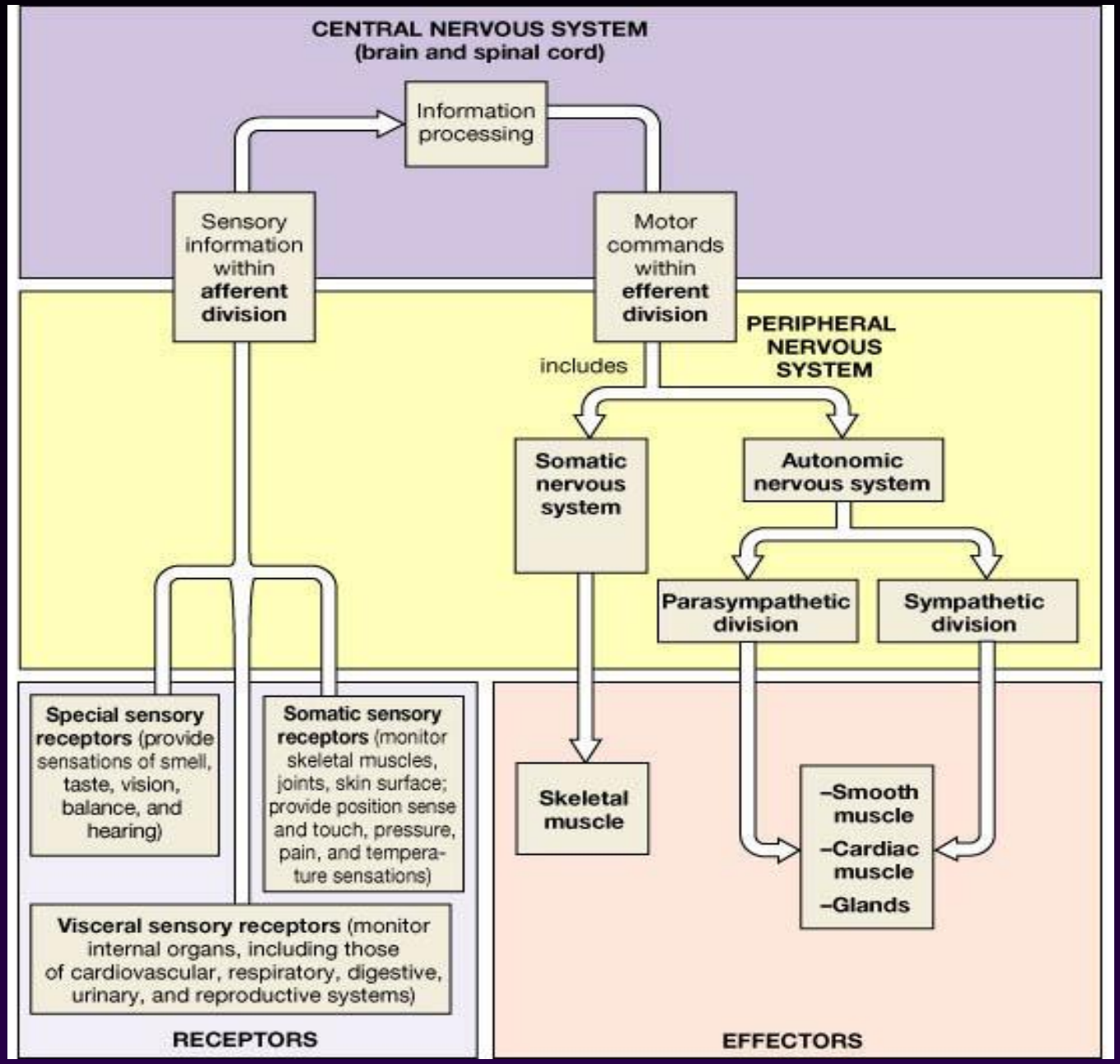
Efferent Peripheral NS: The Autonomic Motor Divisions

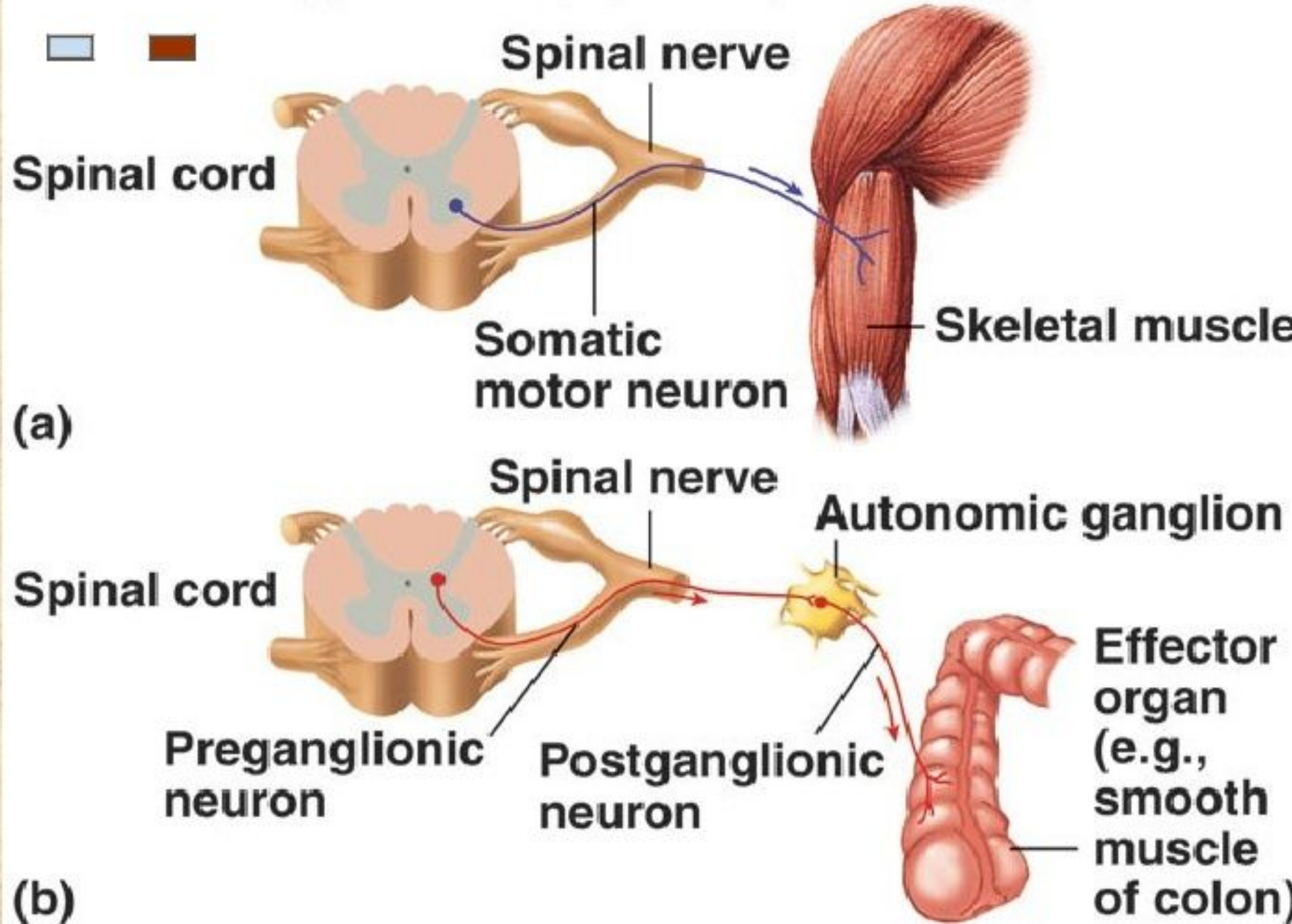
- Autonomic nervous system: A part of the nervous system that regulates key involuntary functions of the body, including the activity of the heart muscle; the smooth muscles, including the muscles of the intestinal tract; and the glands.

Review (again)

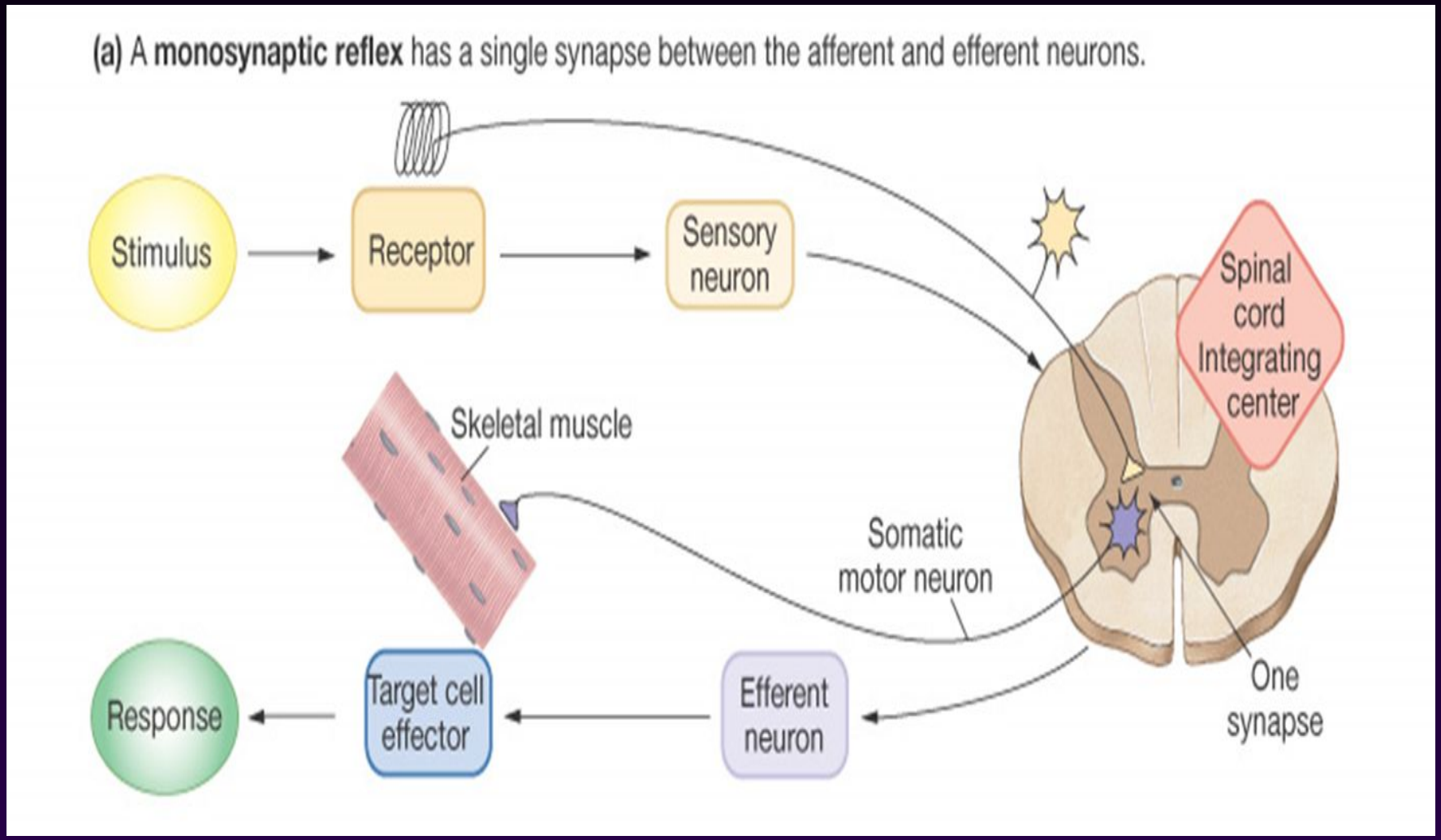


Autonomic Nervous System

- Responsible for control of involuntary or visceral bodily functions
- cardiovascular cardiovascular
- respiratory respiratory
- digestive digestive
- urinary urinary
- reproductive functions
- Key role in the bodies response to stress

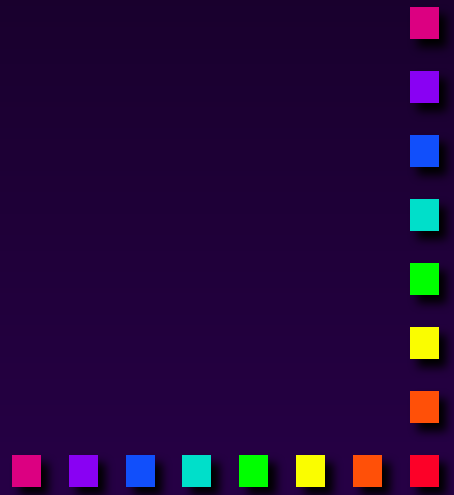


Overview: The Parts of a Reflex



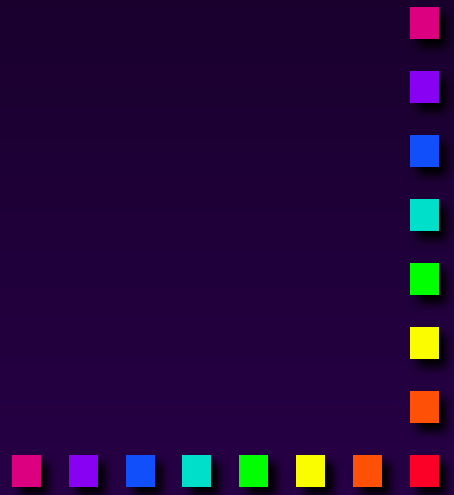
Autonomic Targets

- Smooth Muscle
- Cardiac Muscle
- Exocrine Glands
- Some Endocrine glands
- Lymphoid Tissue
- Adipose



Divisions of ANS

- Sympathetic
- Parasympathetic
- Metasympathetic



Sympathetic and parasympathetic divisions typically function in opposition to each other. But this opposition is better termed complementary in nature rather than antagonistic. For an analogy, one may think of the sympathetic division as the accelerator and the parasympathetic division as the brake.

The *sympathetic division* typically functions in actions requiring quick responses.

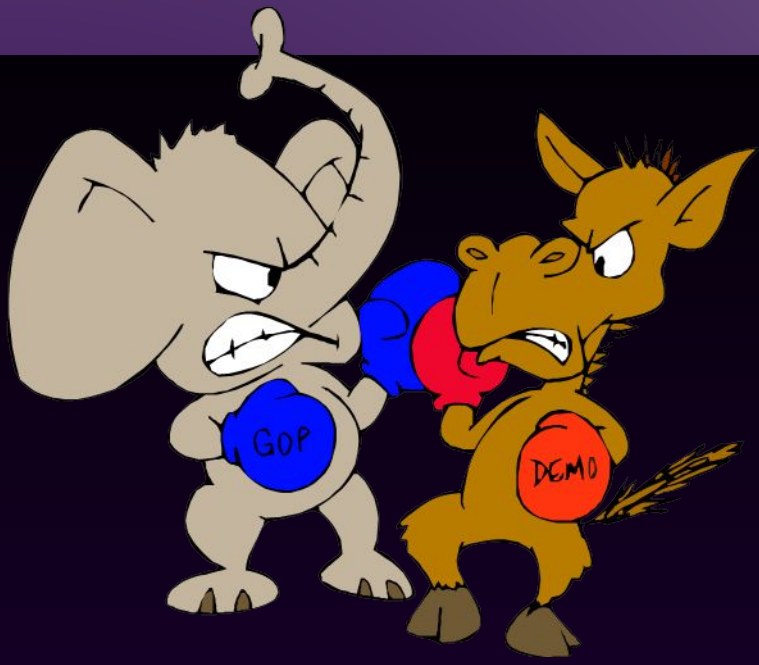
The *parasympathetic division* functions with actions that do not require immediate reaction. Consider sympathetic as "fight or flight" and parasympathetic as "rest and digest".

ANS

2 divisions:

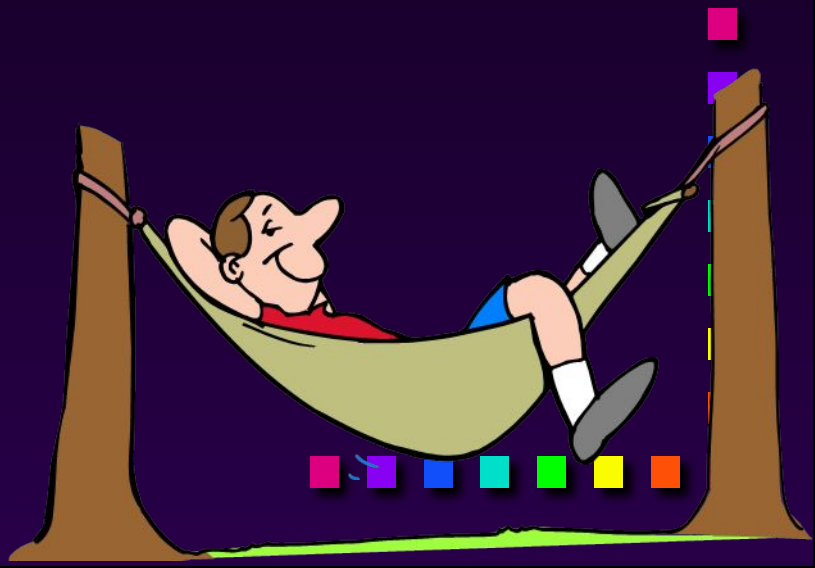
Sympathetic

- "Fight or flight"
- "E" division
- Exercise, excitement, emergency, and embarrassment



Parasympathetic

- "Rest and digest"
- "D" division
- Digestion, defecation, and diuresis



1. The autonomic nervous system (ANS) is an involuntary motor (efferent) system.

2. Autonomic nerves are typically composed of a two-neuron chain. One neuron has its cell body in the central nervous system while the other is outside the CNS.

Autonomic pathway: Two Efferent Neurons in Series

Preganglionic neuron cell body in CNS

↓

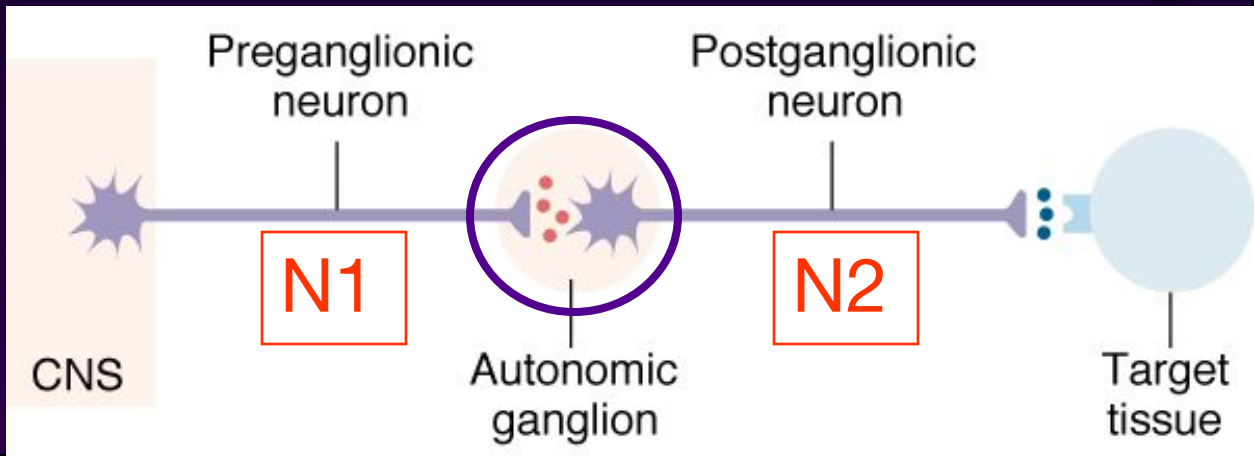
Synapse in autonomic ganglion outside CNS (often divergence!)

