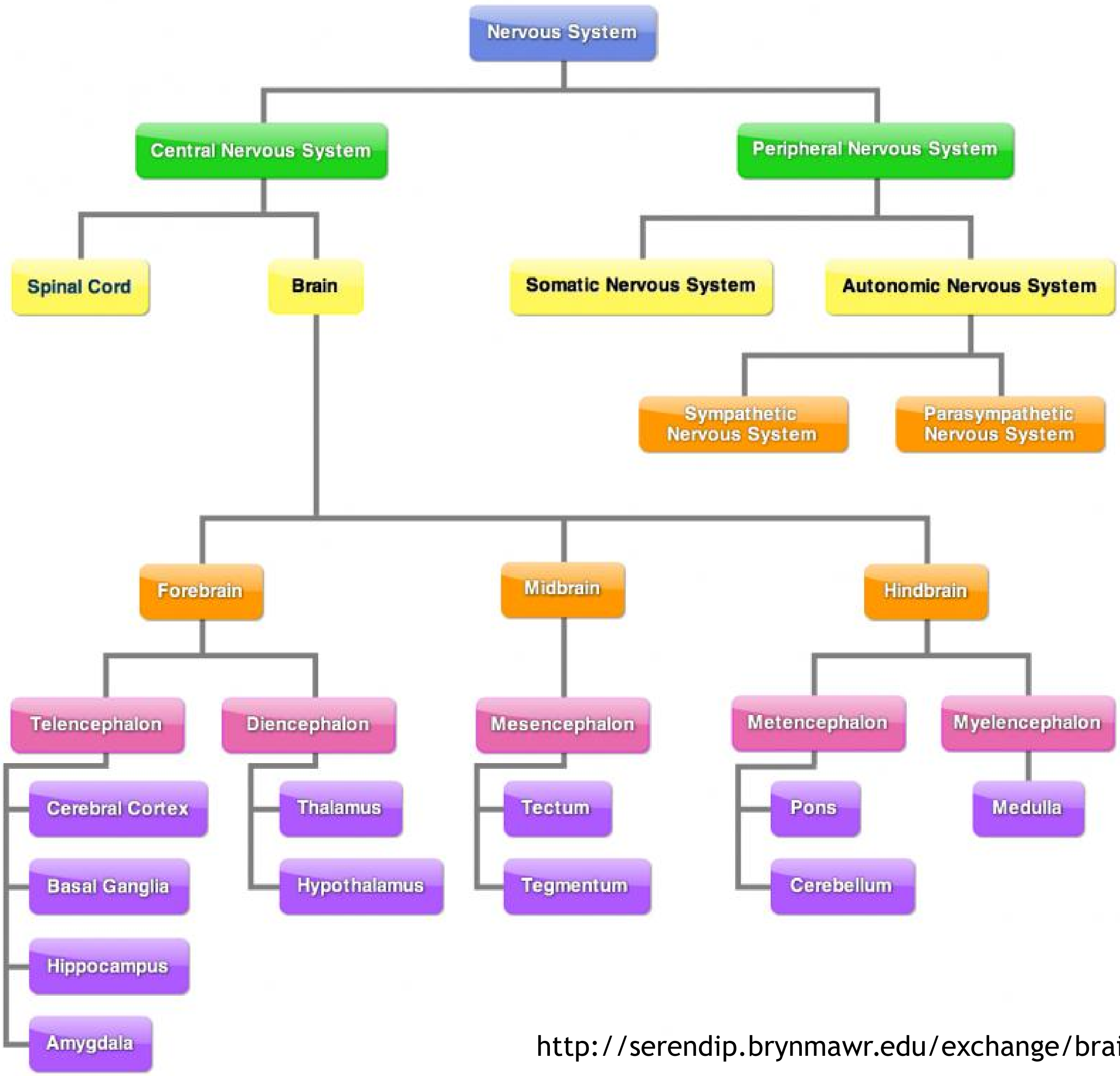
Lecture 11 and 12 – Autonomic nervous system

Material for lecture is from the following links
1) http://www.ib.cnea.gov.ar/~redneu/2013/BOOKS/Principles%20of%20Neural%20Science%20-%20Kandel/gateway.ut.ovid.com/gw2/ovidweb.cgisidnjhkoalgmeho00dbookimagebookdb_7c_2fc~57.htm
2) Links provided at the bottom of the slide

