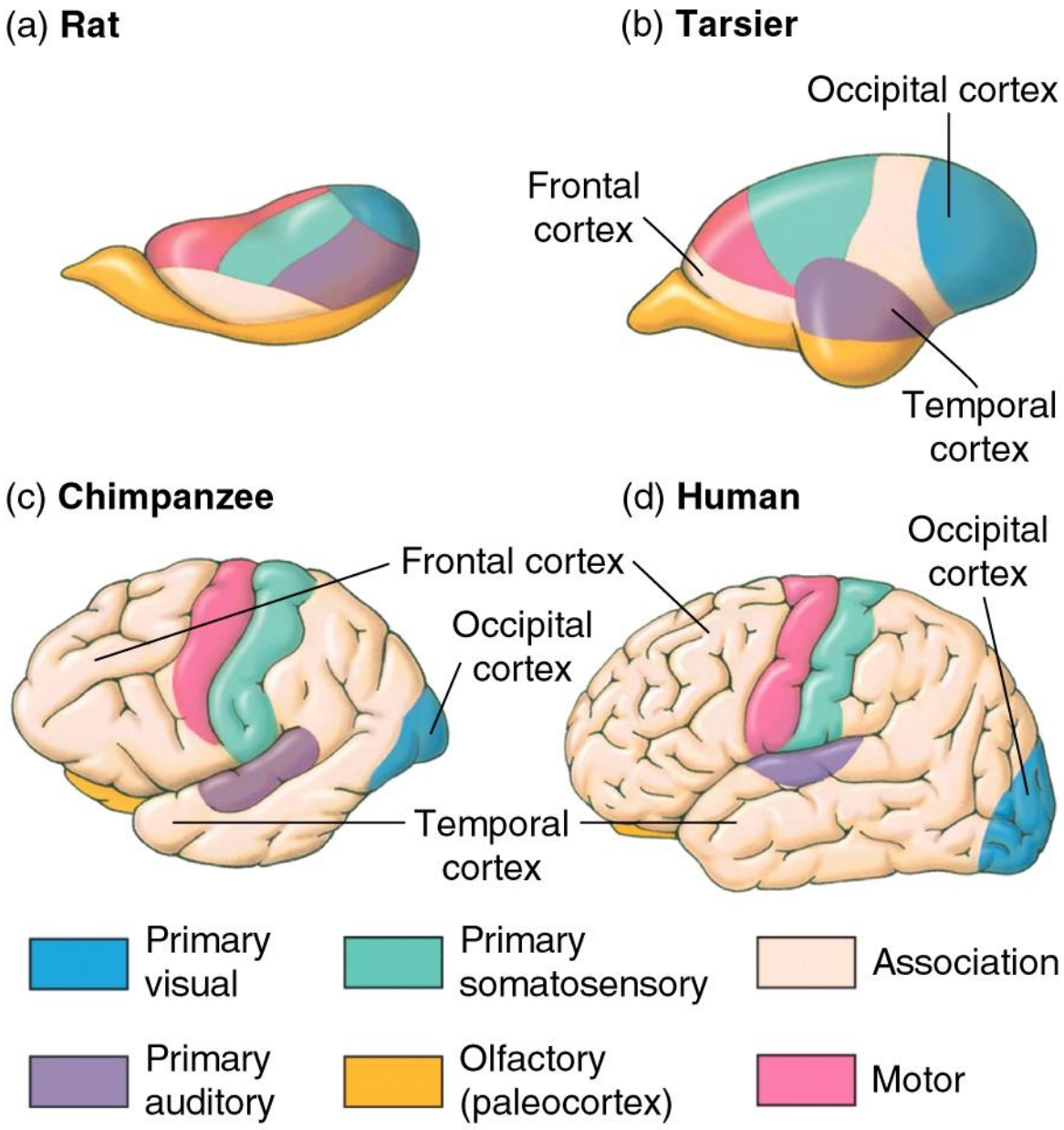
I Olfactory
II Optic
III Oculomotor
IV Trochlear
V Trigeminal
VI Abducens
VII Facial
VIII Vestibulocochlear
IX Glossopharyngeal
X Vagus
XI Spinal accessory
XII Hypoglossal