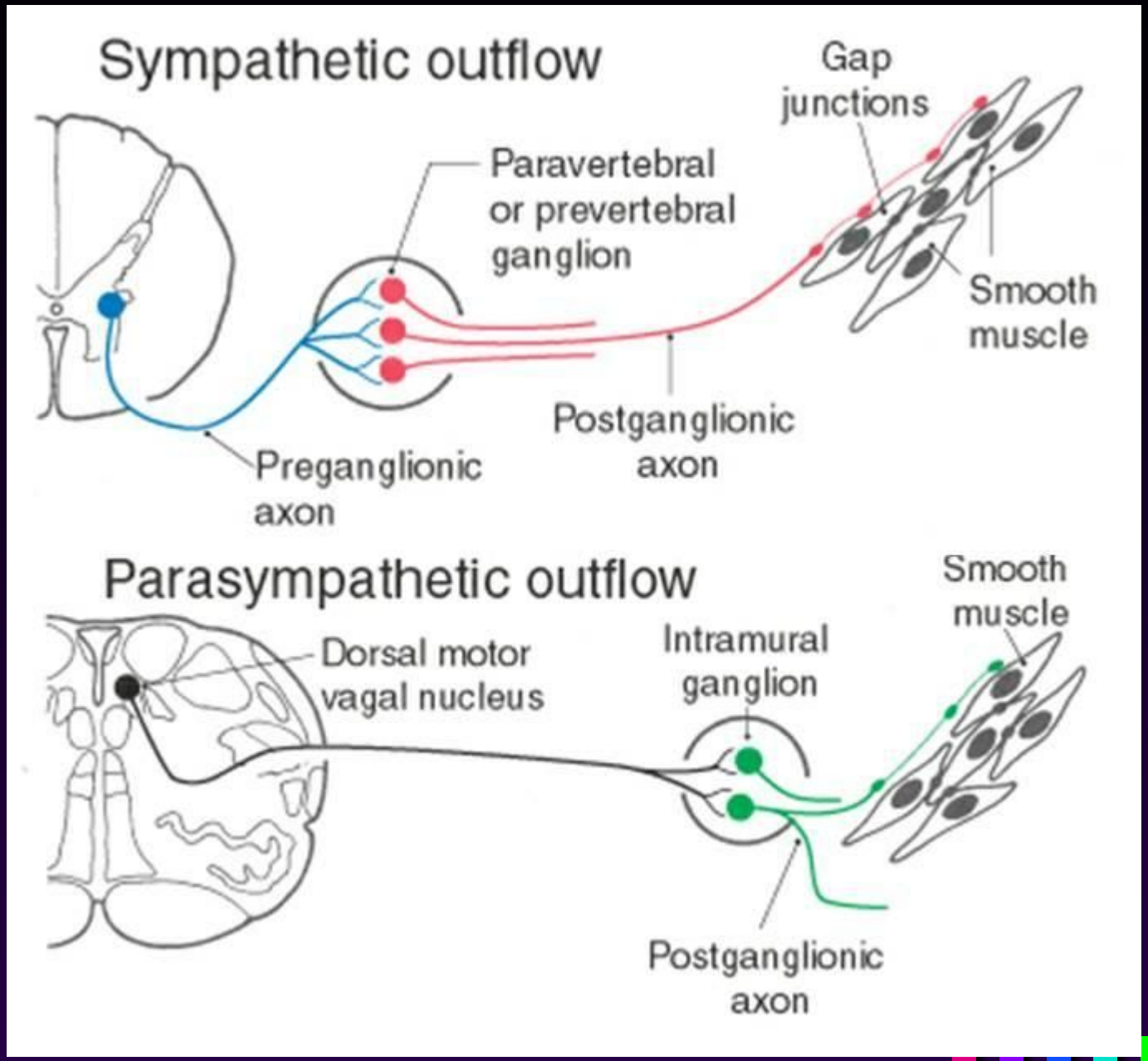
↓

Postganglionic neurons

↓

target cells



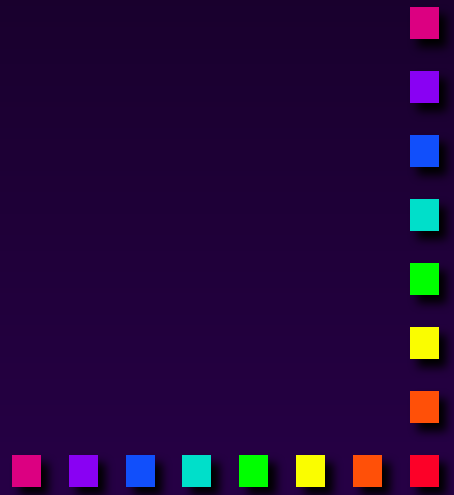

Sympathetic outflow
Gap junctions
Paravertebral or prevertebral ganglion
Smooth muscle
Postganglionic axon
Preganglionic axon
Parasympathetic outflow
Smooth muscle
Intramural ganglion
Dorsal motor vagal nucleus
Postganglionic axon

3. Although “involuntary”, the autonomic nervous system is regulated by higher centers. The best known of these centers is the hypothalamus which has descending projections to cell bodies of the preganglionic neurons. Other areas of the central nervous system affect the activities of the hypothalamus.

4. The autonomic nervous system consists of two divisions:

- a) the sympathetic (or thoracolumbar) division in which the preganglionic cells are located in the thoracic and first two lumbar segments of the spinal cord.
- b) the parasympathetic (or craniosacral) division in which the preganglionic neurons are located in the brain stem and in sacral (S2 - S4) segments of the spinal cord.

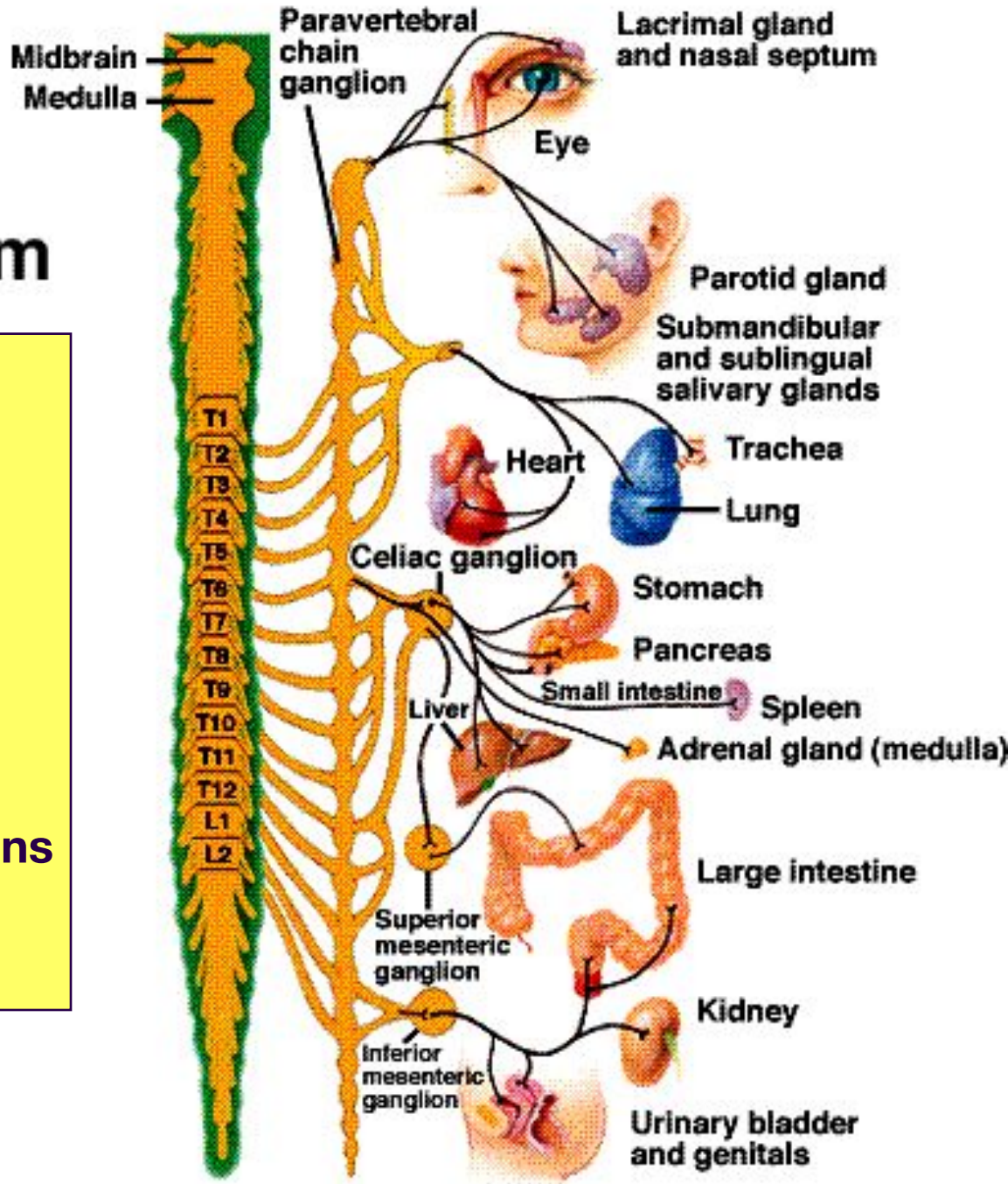
Sympathetic
“Fight or flight”
“E” division
Exercise, excitement, emergency, and embarrassment



Sympathetic Division of the Autonomic Nervous System

= Thoracolumbar division (T1 to L2)

- **Preganglionic neurons (N1)from thoracolumbar region of spinal cord**
- **Pre and paravertebral ganglia**
- **Long postganglionic neurins (N2) secrete NE onto adrenergic receptors**



Sympathetic (preganglionic):

1. The cell bodies giving rise to preganglionic neurons (N_1) are located in the intermediolateral column (lateral horn) of the gray matter in spinal cord segments T_1 through L_2.

2. Preganglionic fibers leave the spinal cord with the ventral roots of spinal nerves arising from cord segments T_1 - L_2.

Sympathetic (postganglionic):

1. The cell bodies giving rise to postganglionic neurons (N_2) are located in the paravertebral ganglia (sympathetic trunk (vertebral chain)).

2. Prevertebral (collateral) ganglia: celiac, superior mesenteric, inferior mesenteric, aorticorenal and renal.

.

Sympathetic ganglia

- Sympathetic chain ganglia (paravertebral ganglia) – preganglionic fibers of the sympathetic NS that carry motor impulses to the body wall or thoracic cavity synapses in chain ganglia
- Collateral ganglia (prevertebral ganglia) – group of second order neurons that innervate organs in the abdominopelvic region

Sympathetic Trunk Ganglia

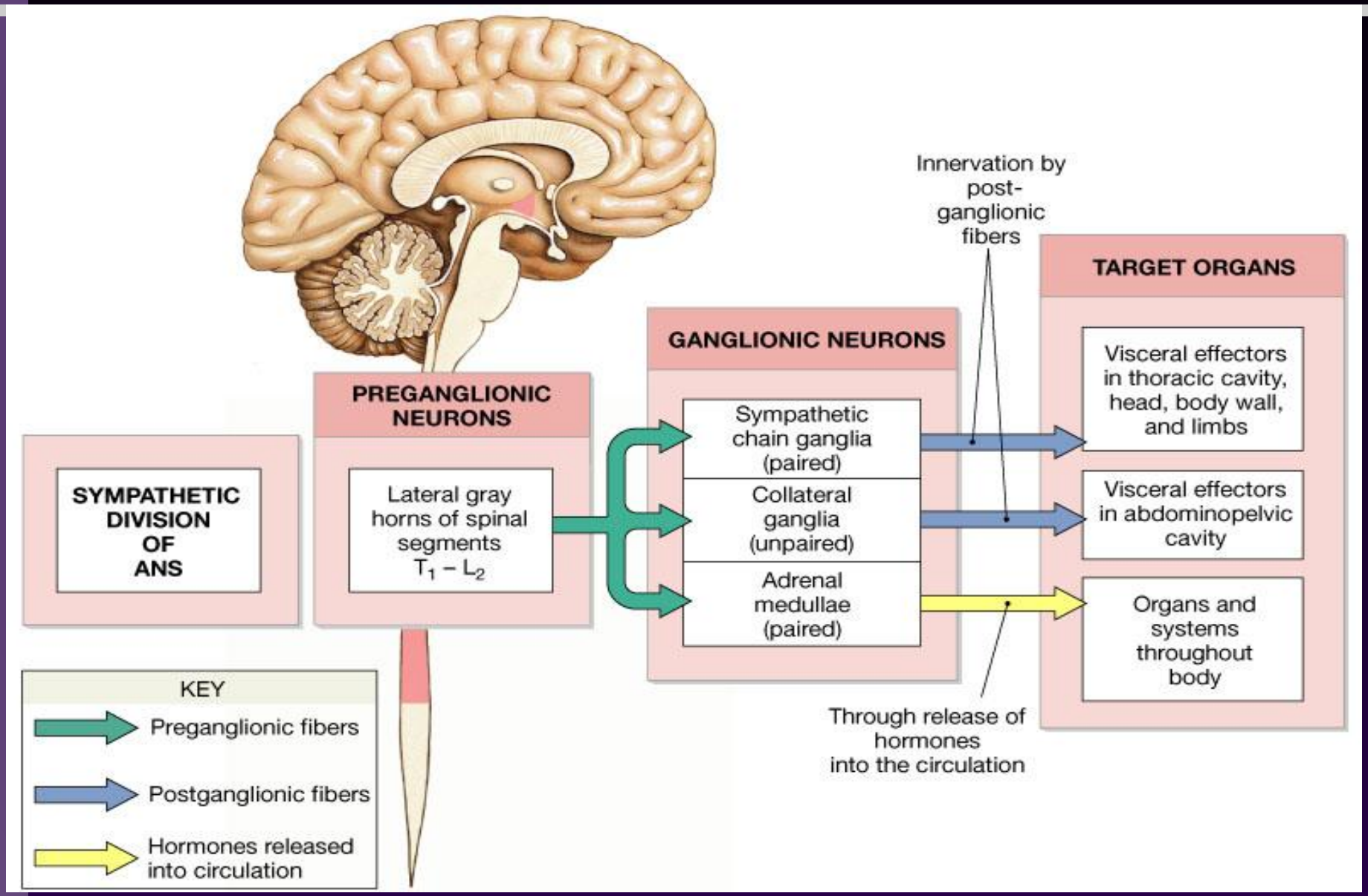
- Located on both sides of the vertebral column
- Linked by short nerves into sympathetic trunks
- Joined to ventral rami by white and gray rami communicantes

Right and left sympathetic trunks extend from the base of the skull to the region of the coccyx; at their distal ends, the right and left trunks are fused.

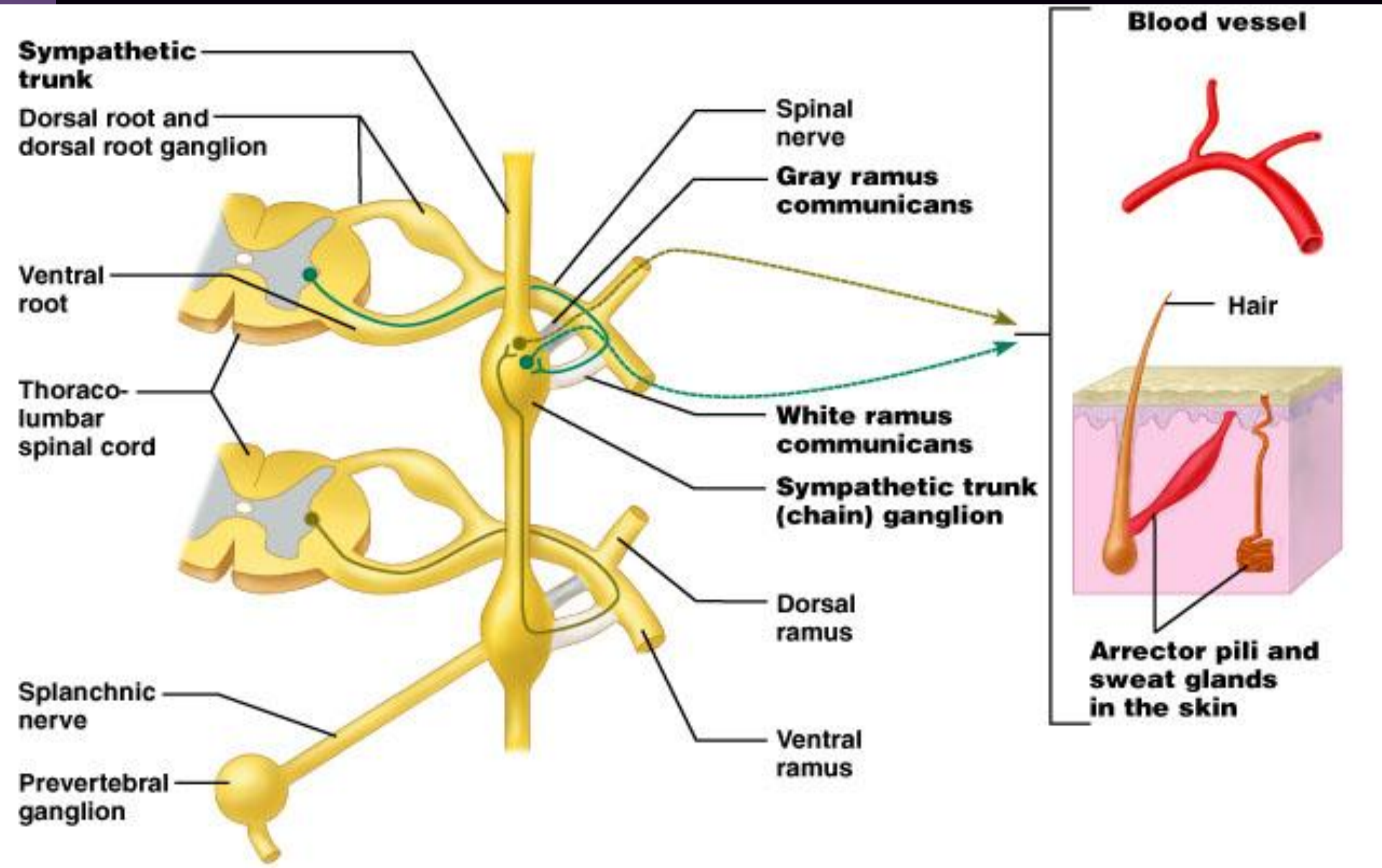
Prevertebral Ganglia

- Unpaired, not segmentally arranged
- Occur only in abdomen and pelvis
- Lie anterior to the vertebral column
- Main ganglia
- Celiac, superior mesenteric, inferior mesenteric, inferior hypogastric ganglia

The Organization of the Sympathetic Division of the ANS



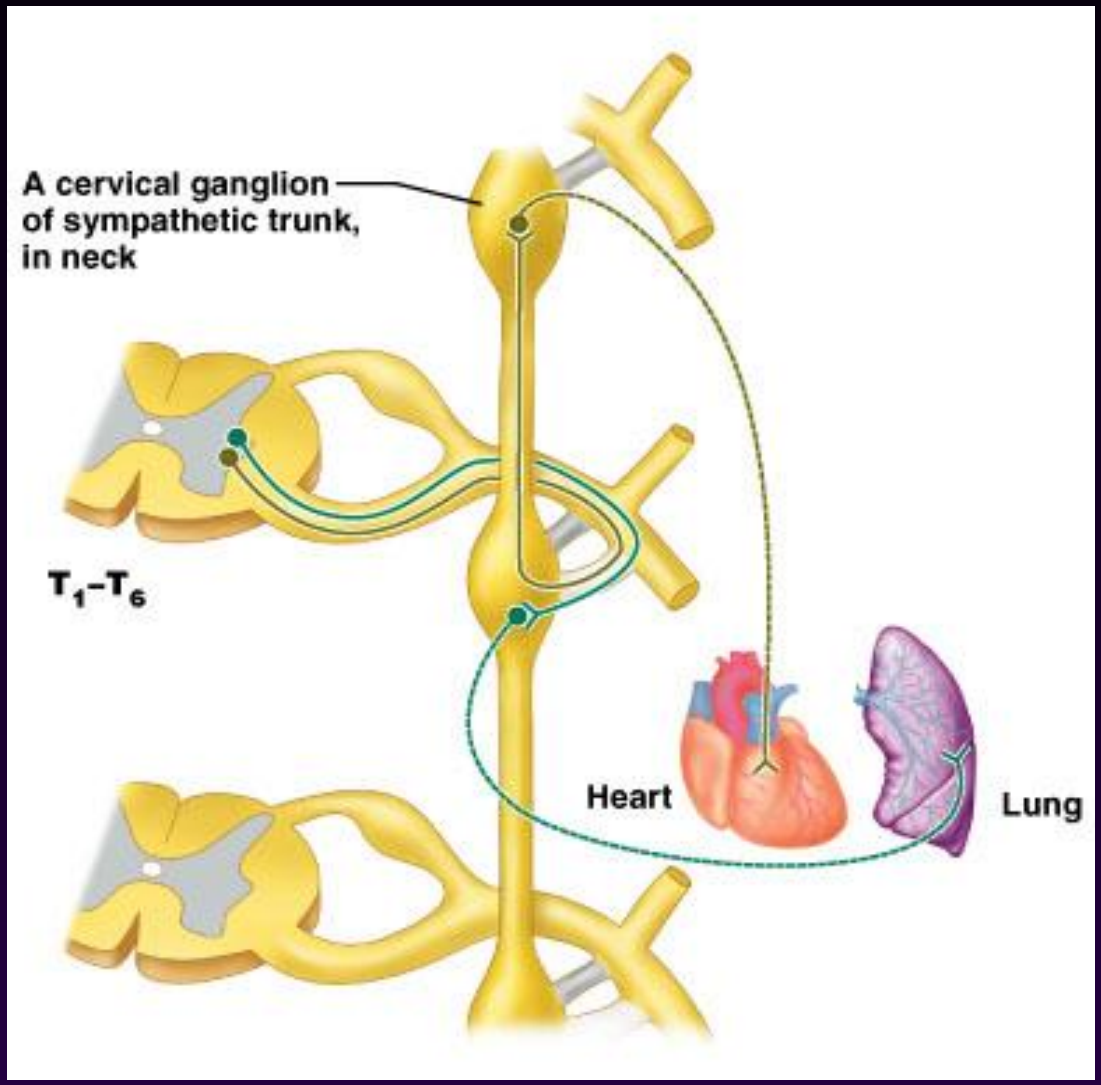
Sympathetic Pathways to Periphery



Postganglionic fibers

- Rejoin spinal nerves and reach their destination by way of the dorsal and ventral rami
- Those targeting structures in the thoracic cavity form sympathetic nerves
  - Go directly to their destination