(a) **Fish**
Optic lobe
(tectum)
Cerebellum
Cerebrum
Medulla
Olfactory bulb
Olfactory tract
Pituitary
Inferior lobe

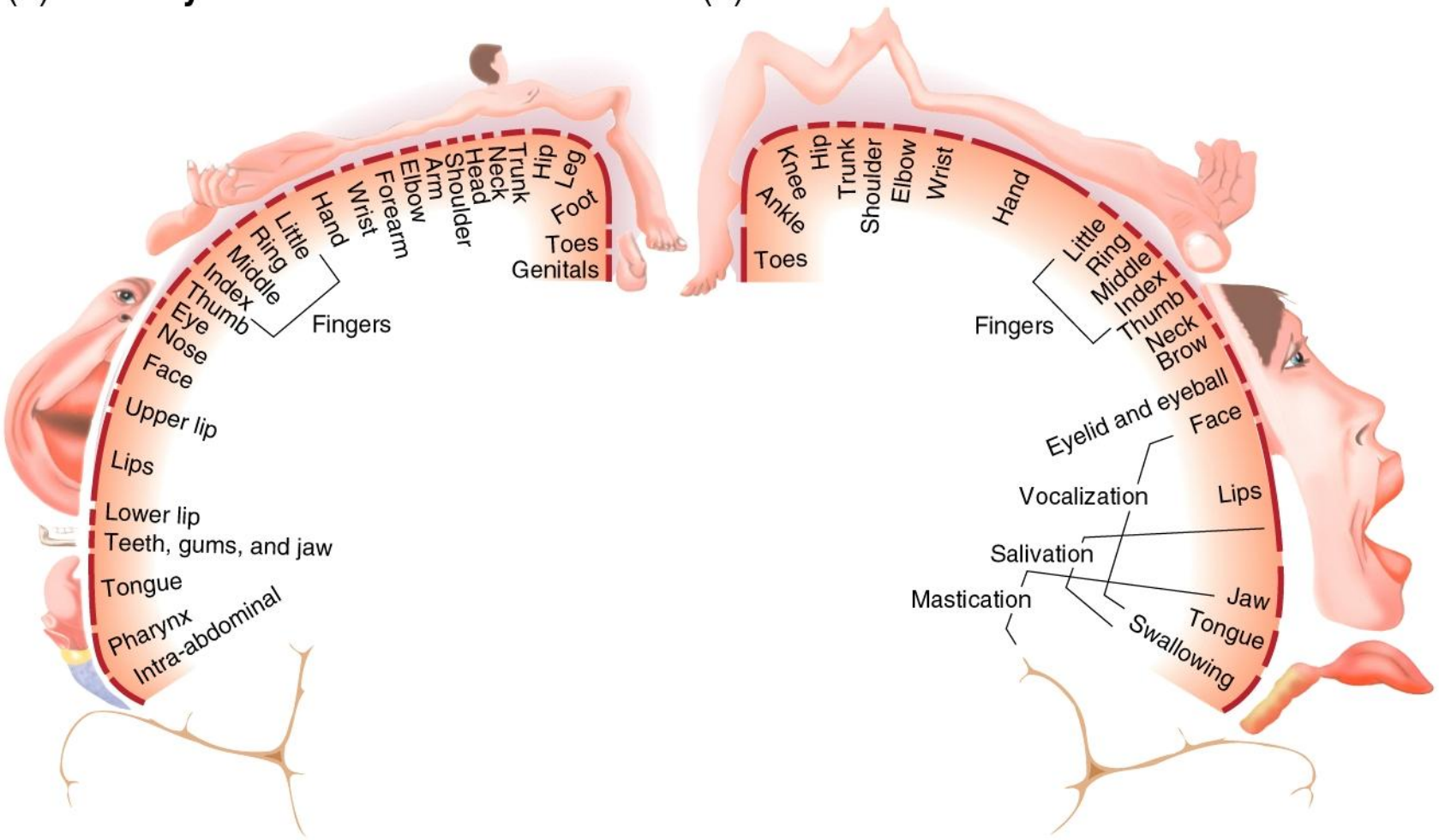

(b) **Frog**
Epiphysis
Optic lobe (tectum)
Cerebrum
Cerebellum
Olfactory bulb
Olfactory lobe
Optic tract
Pituitary
Medulla


(c) Bird
Cerebrum
Epiphysis
Cerebellum
Olfactory bulb
Medulla
Pituitary
Optic lobe (tectum)


(d) Human
Cerebral hemisphere
Corpus callosum
Thalamus
Anterior commissure
Occipital lobe
Hypothalamus
Olfactory bulb
Cerebellum
Optic chiasm
Pituitary
Pons
Medulla


(a) Rat
(b) Tarsier
Occipital cortex
Frontal cortex
Temporal cortex
(c) Chimpanzee
(d) Human
Frontal cortex
Occipital cortex
Occipital cortex
Temporal cortex
Primary visual
Primary somatosensory
Association
Primary auditory
Olfactory (paleocortex)
Motor

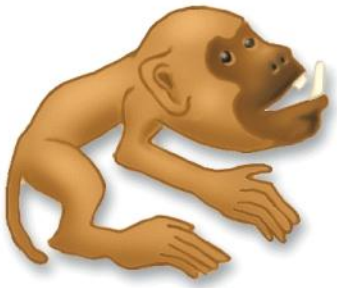
The Man Who Mistook His Wife for a Hat: And Other Clinical Tales by Oliver Sacks


(a) Sensory
Toes
Genitals
Foot
Leg
Hip
Trunk
Neck
Head
Shoulder
Arm
Elbow
Forearm
Wrist
Hand
Little
Ring
Middle
Index
Thumb
Fingers
Eye
Nose
Face
Upper lip
Lips
Lower lip
Teeth, gums, and jaw
Tongue
Pharynx
Intra-abdominal
(b) Motor
Toes
Ankle
Knee
Hip
Trunk
Shoulder
Elbow
Wrist
Hand
Fingers
Little
Ring
Middle
Index
Thumb
Neck
Brow
Eyelid and eyeball
Face
Vocalization
Lips
Salivation
Mastication
Jaw
Tongue
Swallowing