Sympathetic Pathways to Thoracic Organs



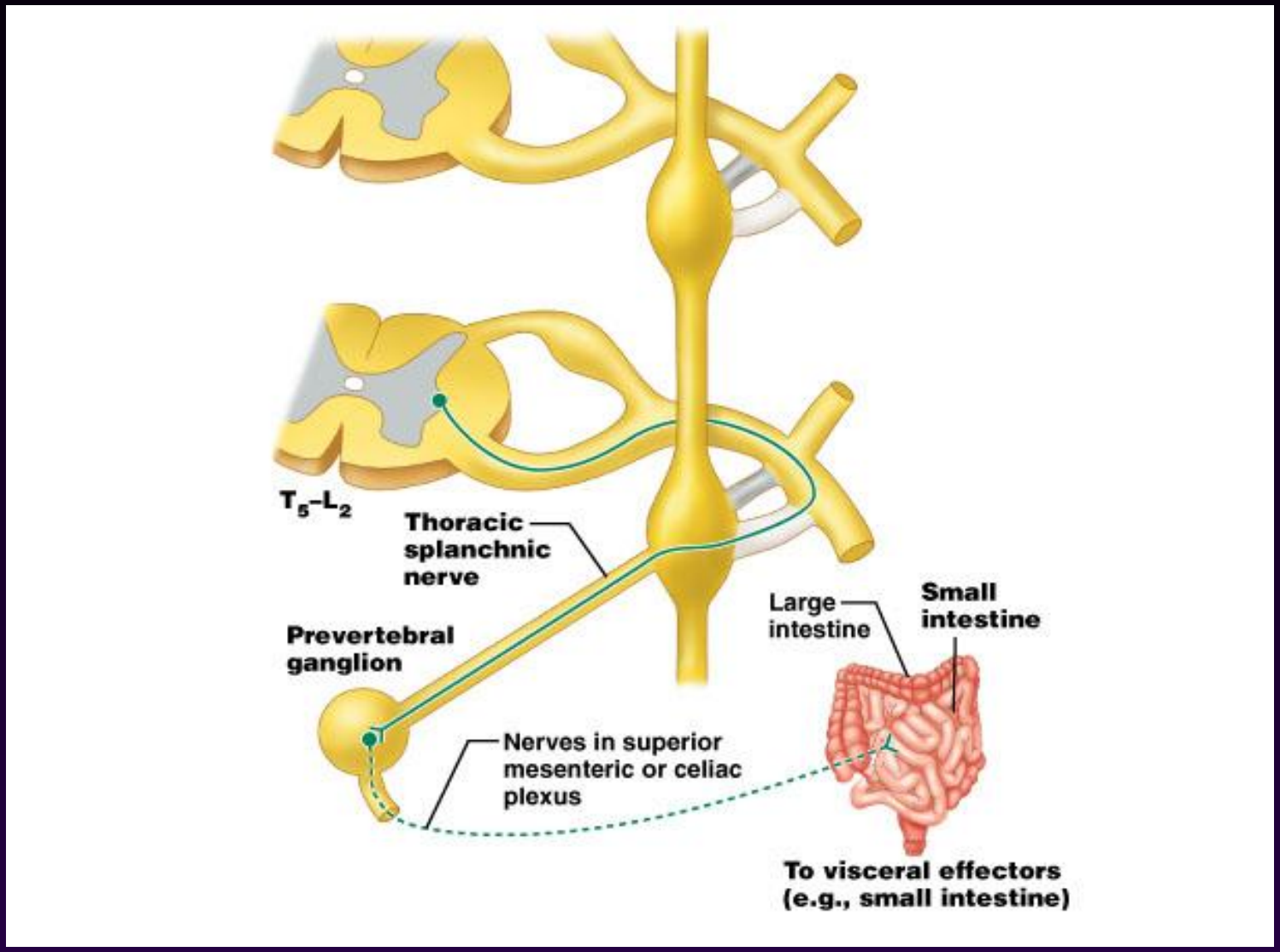
Abdominopelvic viscera

- Sympathetic innervation via preganglionic fibers that synapse within collateral ganglia
  - Splanchic nerves – carry fibers that synapse in collatheral ganglia

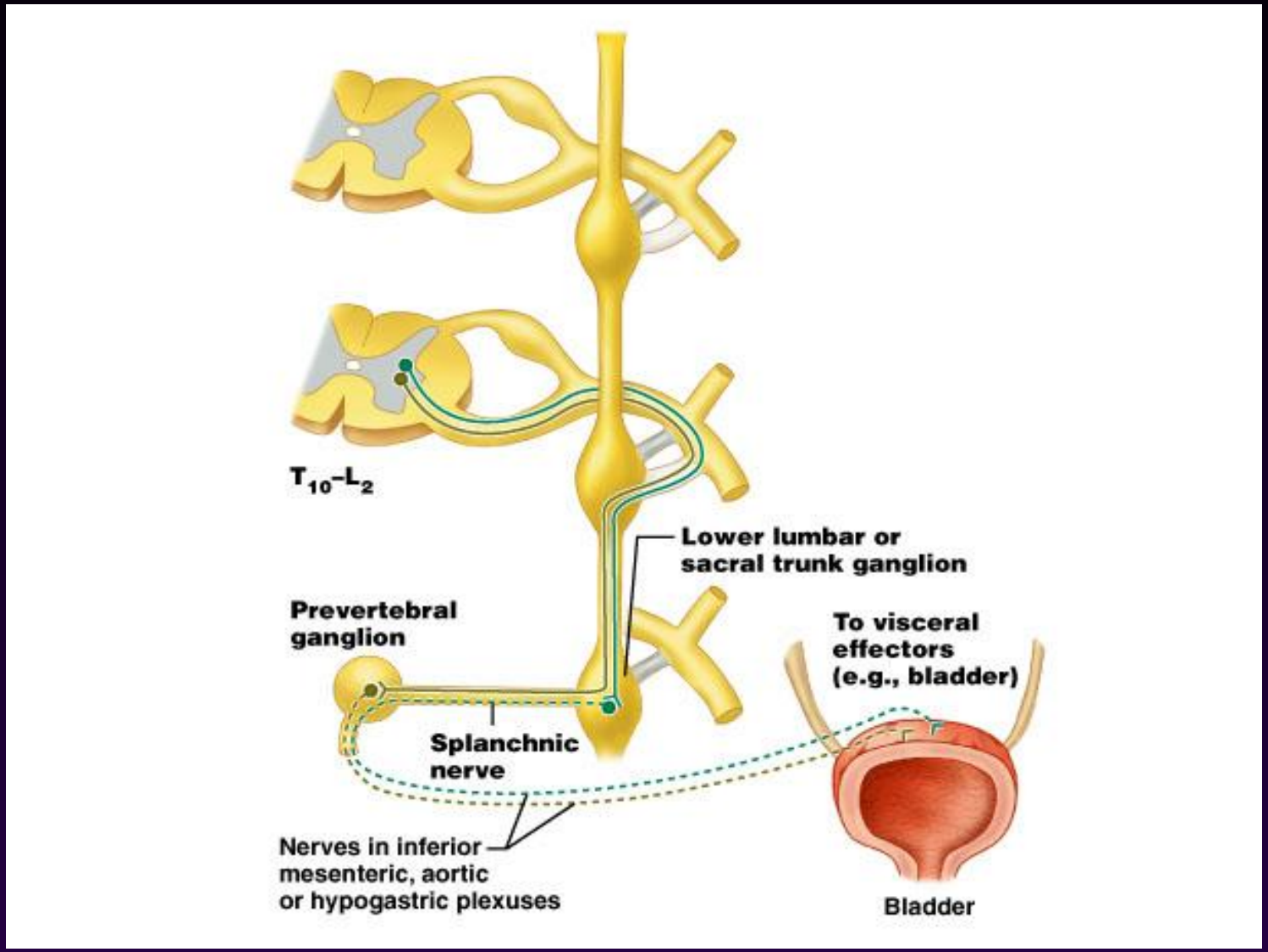
Abdominopelvic viscera

- Celiac ganglion
  - Innervates stomach, liver, gall bladder, pancreas, spleen
- Superior mesenteric ganglion
  - Innervates small intestine and initial portion of large intestine
- Inferior mesenteric ganglion
  - Innervates kidney, urinary bladder, sex organs, and final portion of large intestine

Sympathetic Pathways to the Abdominal Organs

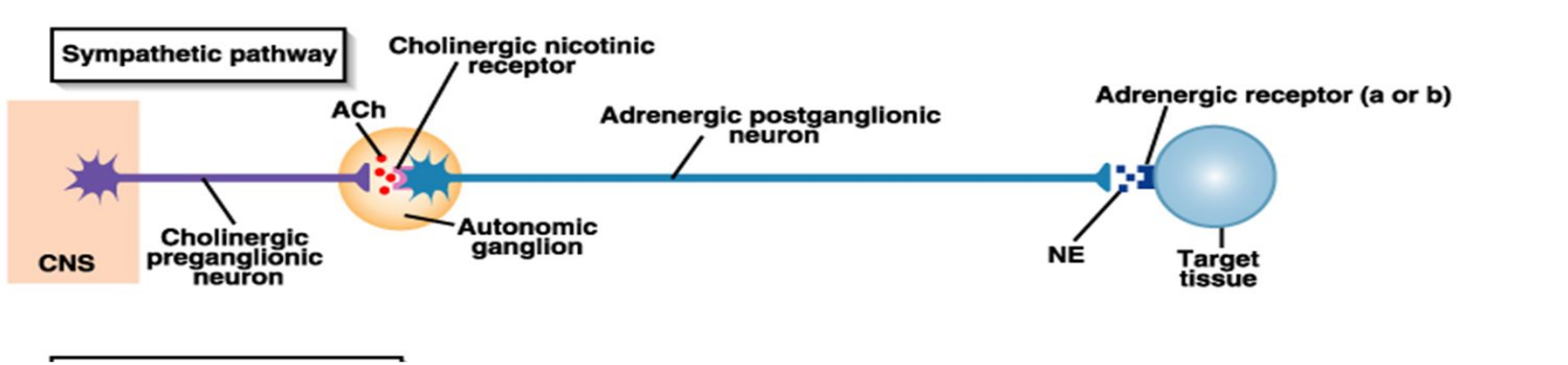


Sympathetic Pathways to the Pelvic Organs



Other important considerations:

ganglion cells are usually located at some distance from the effectors. Accordingly, postganglionic sympathetic fibers are usually long fibers.



Acetylcholine (Ach) - pre-ganglionic ganglionic Neurotransmitter

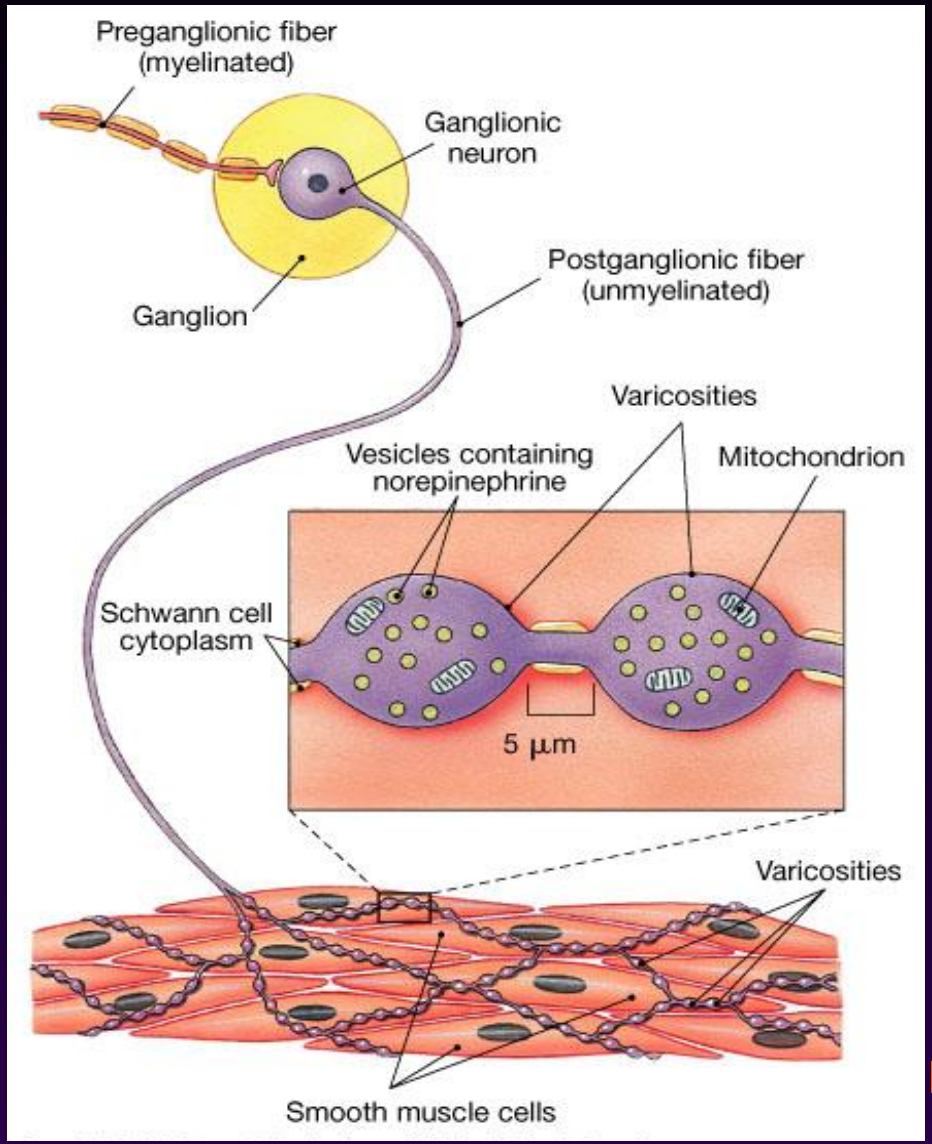
Norepinephrine (NE) - post-ganglionic ganglionic Neurotransmitter

Sympathetic Division

- A single sympathetic preganglionic fiber has many axon collaterals and may synapse with 20 or more postganglionic neurons.

- The postganglionic axons typically terminate in several visceral effectors and therefore the effects of sympathetic stimulation are more widespread than the effects of parasympathetic stimulation.

Sympathetic Variosities



Effects of Sympathetic Division

- *cardiac output increases*
- *SA node*: heart rate (chronotropic) β_1, : ↑*cardiac muscle*: contractility (inotropic) β_1 ↑conduction at AV node β_1 : increases
- *vascular smooth muscle:* α = contracts; β_2 = relaxes
- *smooth muscles of bronchioles* β_2: relaxes;
- *pupil of eye* α_1: relaxes
- *ciliary muscle* β_2 : relaxes
- *smooth muscles of GI tracta*, β_2: relaxes
- *sphincters of GI tract* α_1: contracts
- *glands of GI tract* inhibits

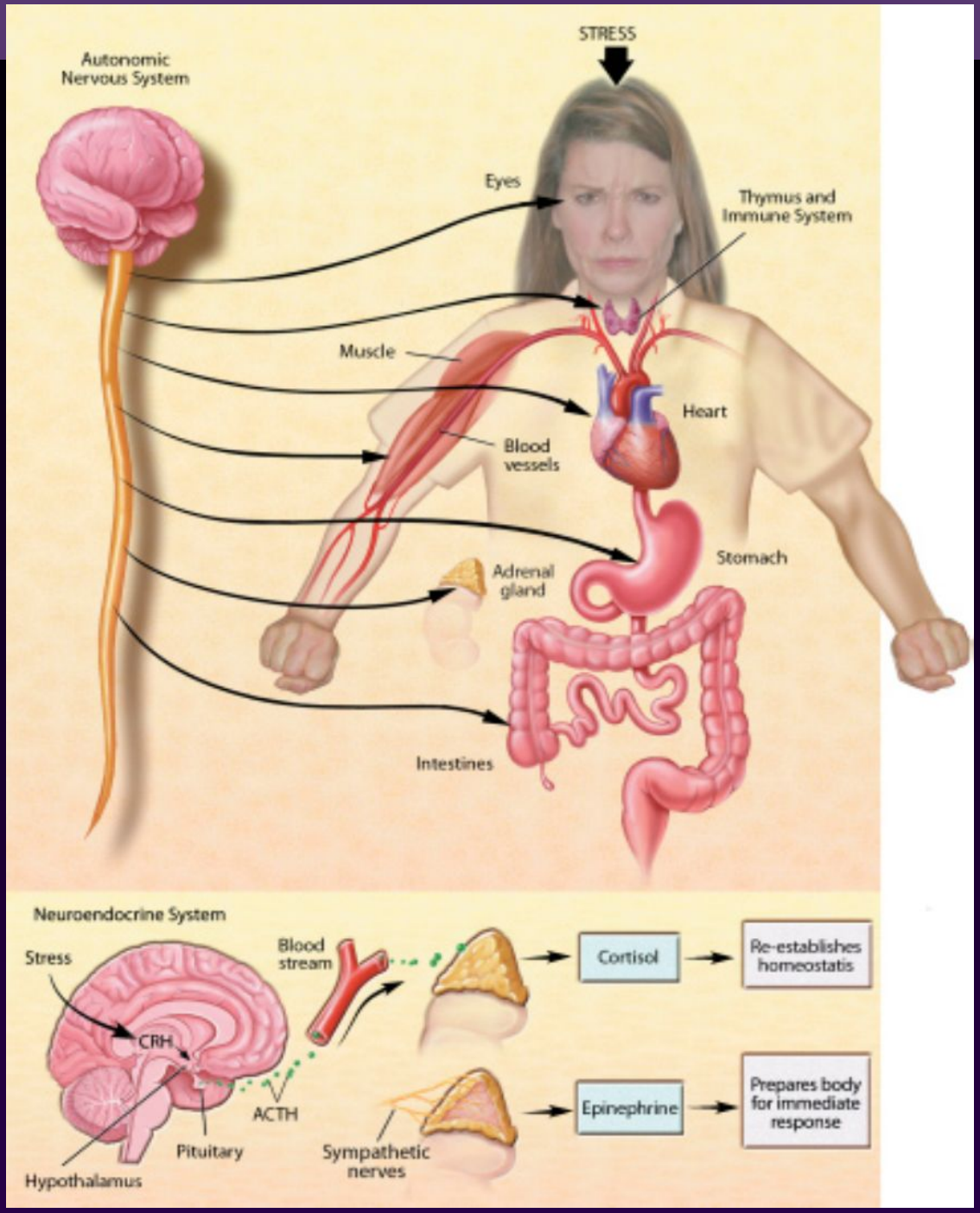
THE STRESS REACTION

- A stressful situation activates three major communication systems in the brain that regulate bodily functions.
- The first of these systems is the voluntary nervous system, which sends messages to muscles so that we may respond to sensory information.
- The second communication system is the autonomic nervous system.
- The brain's third major communication process is the neuroendocrine system, which also maintains the body's internal functioning.