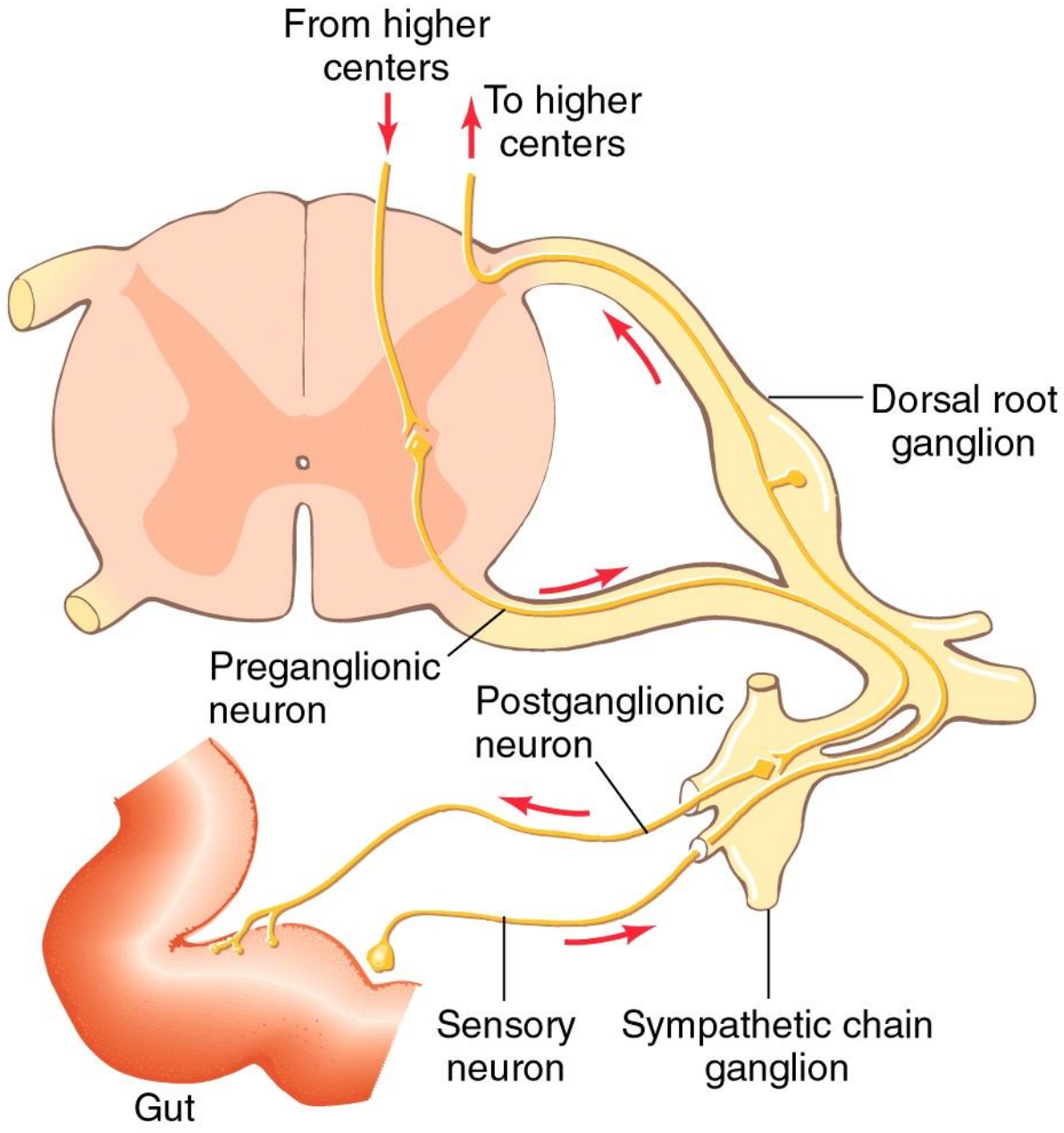
Rabbit

Cat

Monkey



Human


From higher centers
To higher centers
Dorsal root ganglion
Preganglionic neuron
Postganglionic neuron
Gut
Sensory neuron
Sympathetic chain ganglion

Fight-or-Flight Response

General Adaptation Syndrome (GAS)

- Alarm & mobilization stage
  - Become aware of stressor
- Resistance stage
  - Preparation to fight the stressor
- Exhaustion stage
  - Negative consequences of stress appear

Table 8-1 **Opposing effects on target tissues of the sympathetic and parasympathetic divisions of the autonomic nervous system**

Target tissue	Sympathetic division	Parasympathetic division
Glands		
Lacrimal (tear) glands	No effect	Stimulates production of tears
Salivary glands	Stimulates production of a small amount of viscous saliva ("dry mouth")	Stimulates production of a large amount of dilute saliva
Adrenal medulla	Stimulates secretion	No effect
Eye		
Radial muscles of iris	Pupillary dilation	No effect
Iris sphincter muscles	No effect	Pupillary constriction
Ciliary muscle (controls thickness of lens)	Relaxation (focuses on distant objects)	Contraction (focuses on close objects)
Heart		
Pacemaker cells	Increases rate of heartbeat	Decreases rate of heartbeat
Ventricular contractile fibers	Increases force of contraction	Little or no effect

Table 8-1 **Opposing effects on target tissues of the sympathetic and parasympathetic divisions of the autonomic nervous system**