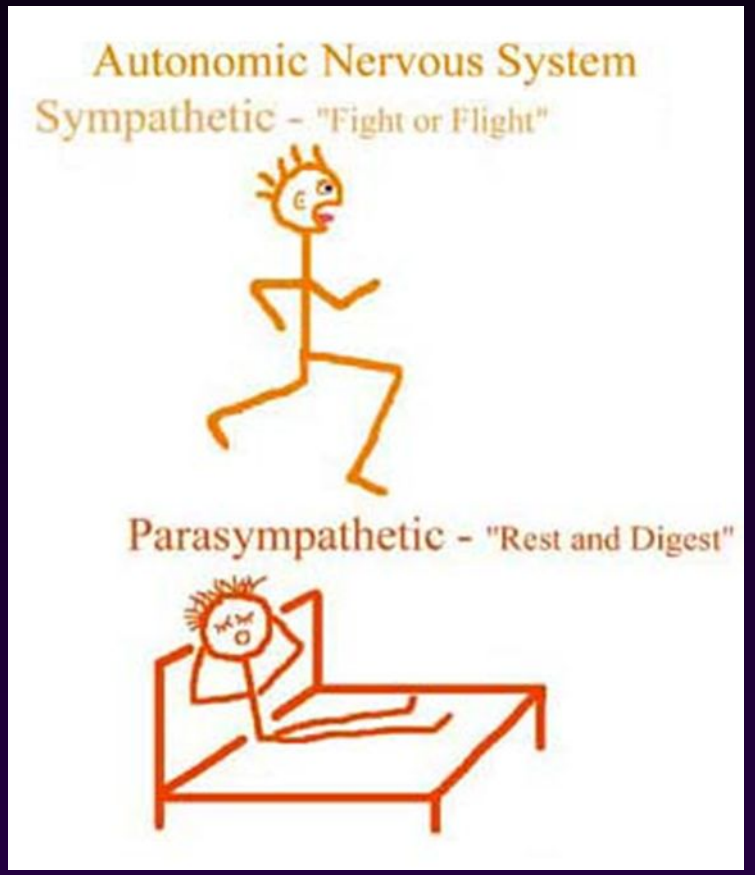
THE STRESS REACTION

When stress occurs, the sympathetic nervous system is triggered. Norepinephrine is released by nerves; epinephrine and norepinephrine is secreted by the adrenal glands. By activating receptors in blood vessels and other structures, these substances ready the heart and working muscles for action.

Acetylcholine is released in the parasympathetic nervous system, producing calming effects. The digestive tract is stimulated to digest a meal, the heart rate slows, and the pupils of the eyes become smaller. The neuroendocrine system also maintains the body's normal internal functioning.

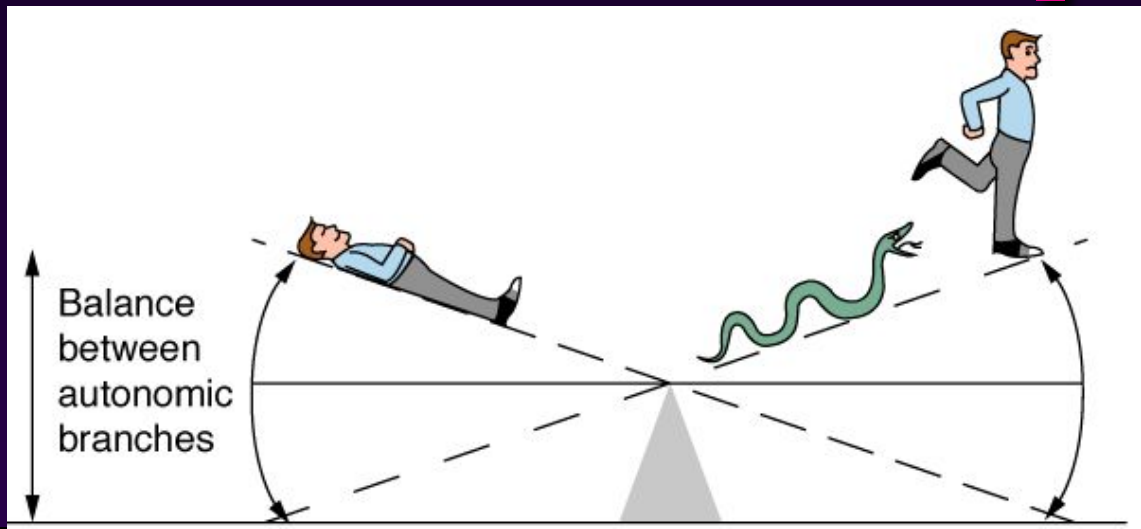

STRESS
Autonomic Nervous System
Eyes
Thymus and Immune System
Muscle
Heart
Blood vessels
Stomach
Adrenal gland
Intestines
Neuroendocrine System
Stress
Blood stream
CRH
ACTH
Pituitary
Hypothalamus
Sympathetic nerves
Cortisol
Re-establishes homeostatis
Epinephrine
Prepares body for immediate response

The two divisions of the autonomic nervous system are not infrequently said to be antagonists in the sense of their having opposite effects



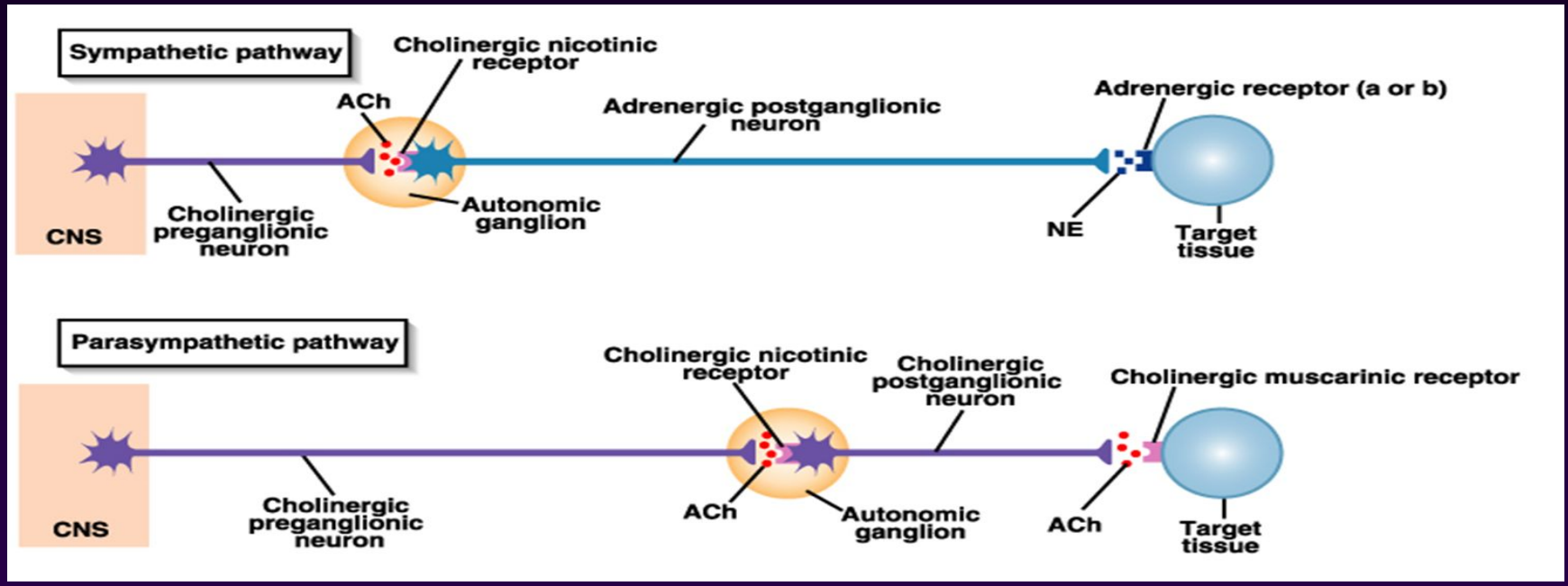
Homeostasis and the Autonomic Division

- BP, HR, Resp., H_2O balance, Temp. . .
- **Mostly dual reciprocal innervation**
  - i.e., agonist/antagonist or excitatory/inhibitory
- **Sympathetic:**
  - AKA Thoracolumbar
  - flight-or-fight
- **Parasympathetic:**
  - AKA Craniosacral
  - rest and digest

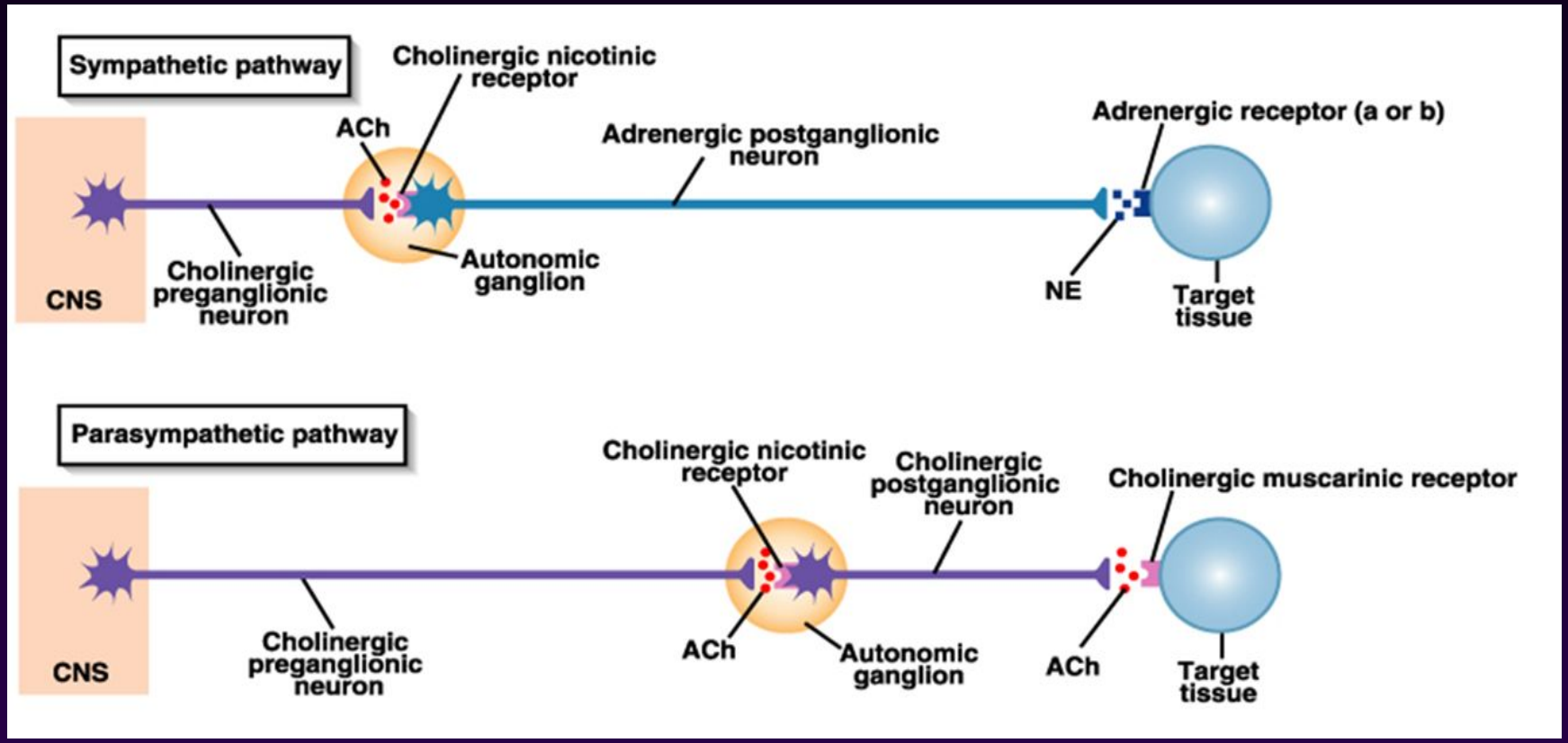


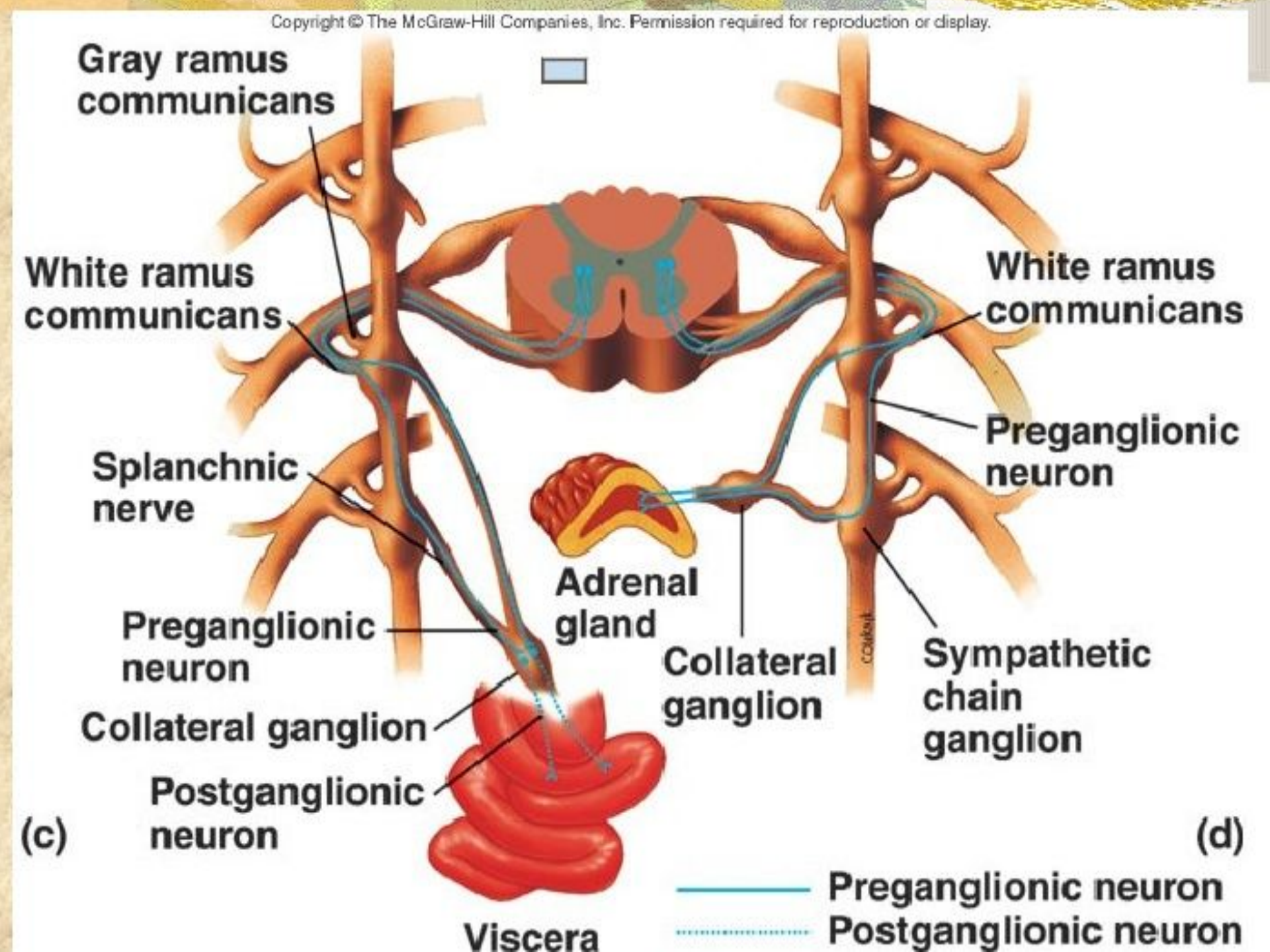
Other important considerations:

ganglion cells are usually located at some distance from the effectors. Accordingly, postganglionic sympathetic fibers are usually long fibers.

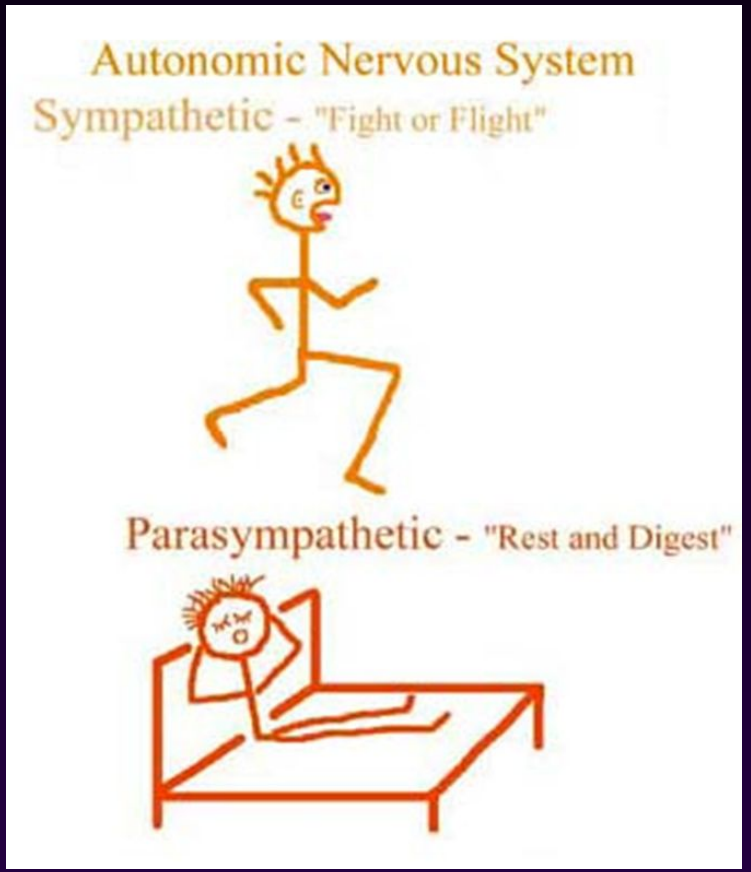


The terminations of most, but not all, sympathetic postganglionic fibers release a substance (norepinephrine). Such postganglionic fibers are commonly called adrenergic fibers.

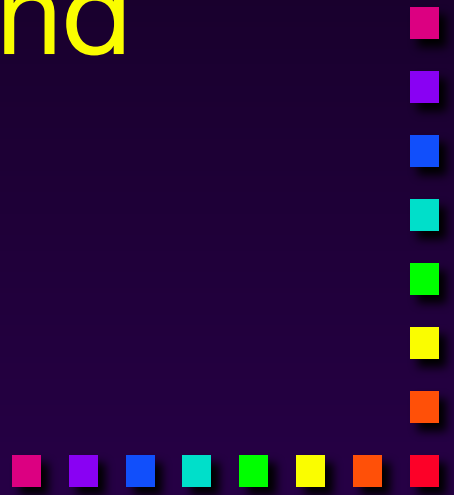




The effects elicited by the action of the sympathetic division of the ANS are typically effects useful in “fight or flight”. These include dilation of the pupil, increase in heart rate, elevation of blood pressure, diversion of blood from the alimentary tract to skeletal muscles, etc.



Parasympathetic
“Rest and digest”
“D” division
Digestion, defecation, and diuresis



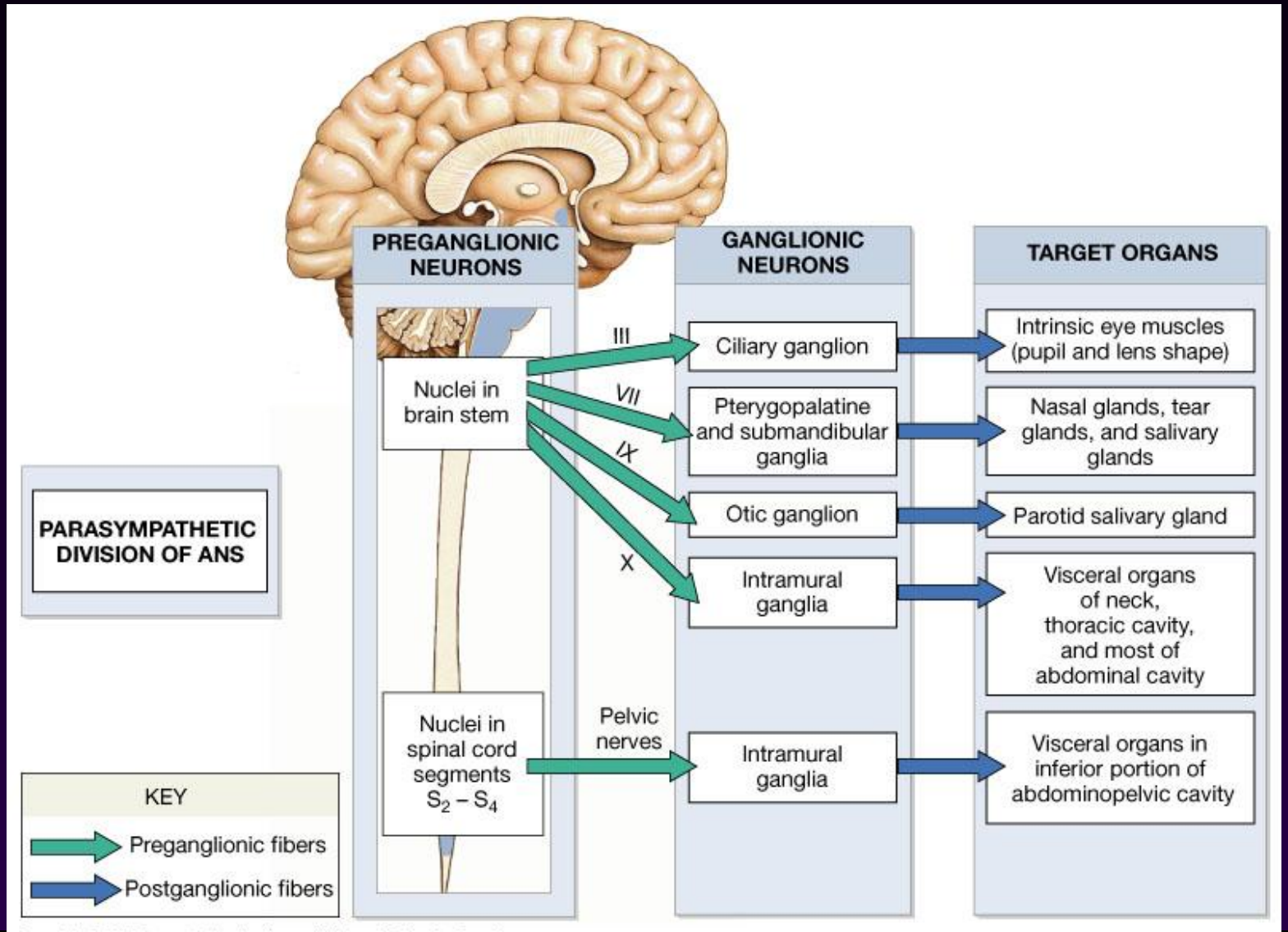
Parasympathetic: Craniosacral or rest and digest

Center of parasympathetic division the ANS

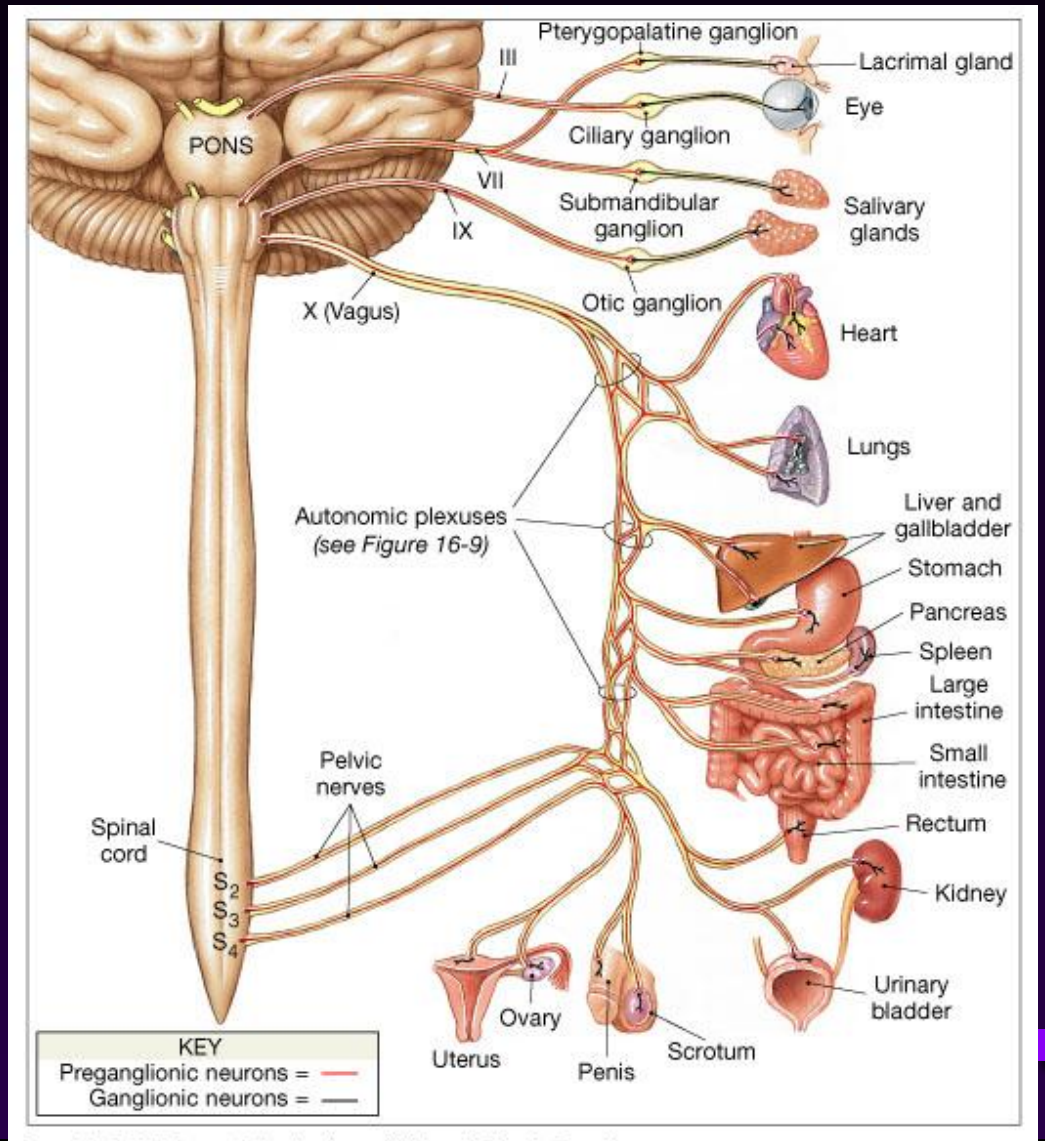
Has preganglionic cell bodies (N2) in the midbrain and brainstem and in sacral segments 2, 3 and 4 of the spinal cord.

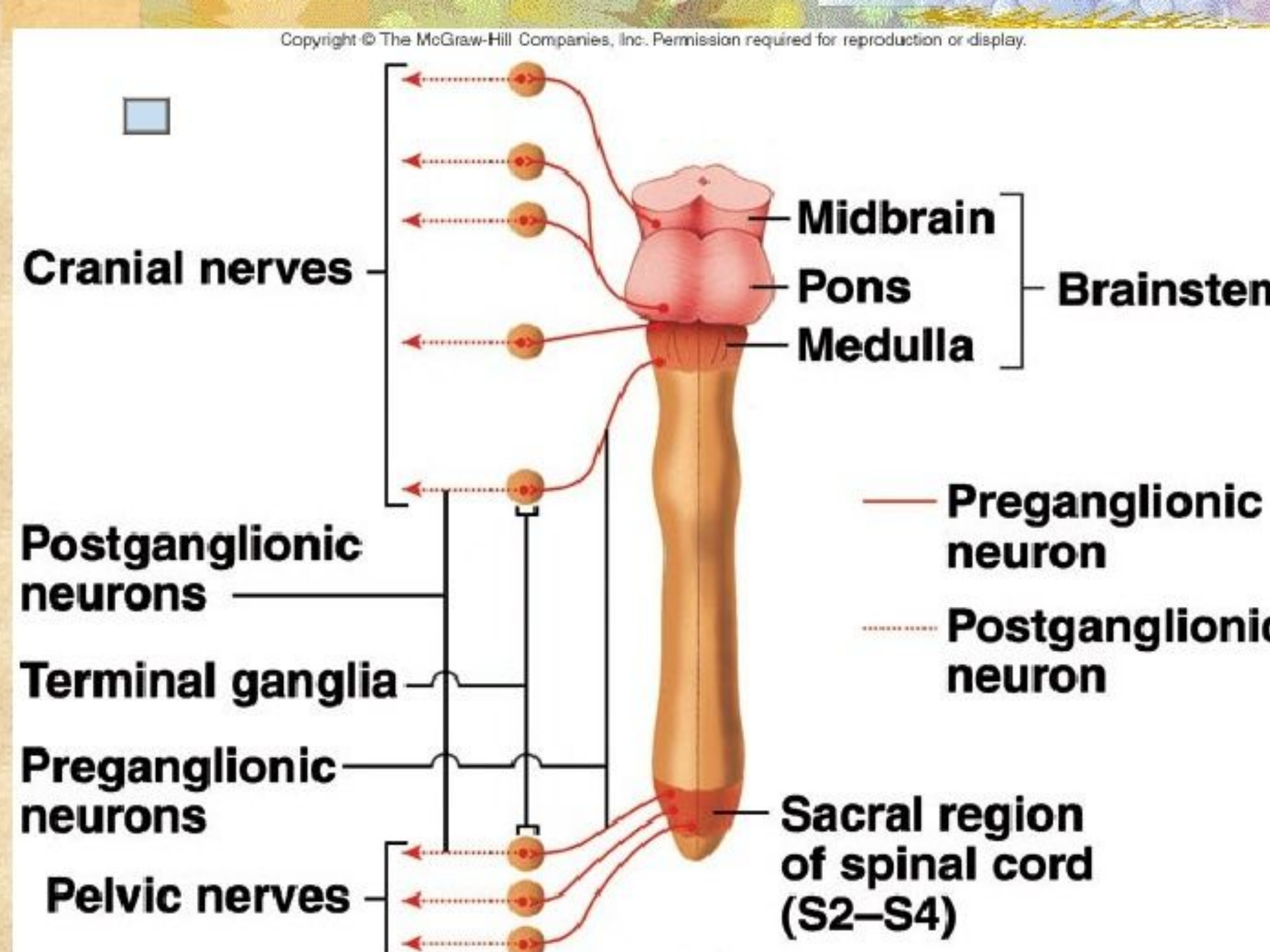
- The fibers of cells in the midbrain and brainstem are in the oculomotor (III), facial (VII), glossopharyngeal (IX), and vagus (X) nerves. They innervate smooth muscles of the eye (III), lacrimal and salivary glands (VII and IX), and smooth muscles of the thoracic and abdominal viscera (X).

The Organization of the Parasympathetic Division of the ANS

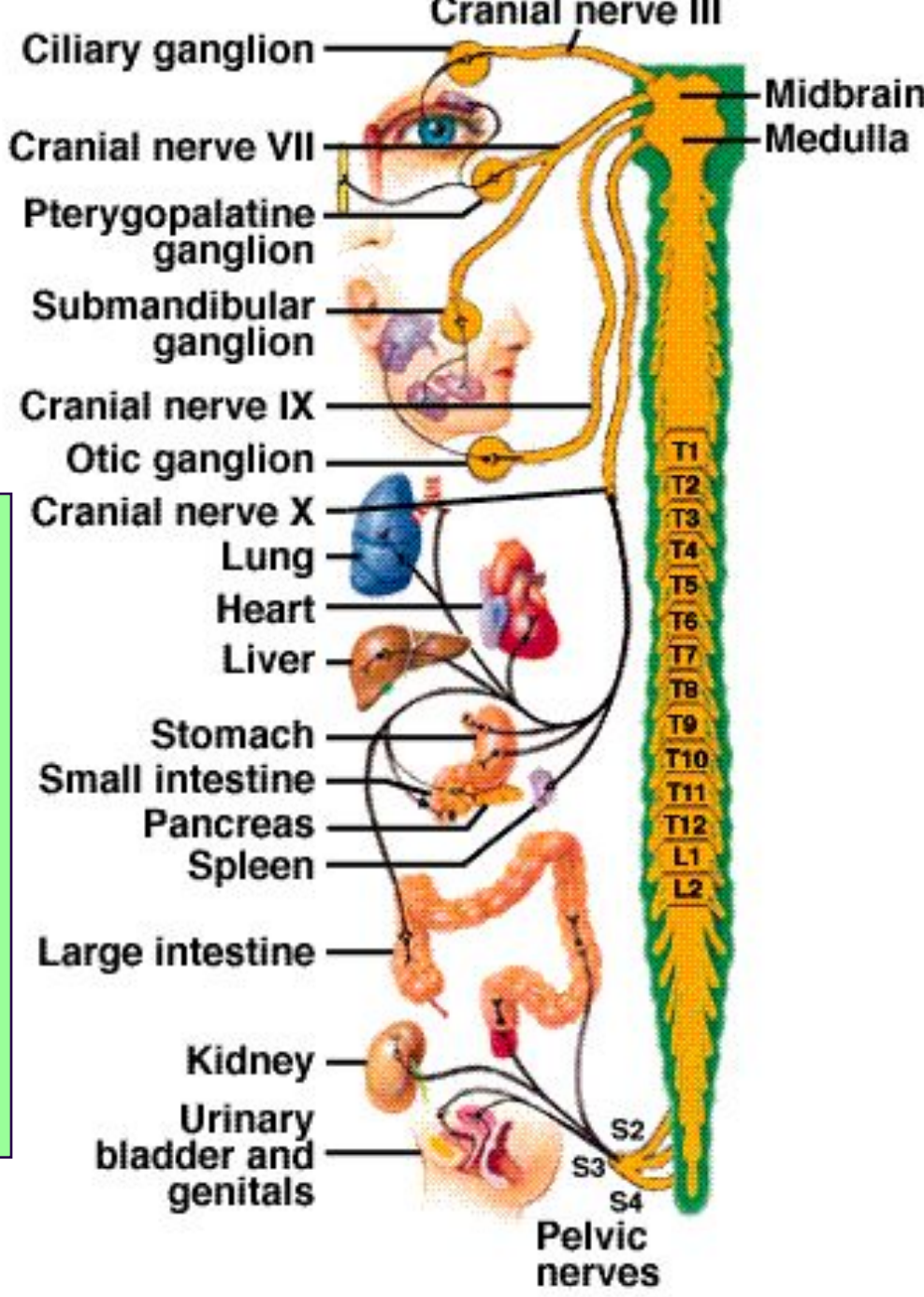


The Distribution of Parasympathetic Innervation





Parasympathetic Division of the Autonomic Nervous System



= Craniosacral Division

- Long preganglionic axons from brain & S2- S4
- Intramural ganglia
- Postganglionic (nonmyelinated) neurons secrete ACh onto cholinergic muscarinic receptors

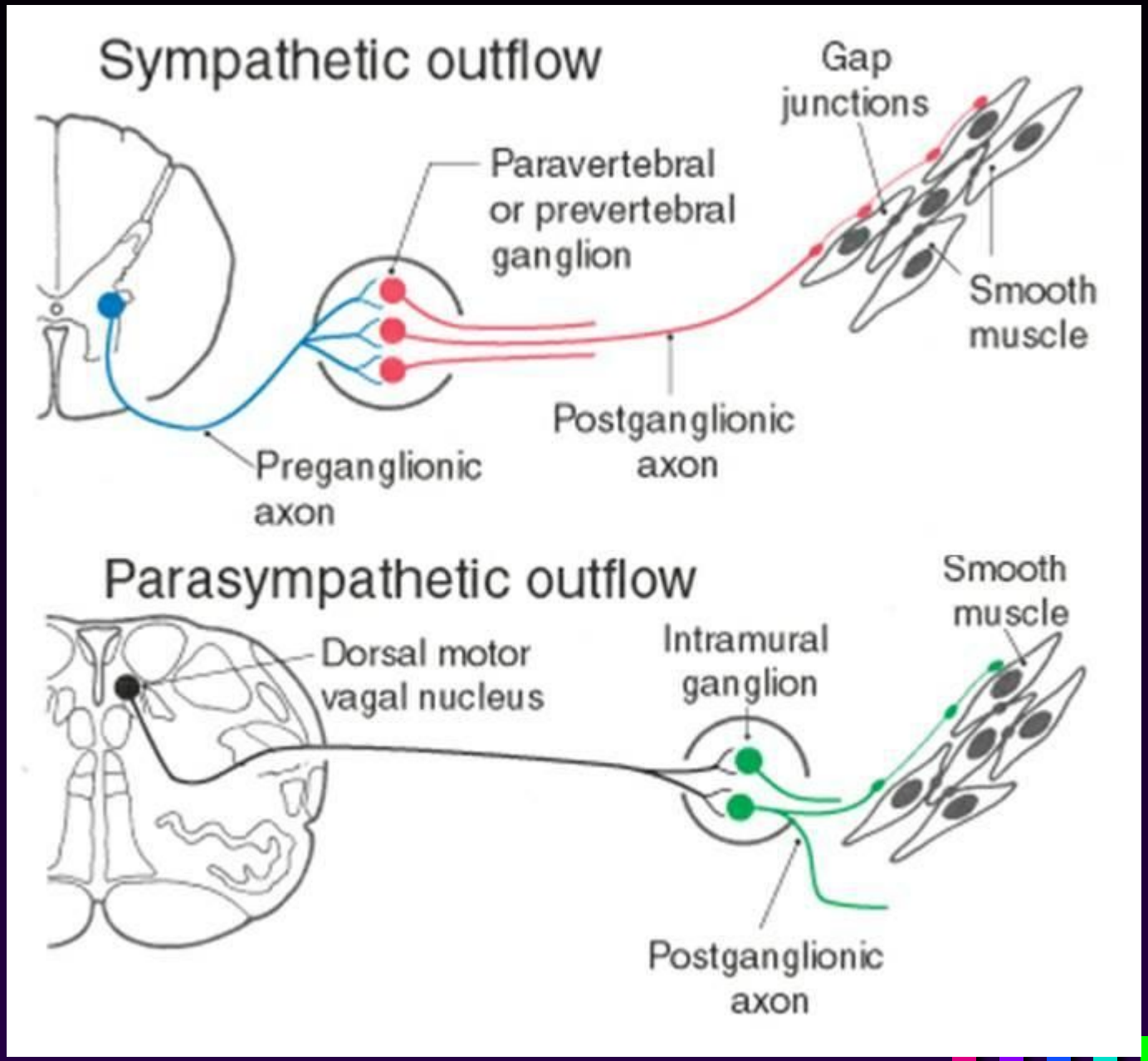
Parasympathetic: Craniosacral or rest and digest

Center of parasympathetic division the ANS

The cell bodies giving rise to postganglionic neurons (N2) are located in the Intramural ganglia.

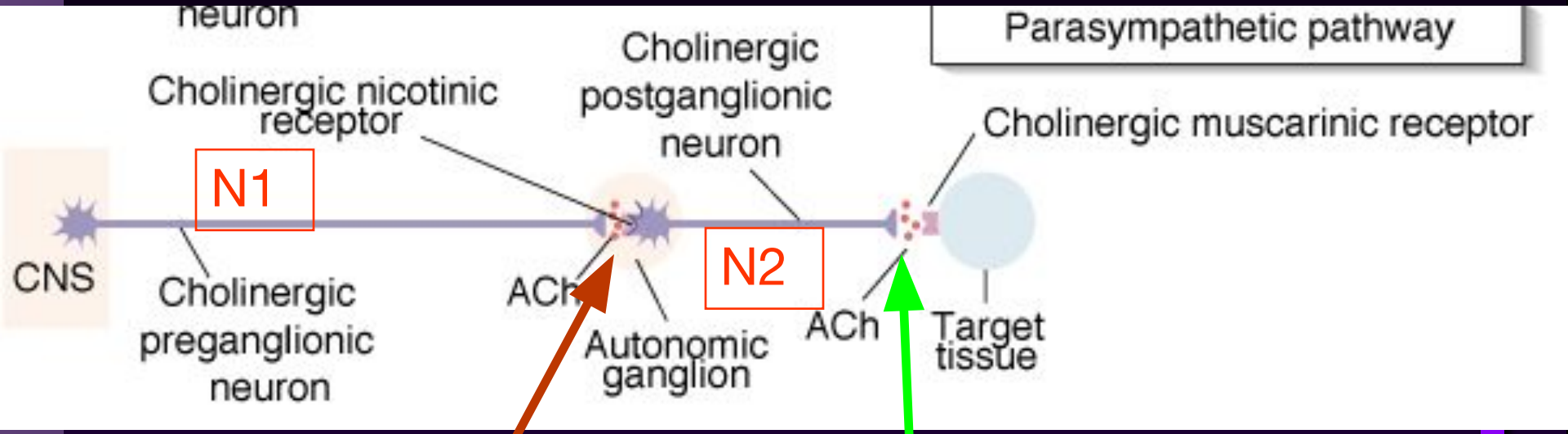
The ganglion cells of the parasympathetic system are located in or on the wall of the organs supplied or in specific ganglia located near the organs supplied. Hence the postganglionic fibers are short.

Except for the vagus nerves, the area of distribution of parasympathetic nerves is somewhat limited. The number of synaptic connections is smaller than in the sympathetic division. Accordingly, the effects of the parasympathetic division tend to be local rather than widespread.


Sympathetic outflow
Gap junctions
Paravertebral or prevertebral ganglion
Smooth muscle
Postganglionic axon
Preganglionic axon
Parasympathetic outflow
Smooth muscle
Intramural ganglion
Dorsal motor vagal nucleus
Postganglionic axon

- Most postganglionic parasympathetic fibers release acetylcholine at their terminations. These fibers are, hence, often called cholinergic fibers. They may also release a variety of peptides that influence smooth muscle activity.