Target tissue	Sympathetic division	Parasympathetic division
Lungs		
Smooth muscles in walls of bronchioles	Dilates bronchioles	Constricts bronchioles
Mucous glands	No effect	Stimulates secretion of mucus
Gastrointestinal tract		
Sphincter muscles	Contraction	Relaxation
Smooth muscles in walls of tract	Reduces tone and motility	Increases tone and motility
Exocrine glands	Inhibits secretion	Stimulates secretion
Gallbladder	Inhibits contraction	Stimulates contraction
Liver	Increases glycogenolysis and therefore blood sugar	No effect
Other tissues		
Urinary bladder	No effect	Stimulates muscle contraction
Arterioles	Vasoconstriction in vessels supplying skin and gut; vasodilation in some vessels supplying skeletal muscle	No effect

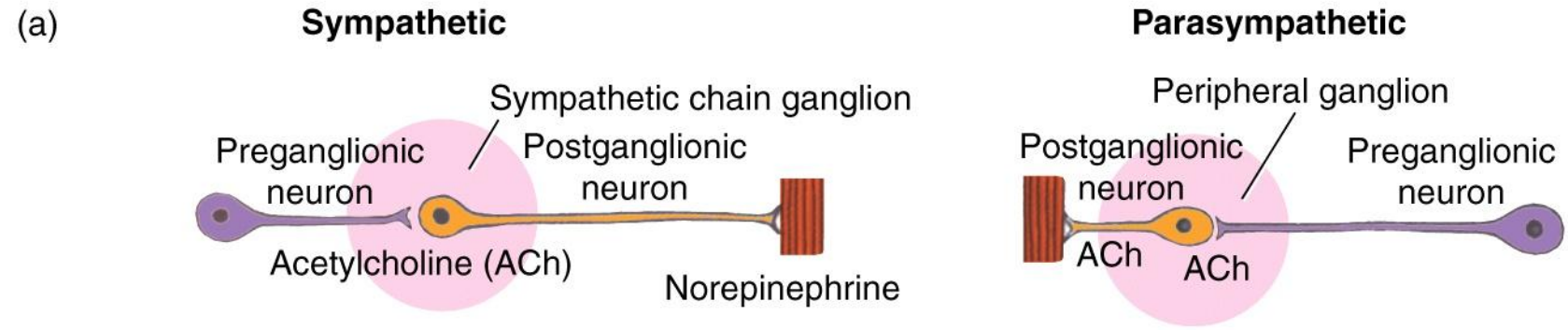


Table 8-2 **Pharmacology of neurotransmission in the autonomic nervous system**

	Transmitter of preganglionic neuron	Receptors on postganglionic neuron	Transmitter of postganglionic neuron	Receptors on target tissue
Sympathetic division	Acetylcholine (ACh)	Nicotinic ACh receptors	Norepinephrine	α- or β-adrenergic receptors
Parasympathetic division	Acetylcholine	Nicotinic ACh receptors	Acetylcholine	Muscarinic ACh receptors