Summary: Pre- & Postganglionic Parasympathetic Neurons Release ACh



nicotinic

muscarinic

Receptor s

Neurotransmitters and parasympathetic functions

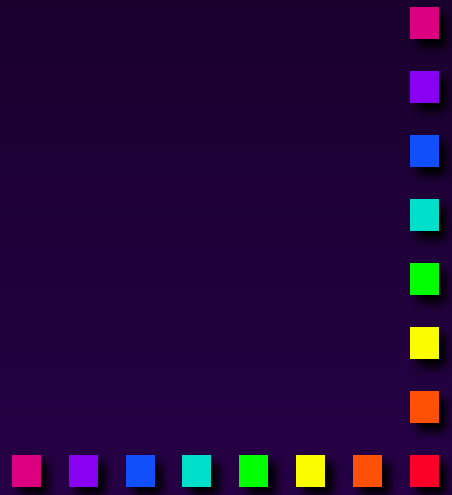
- All parasympathetic fibers release ACh
- Short-lived response as ACH is broken down by AChE and tissue cholinesterase

Parasympathetic (muscarinic)

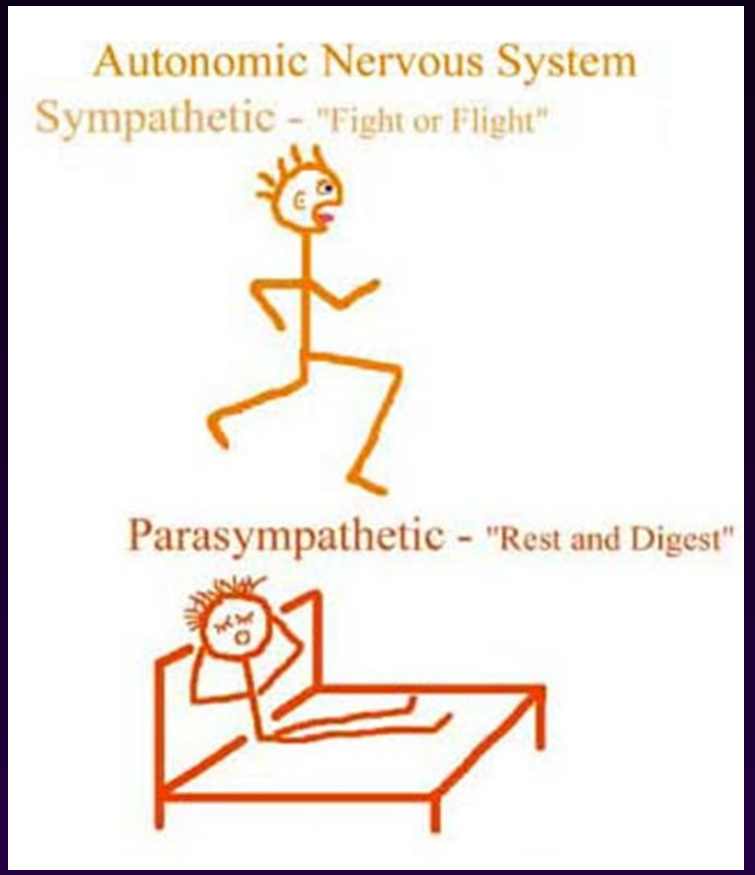
- cardiac output M2: decreases
- SA nodeSA node: heart rate (chronotropic) M2: decreases
- cardiac musclecardiac muscle: contractility (inotropiccardiac muscle: contractility (inotropic) M2: decreases (atria only)
- conduction at AV node M2: decreases
- smooth musclessmooth muscles of bronchioles M3: contracts
- pupilpupil of eye M3: contracts
- ciliary muscle M3: contracts
- salivary glands: secretions stimulates watery secretions
- GI tract motility M1, M3: increases
- smooth musclessmooth muscles of GI tract M3: contracts
- sphinctersphincters of GI tract M3: relaxes

Parasympathetic activation

- Effects produced by the parasympathetic division
  - relaxation
  - food processing
  - energy absorption



The parasympathetic division controls body process during ordinary situations. Generally, it conserves and restores. It slows the heart rate and decreases blood pressure. It stimulates the digestive tract to process food and eliminate wastes. Energy from the processed food is used to restore and build tissues.



Most Common Autonomic NTs:

- **Acetylcholine (ACh)**

  ACh neurons & ACh receptors are called **cholinergic (nicotinic or muscarinic). Located at autonomic preganglionic & para-sympathetic postganglionic synapses**

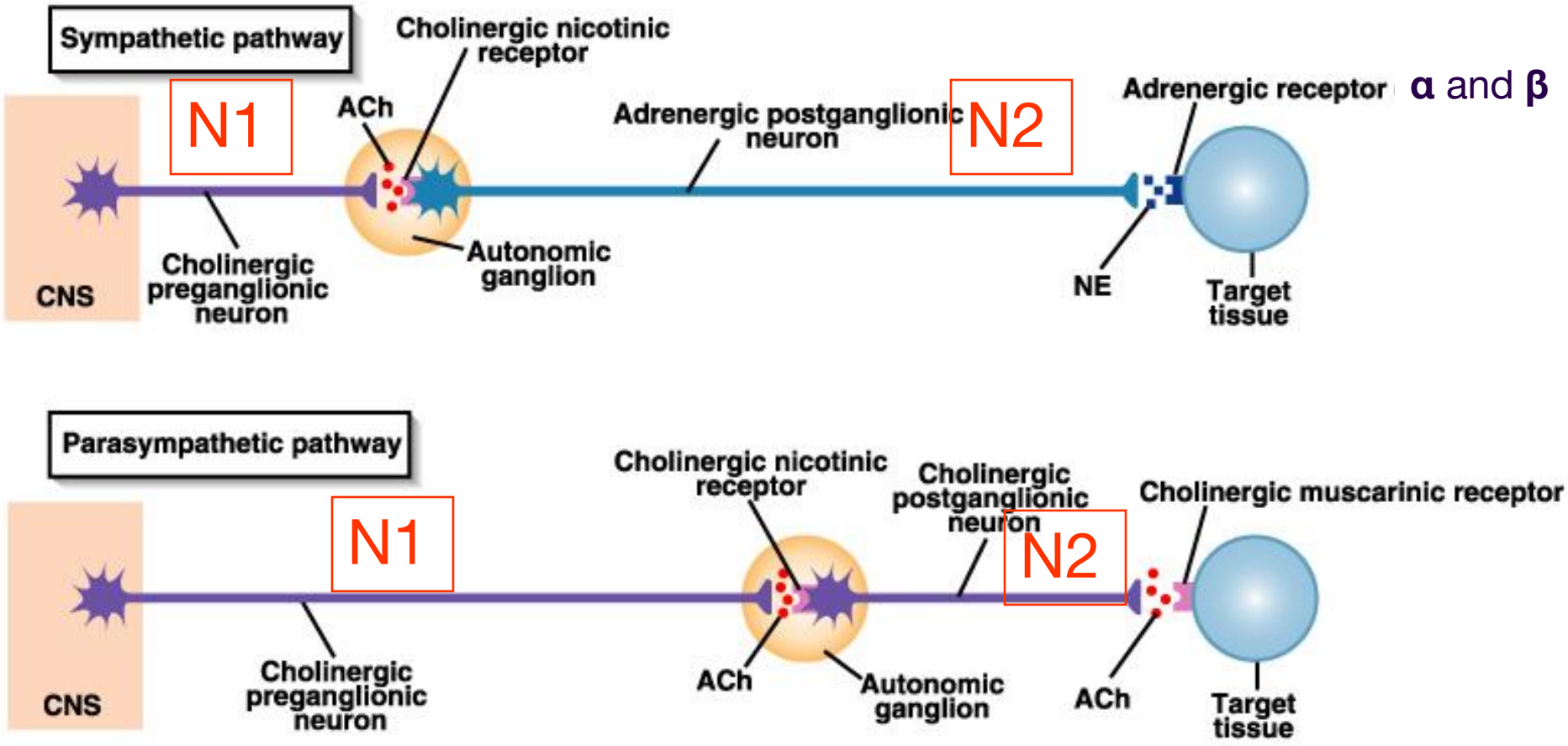
- **Norepinephrine (NE)**

  NE neurons & receptors are called (nor) **adrenergic (α and β). Located at sympathetic postganglionic synapses**

Fig 11-7

NTs of Autonomic NS

Compare to *Fig 11-7*



Neuroeffector Junction

= Synapse between postganglionic cell and target

- Most are different from model synapse *(compare to Fig 8-20, p. 270)*
- ANS synapse: axon has varicosities containing neurotransmitter
  - May supply many cells, resulting in less specific communication
  - Synthesis of NT is in the varicosity

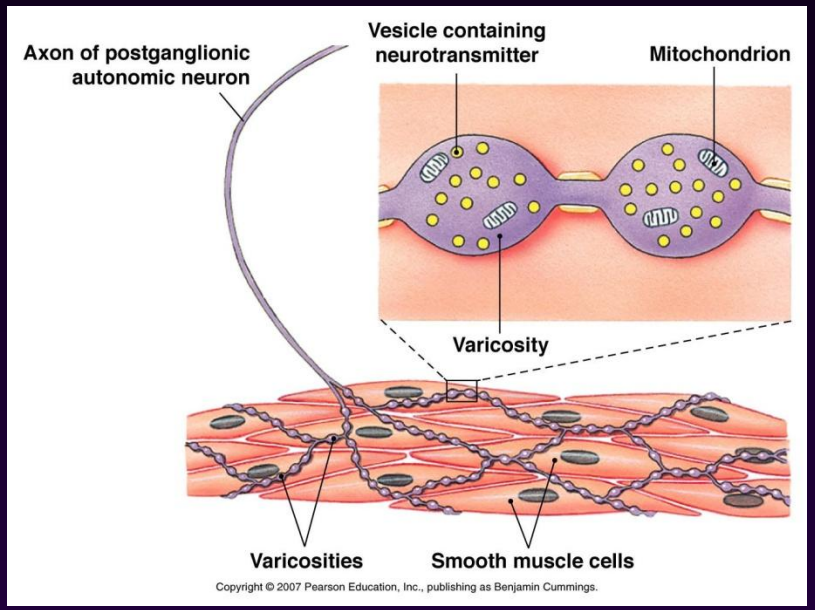
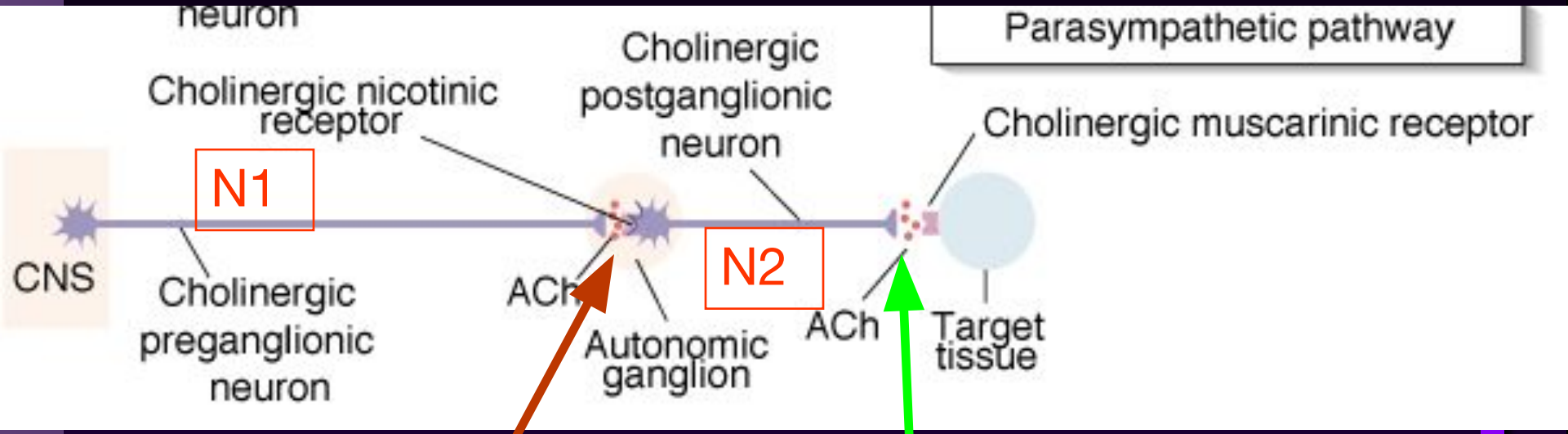


Fig 11-8

Summary: Pre- & Postganglionic Parasympathetic Neurons Release ACh



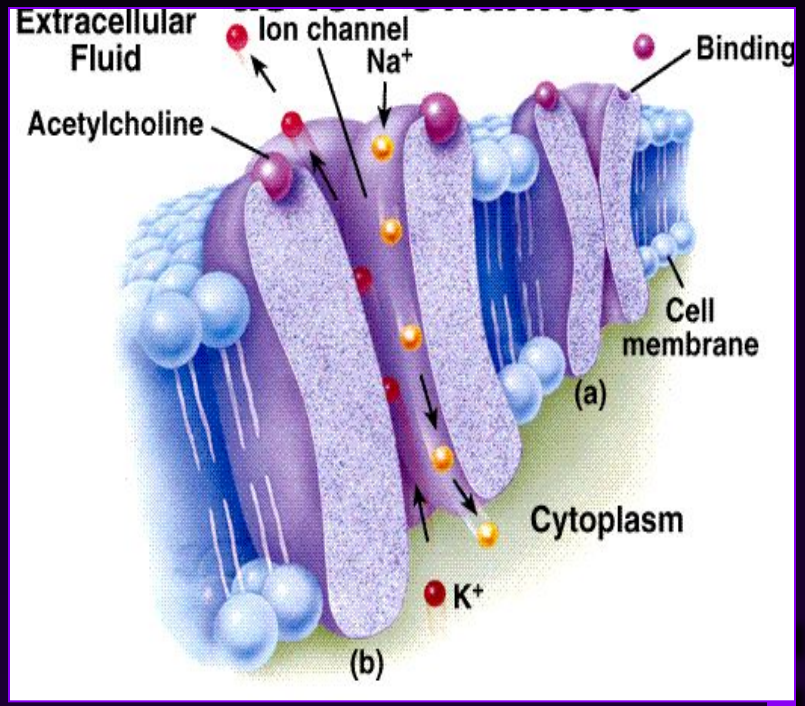
nicotinic

muscarinic

Receptor s

Two Types of Cholinergic Receptors: Nicotinic and Muscarinic

1) Nicotinic cholinergic receptor



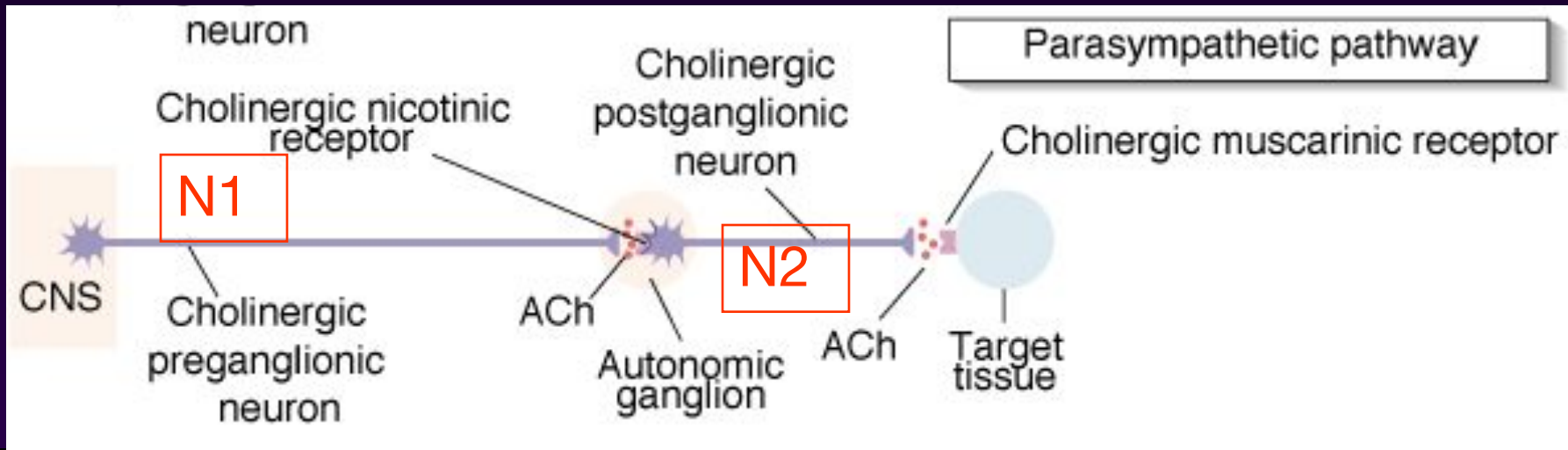
1. Nicotine = agonist
2. In autonomic ganglia & somatic NS
3. Directly opens a Na^+ & K^+ channel: ⇒ ?
4. Curare = antagonist

- When the neurotransmitter, acetylcholine, attaches to the portion of the nicotinic receptor outside of the cell wall, it induces a conformational change that selectively opens up the channel to sodium ions. The resulting influx of positively charged sodium then triggers membrane depolarization.

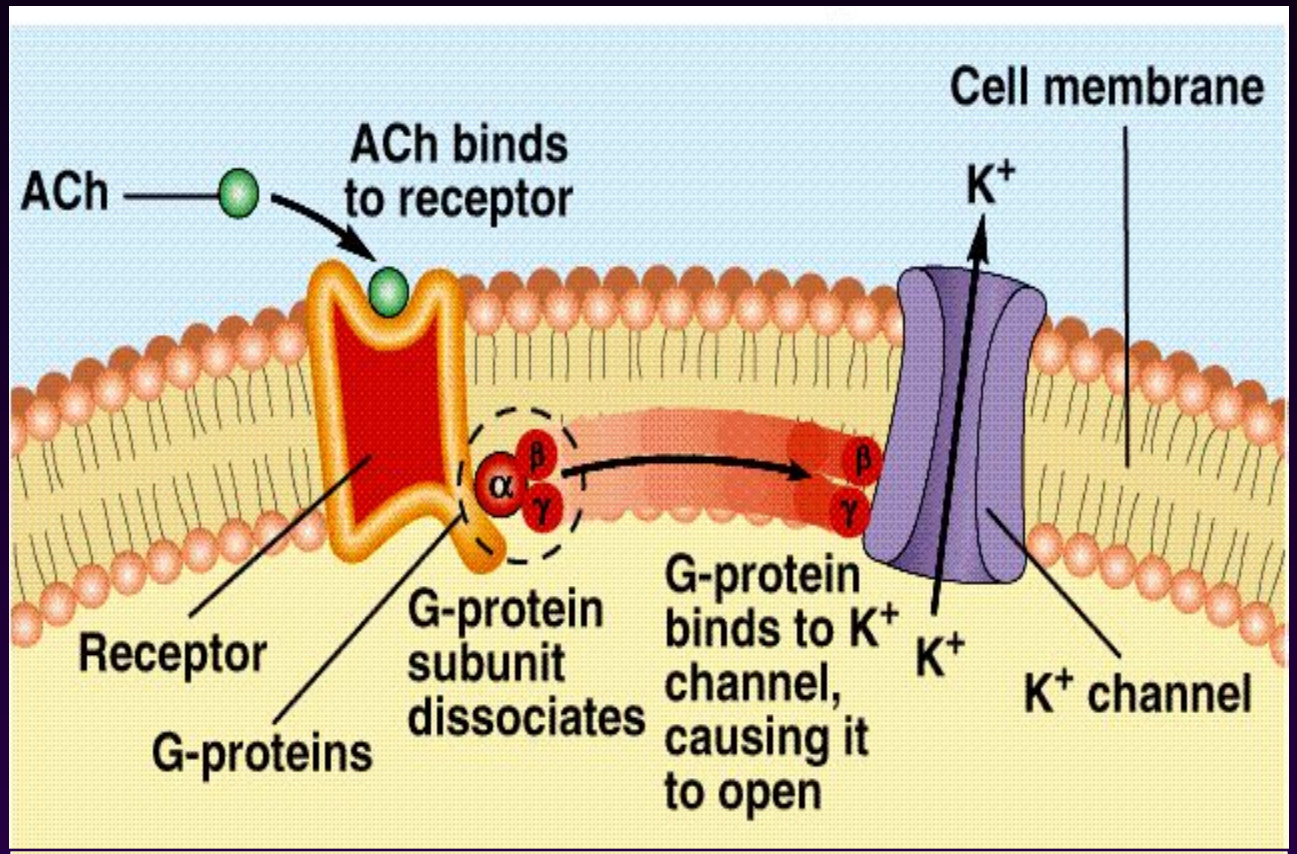
2) Muscarinic cholinergic receptor

Amanita muscarina

- Muscarine = agonist
- Found in neuro-effector junctions of parasympathetic branch
- G-protein coupled mechanisms
- Atropine = antagonist



Muscarinic ACh are G-protein Mediated Receptor Mechanism of Sweat Glands:

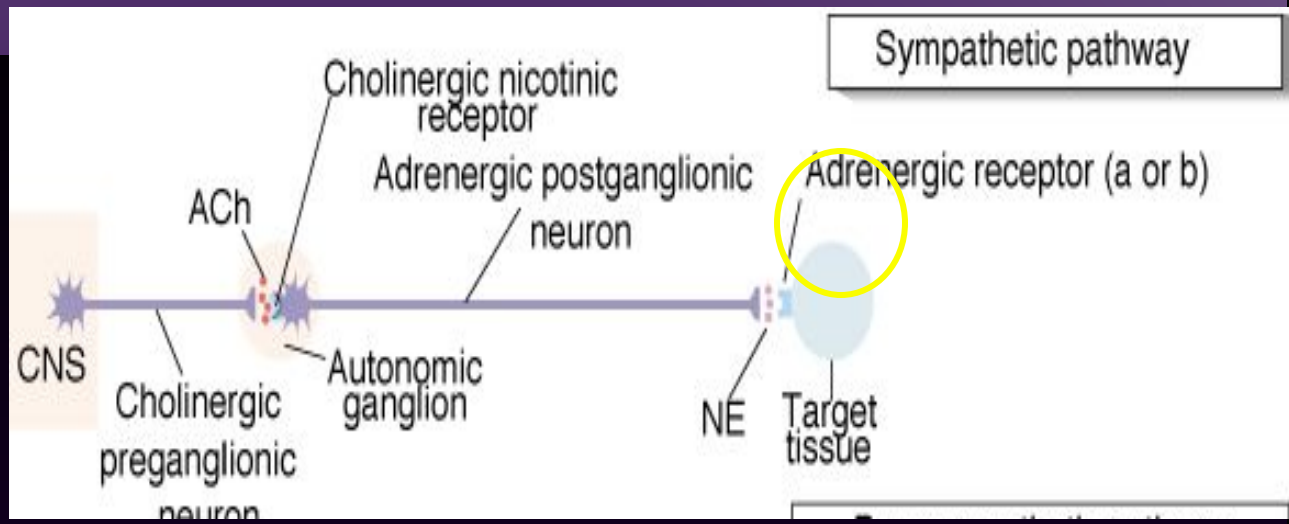


Also some 2nd messenger mechanisms

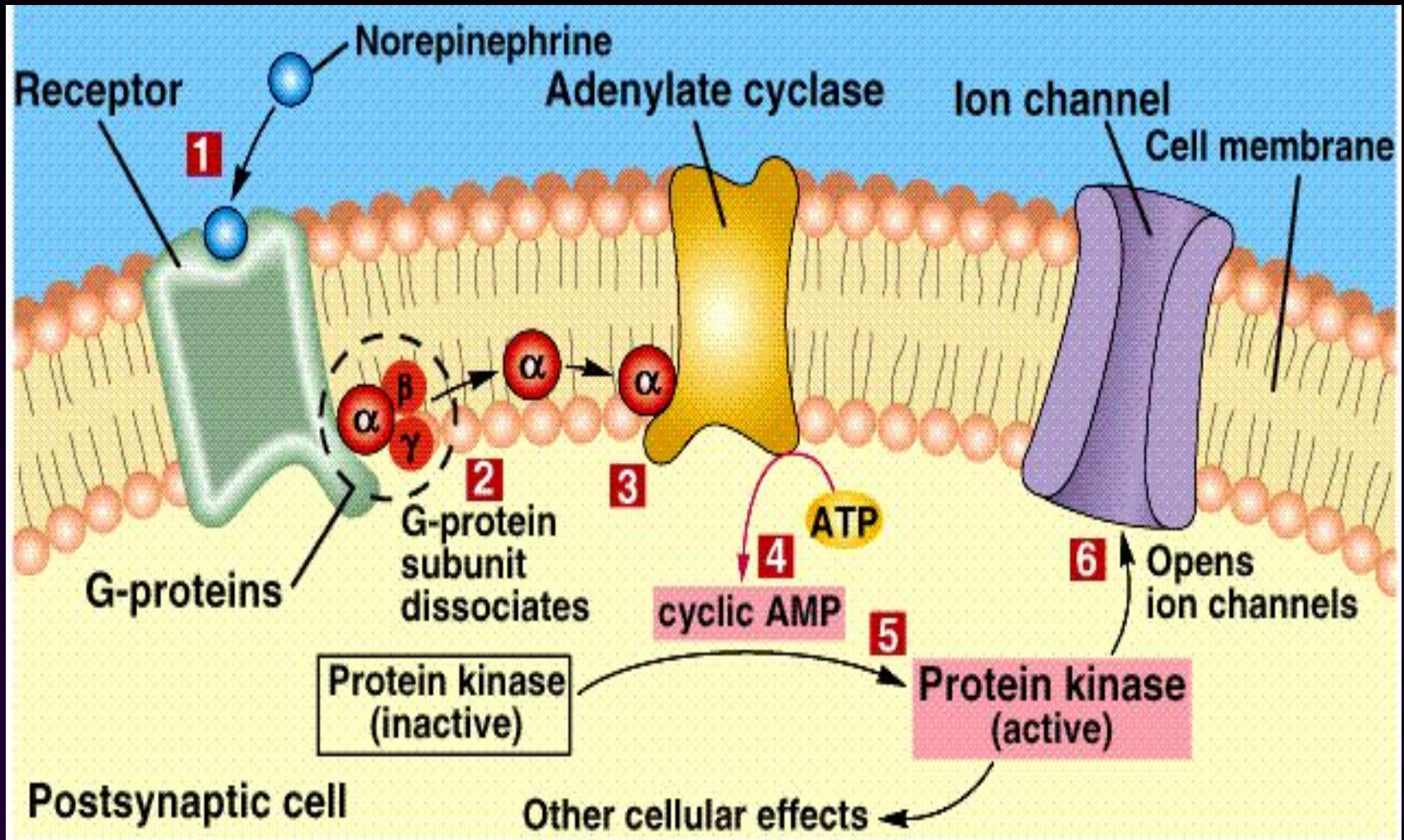
Note on G-Proteins:

- Many functions of the nervous system (e.g., memory) require prolonged changes in neurons after the initial neurotransmitter is gone. Ligand-gated channels (such as those found in nicotinic receptors) are not suitable for this because the channels close in milliseconds. Prolonged changes can be achieved, however by activating G-proteins inside the post-synaptic neuron. It is then the G-proteins that trigger the prolonged effects.

Adrenergic Receptors



- Found in neuroeffector junctions of sympathetic branch
- G protein linked, with various 2nd mess. Mech
- NT is NE
- α- and β- Receptors

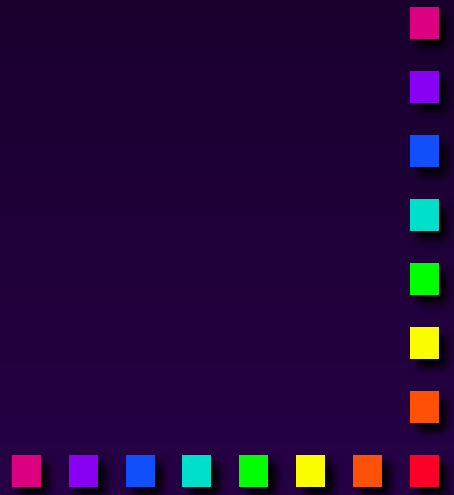


The binding of norepinephrine to it's receptor (1) causes the dissociation of G-proteins (2). Binding of the alpha G-protein subunit to the enzyme adenylate cyclase (3) activates this enzyme, leading to the production of cyclic AMP (4). Cyclic AMP, in turn, activates protein kinase (5), which can open ion channels (6) and produce other effects.

Sympathetic Receptors

α Receptors:

- NT is NE
- (most common) ⇒ **Excitation [Ca2+] In↑ ⇒ muscle contraction or secretion by exocytosis.**
- **⇒ Inhibition of GI tract and pancreas**



β – Receptors Clinically more important

- β_1 ⇒ **Excitation heart** ([E] = [NE])
  - **"β - blockers" = Antagonists** (e.g.: Propranolol)
- β_2 **usually inhibitory: smooth muscle relaxation of some blood vessels and bronchioles** ([E] > [NE])
- β_3 **Adipose; [NE]>[E]**
- **"β -blockers" = Antagonists** (e.g.: Propranolol)

Termination of NT Activity

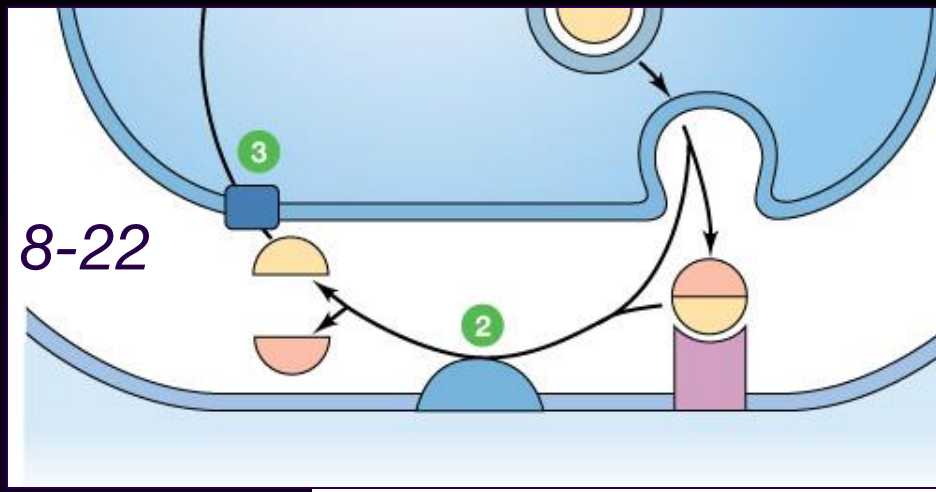


Fig 8-22

- ACh:
  - ACh esterase
- Catecholamine reuptake
  - repackaging
  - degradation (MAO)
  - Blocked by cocaine

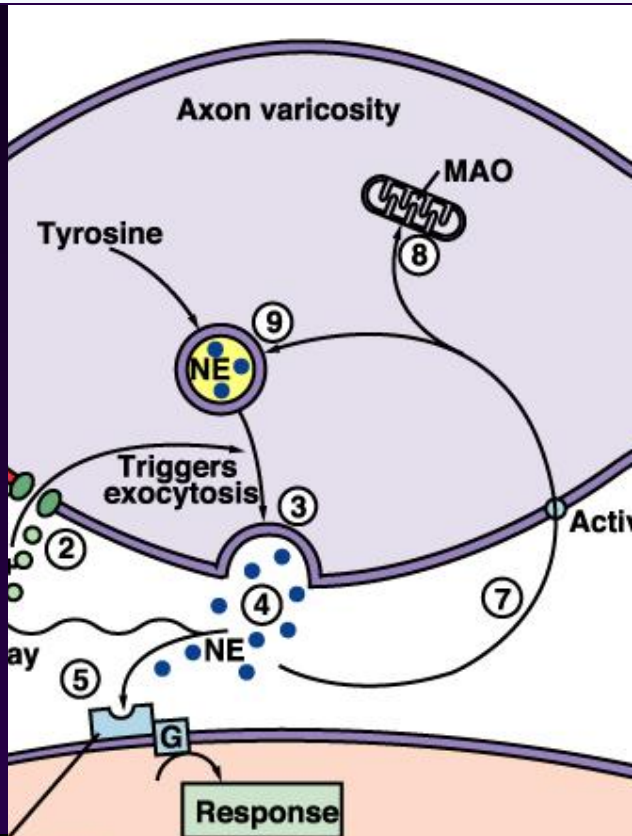


Fig 11-9

Somatic Motor Division

- Pathway consists of single neuron from CNS to target
- Neuromuscular junction: nicotinic cholinergic receptors
  - Similar to synapse; post – synaptic membrant called Motor End Plate
  - Recall Motor Unit
- Always excitatory ⇒ muscle contracts
- All Ach mediated
  - Degraded by Ach esterase

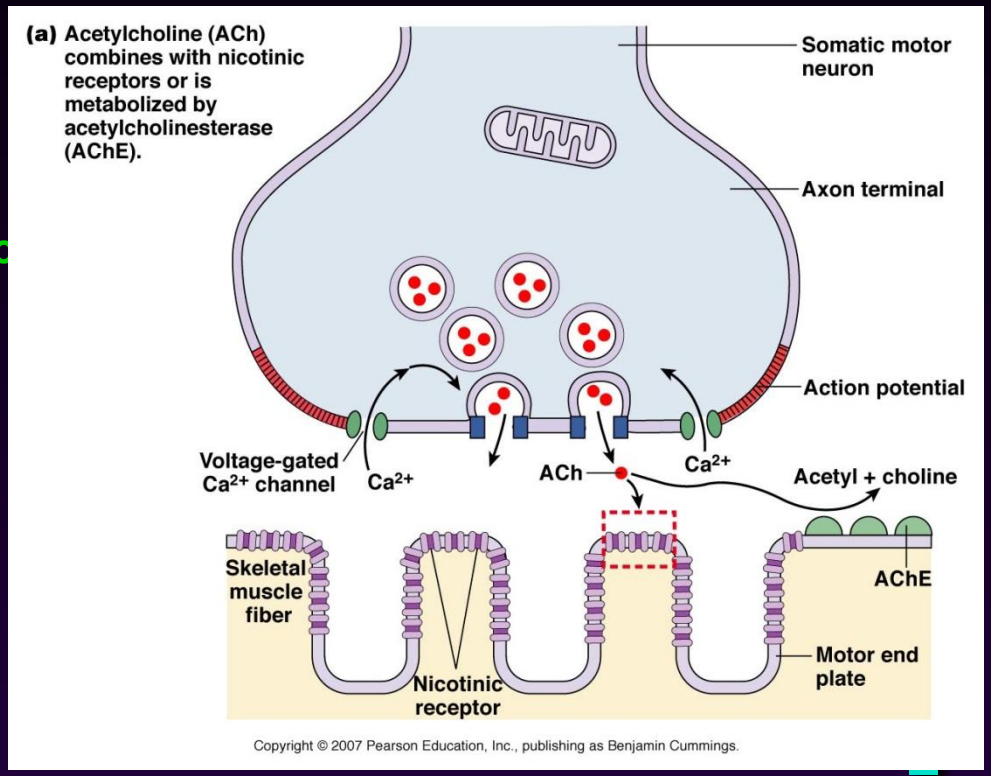


Fig 11-13

Myasthenia gravis

Table 11-3: Agonists and Antagonists of Neurotransmitter Receptors

RECEPTOR	AGONISTS	ANTAGONISTS	INDIRECT AGONISTS/ANTAGONISTS
Cholinergic	Acetylcholine		*AChE* inhibitors*: neostigmine, parathion *Inhibit ACh release*: botulinus toxin
Muscarinic	Muscarine	Atropine, scopolamine	
Nicotinic	Nicotine	α-bungarotoxin (muscle only), tetraethylammonium (TEA) (ganglia only), curare	
Adrenergic	Norepinephrine, epinephrine		*Stimulate NE release*: ephedrine, amphetamines *Prevent NE uptake*: cocaine
Alpha (α)	Phenylephrine	"Alpha-blockers"	
Beta (β)	Isoproterenol	"Beta-blockers": propranolol (β_1 and β_2), metoprolol (β_1 only)	

* AChE = acetylcholinesterase.

MG: Antibodies block, alter, or destroy the receptors for acetylcholine at the neuromuscular junction

Direct (Ant)agonist = mimic or block the NT receptor
(Ant)agonist = mimic or block secretion, reuptake or degradation of NT

TABLE 11-3 Agonists and Antagonists of Neurotransmitter Receptors

RECEPTOR TYPE	NEUROTRANSMITTER	AGONIST	ANTAGONISTS	INDIRECT AGONISTS/ANTAGONISTS
Cholinergic	Acetylcholine			AChE* *inhibitors:* neostigmine,
Muscarinic		Muscarine	Atropine, scopolamine	
Nicotinic		Nicotine	α-bungarotoxin (muscle only), TEA (tetraethylammonium; ganglia only), curare	
Adrenergic	Norepinephrine (NE), epinephrine			*Stimulate NE release:* ephedrine, amphetamines *Prevents NE uptake:* cocaine
Alpha		Phenylephrine	"Alpha-blockers"	
Beta		Isoproterenol	"Beta-blockers": propranolol (β_1 and β_2), metoprolol (β_1 only)	

*AChE = acetylcholinesterase.

Direct **Antagonists**

- **Atropine** → muscarinic
- Curare → nicotinic
- Propranolol → β_1 and β_2
- Metoprolol → β_1

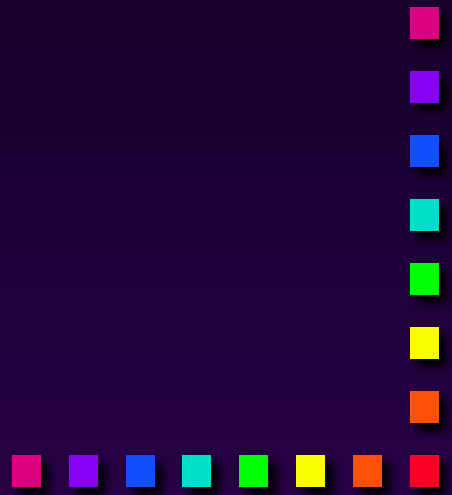
Strychnos Toxifera (Curare) from *Koehler's Medicinal-Plants* 1887

Indirect (Ant)agonists

- Botulinum toxin
  - → inhibits ACh release
- Parathion, malathion
  - organophosphate insecticides → inhibit AChE (anticholinesterases)
- Cocaine
  - → prevents NE reuptake
- Amphetamines
  - → stimulates NE release

Comparison of the two divisions

- Important physiological and functional differences exist



Overview: The ANS

TABLE 11-4 Comparison of Sympathetic and Parasympathetic Branches

	SYMPATHETIC	PARASYMPATHETIC
Point of CNS origin	1st thoracic to 2nd lumbar segments	Midbrain, medulla, and 2nd–4th sacral segments
Location of peripheral ganglia	Primarily in paravertebral sympathetic chain; 3 outlying ganglia located alongside descending aorta	On or near target organs
Structure of region from which neurotransmitter is released	Varicosities	Varicosities and axon terminals
Neurotransmitter at target synapse	Norepinephrine (adrenergic neurons)	ACh (cholinergic neurons)
Inactivation of neurotransmitter at synapse	Uptake into varicosity, diffusion	Enzymatic breakdown, diffusion
Neurotransmitter receptors on target cells	α and β	Muscarinic
Ganglionic synapse	ACh on nicotinic receptor	ACh on nicotinic receptor
Neuron-target synapse	NE on α- or β-receptor	ACh on muscarinic receptor

Table 11-4

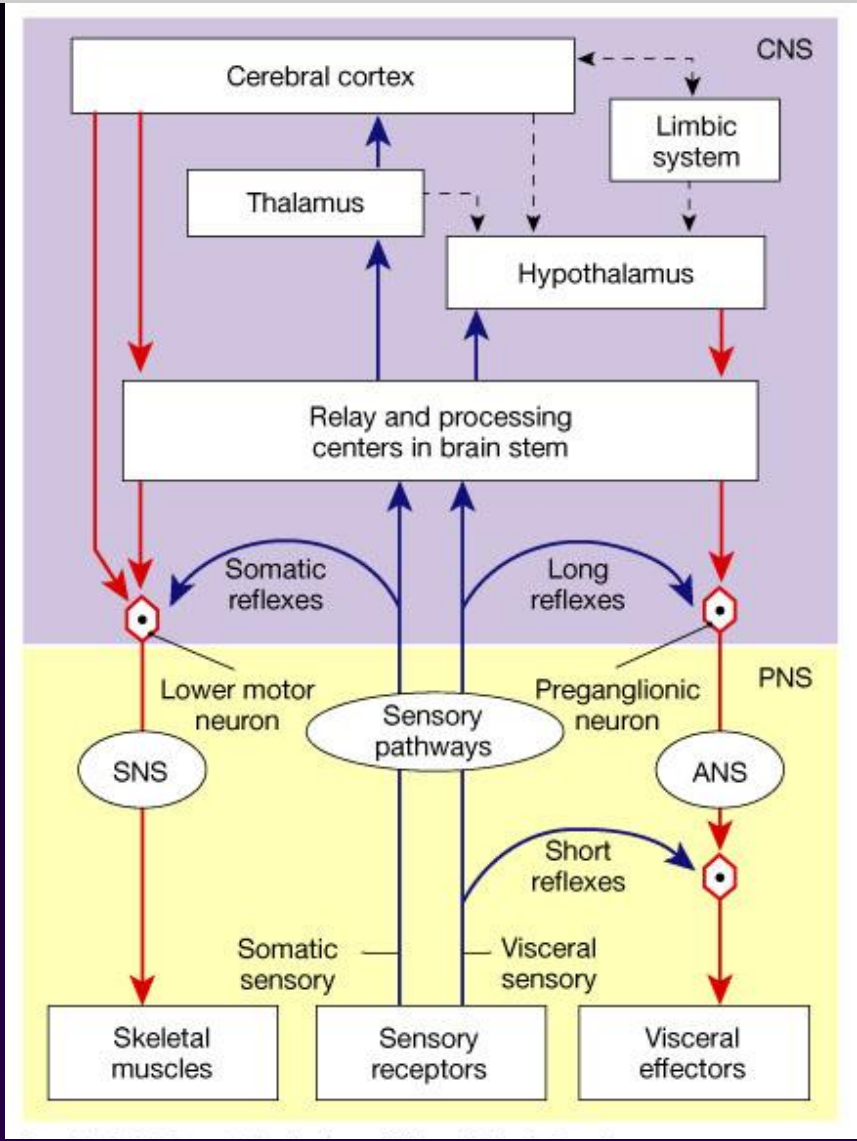
Overview: The ANS

Compare the somatic motor pathway to the parasympathetic and sympathetic motor pathways