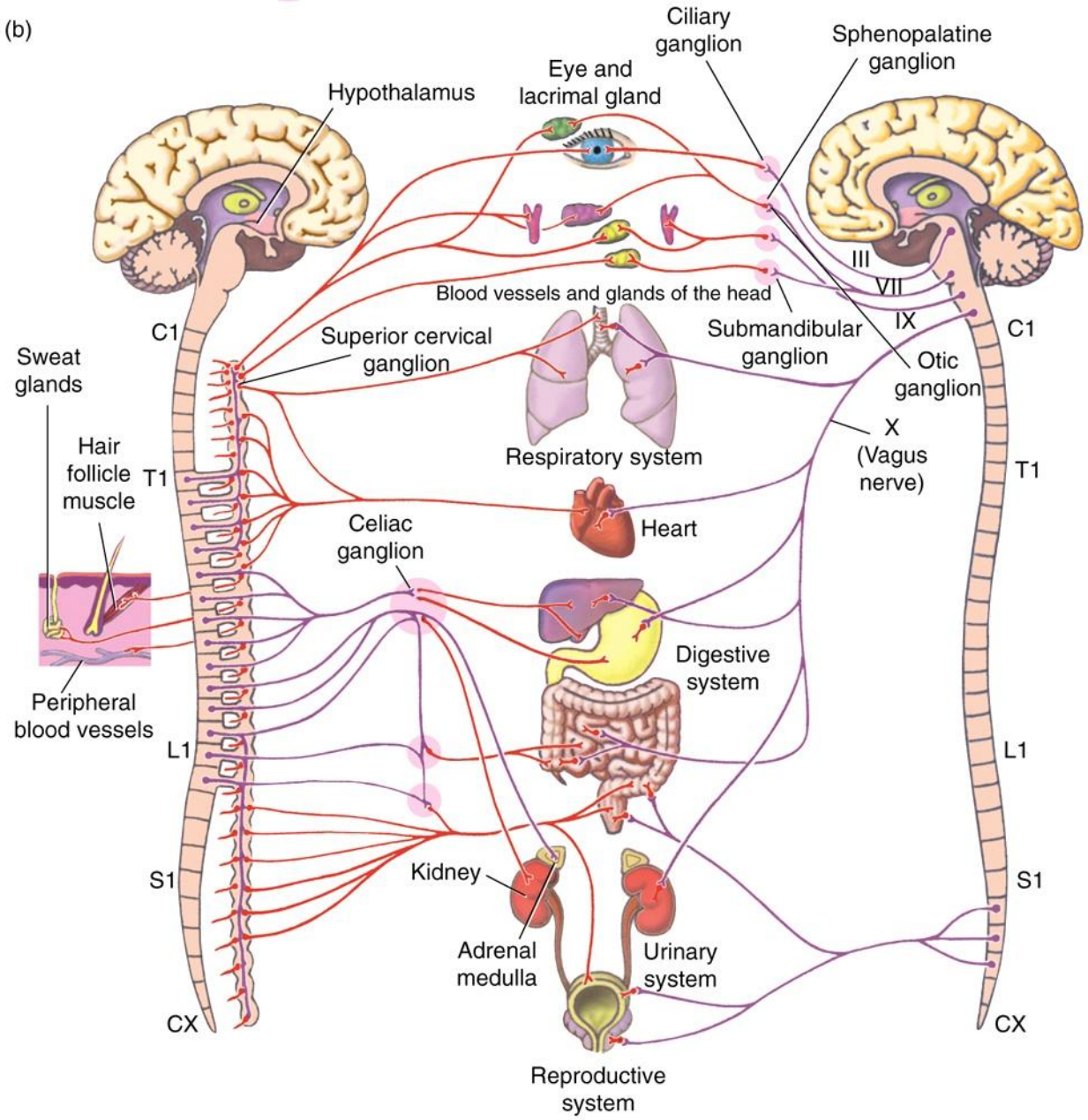

(b)
Ciliary ganglion
Sphenopalatine ganglion
Eye and lacrimal gland
Hypothalamus
III
VII
IX
Blood vessels and glands of the head
Submandibular ganglion
Otic ganglion
C1
Superior cervical ganglion
Sweat glands
Hair follicle muscle
T1
Respiratory system
X (Vagus nerve)
Heart
Celiac ganglion
Digestive system
Peripheral blood vessels
L1
S1
Kidney
Adrenal medulla
Urinary system
CX
Reproductive system

Table 8-2 **Pharmacology of neurotransmission in the autonomic nervous system**

	Transmitter of preganglionic neuron	Receptors on postganglionic neuron	Transmitter of postganglionic neuron	Receptors on target tissue
Sympathetic division	Acetylcholine (ACh)	Nicotinic ACh receptors	Norepinephrine	α- or β-adrenergic receptors
Parasympathetic division	Acetylcholine	Nicotinic ACh receptors	Acetylcholine	Muscarinic ACh receptors