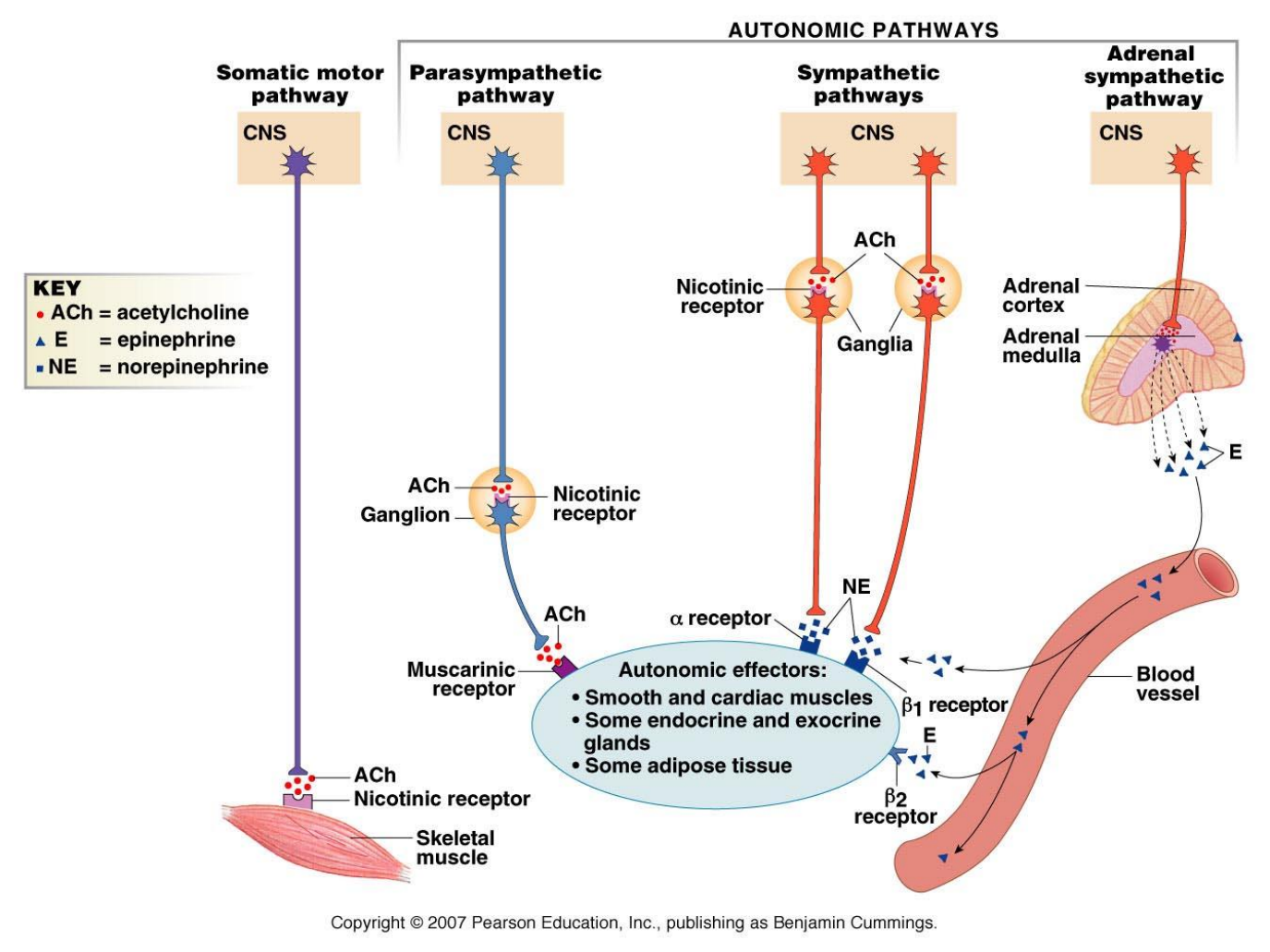
TABLE 11-5 Comparison of Somatic and Autonomic Divisions

	SOMATIC	AUTONOMIC
Number of neurons in efferent path	1	2
Neurotransmitter/receptor at neuron-target synapse	ACh/nicotinic	ACh/muscarinic or NE/α or β
Target tissue	Skeletal muscle	Smooth and cardiac muscle; some endocrine and exocrine glands; some adipose tissue
Neurotransmitter released from	Axon terminals	Varicosities and axon terminals
Effects on target tissue	Excitatory only: muscle contracts	Excitatory or inhibitory
Peripheral components found outside the CNS	Axons only	Preganglionic axons, ganglia, postganglionic neurons
Summary of function	Posture and movement	Visceral function, including movement in internal organs and secretion; control of metabolism

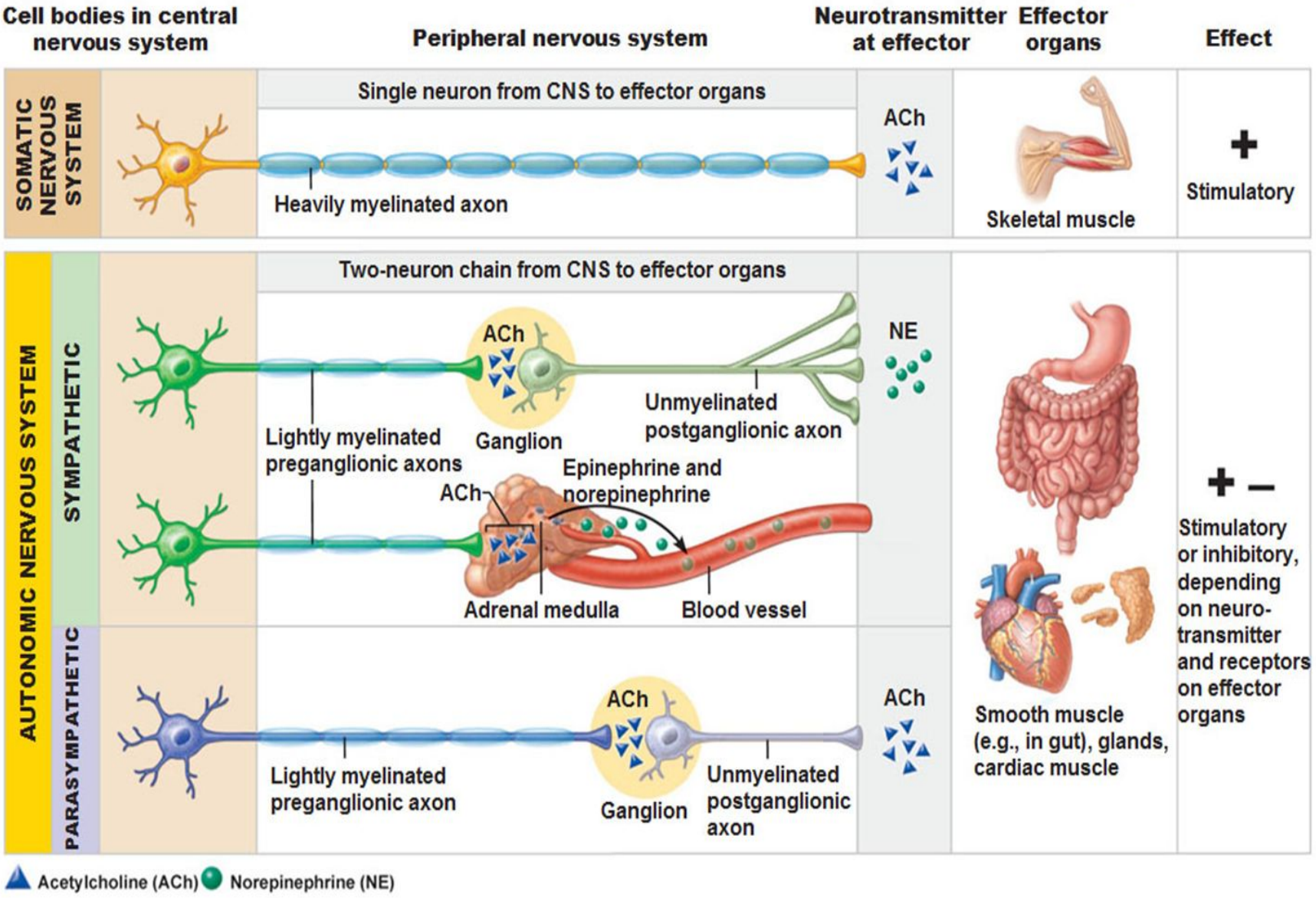
A Comparison of Somatic and Autonomic Function



Summary of Efferent NS



Comparison of Autonomic and Somatic Motor Systems

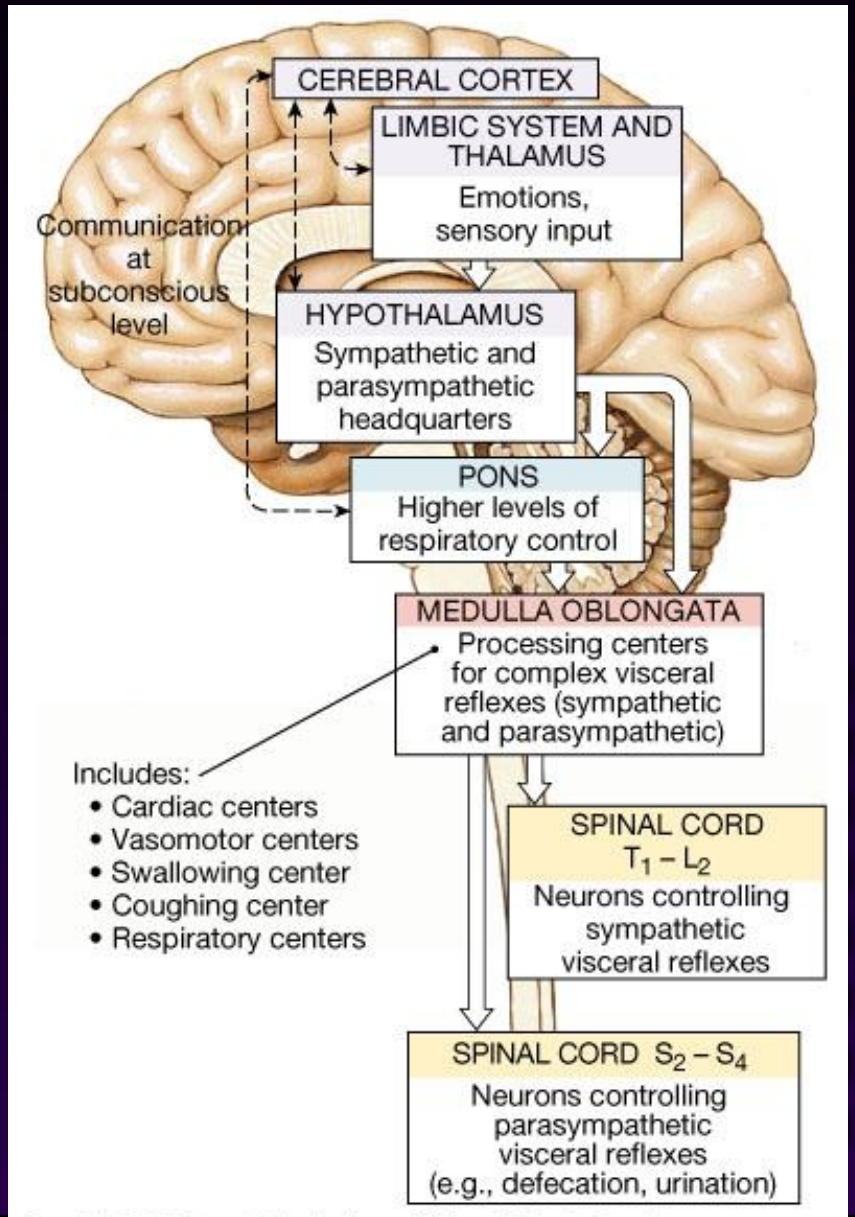


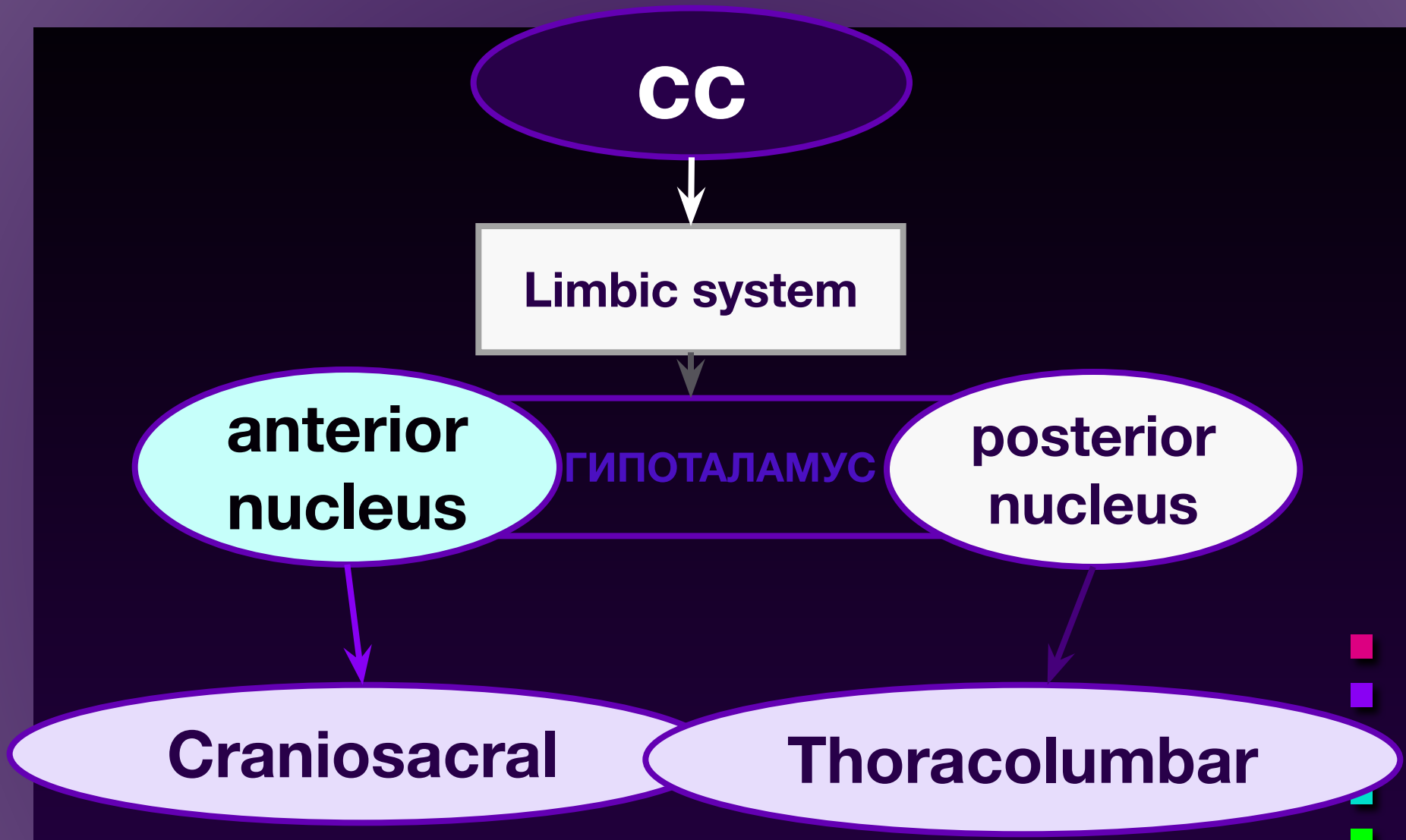
Higher levels of autonomic control

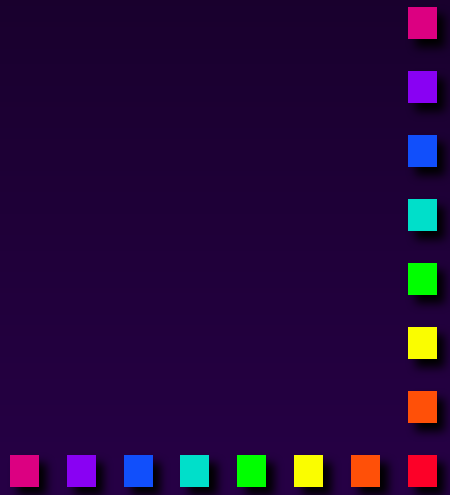
- Activity in the ANS is controlled by centers in the brainstem that deal with visceral functioning

Levels of Autonomic Control

Example of higher-level of autonomic function would be increased heart rate when you see a person that you dislike.

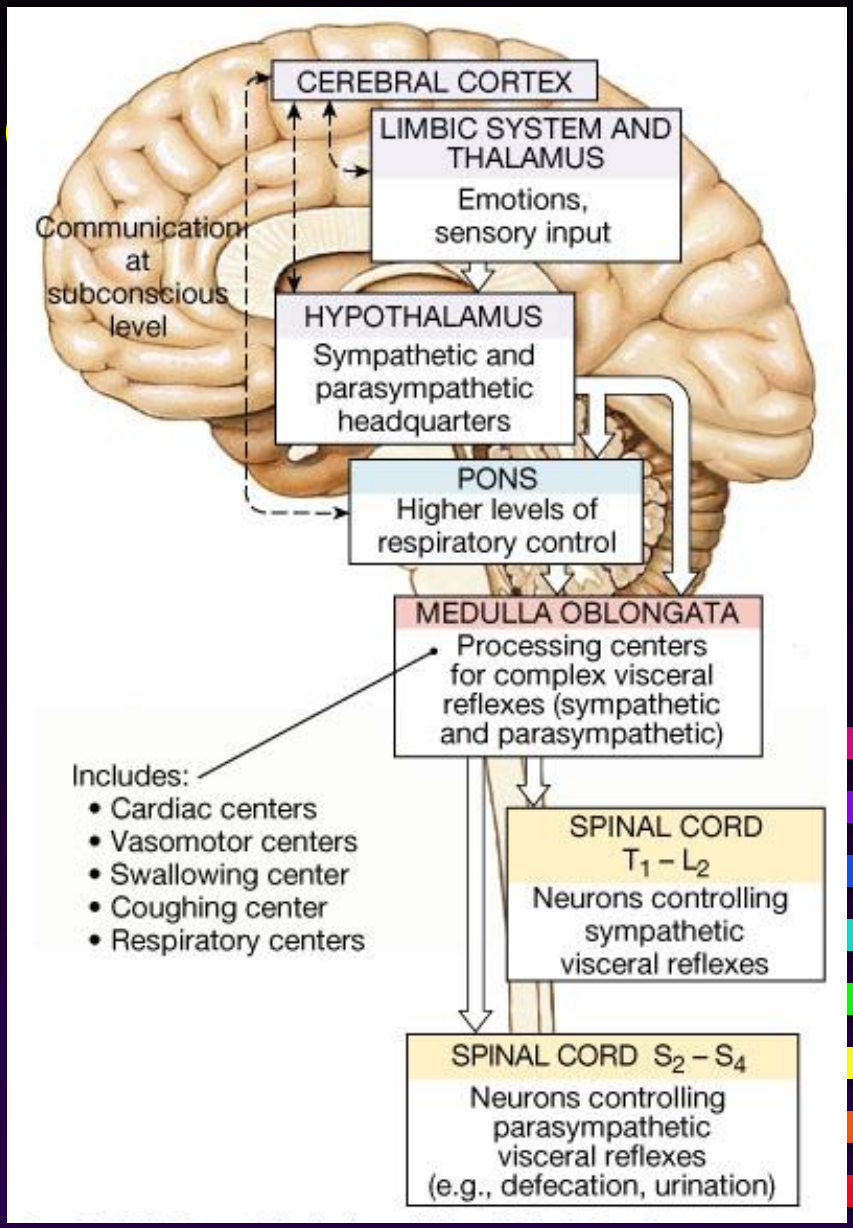



CC
Limbic system
anterior nucleus
ГИПОТАЛАМУС
posterior nucleus
Craniosacral
Thoracolumbar



Levels of Auton

Example of higher-level of autonomic function would be increased heart rate when you see a person that you dislike.



Visceral Afferents and Referred Pain