Raghav Rajan
Bio 354 – Neurobiology 2
February 11th 2015

Divisions of the nervous system



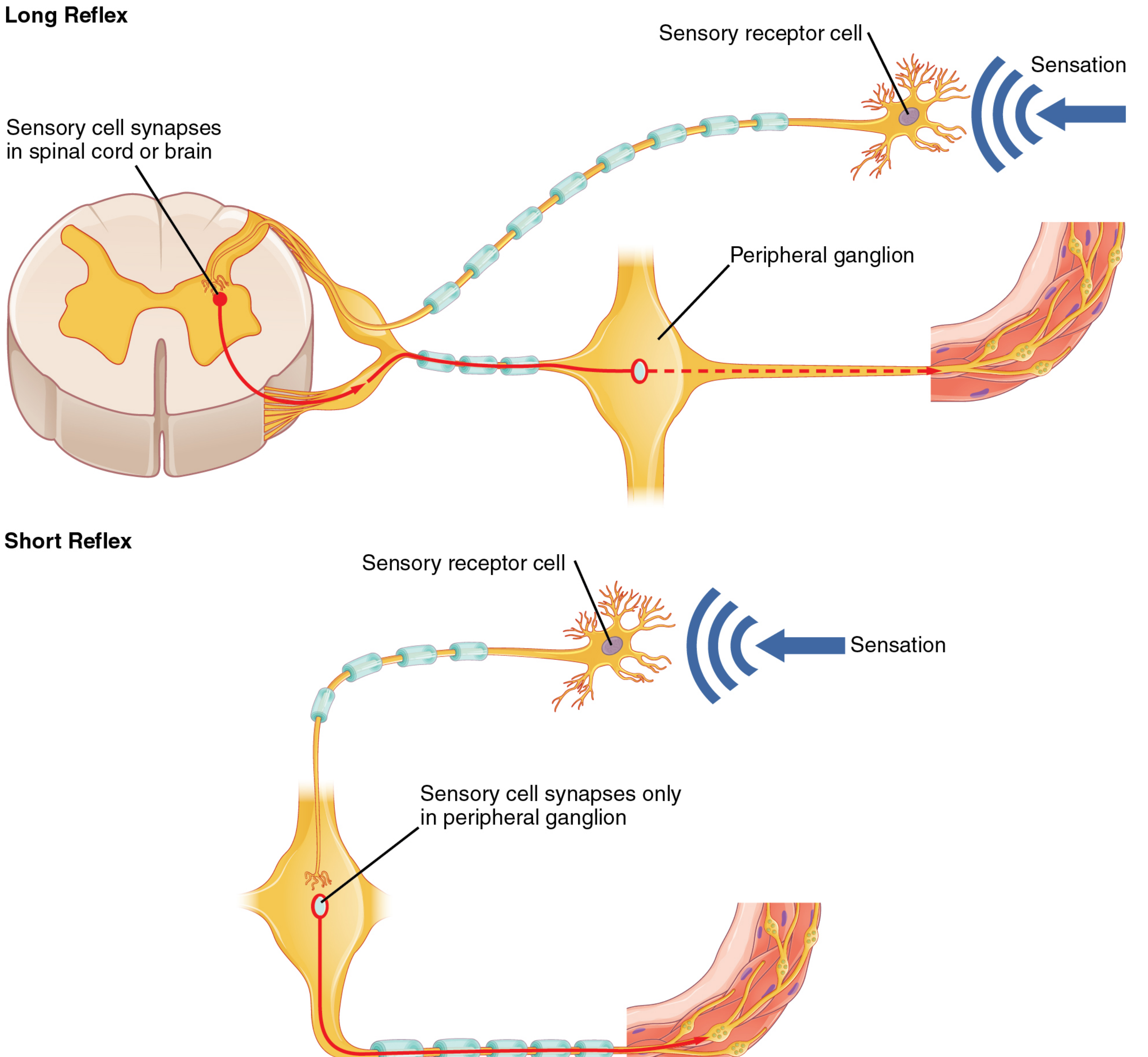
http://serendip.brynmawr.edu/exchange/brains/structures

What is the function of the autonomic nervous system?

- “Fight or Flight”
-
- Largely co-ordinates visceral and reflexive actions
- Mostly not under conscious control (there are exceptions)
- Senses the internal environment of the body and acts accordingly
  - Consists of both visceral sensory and motor neurons
- Also called “involuntary nervous system”

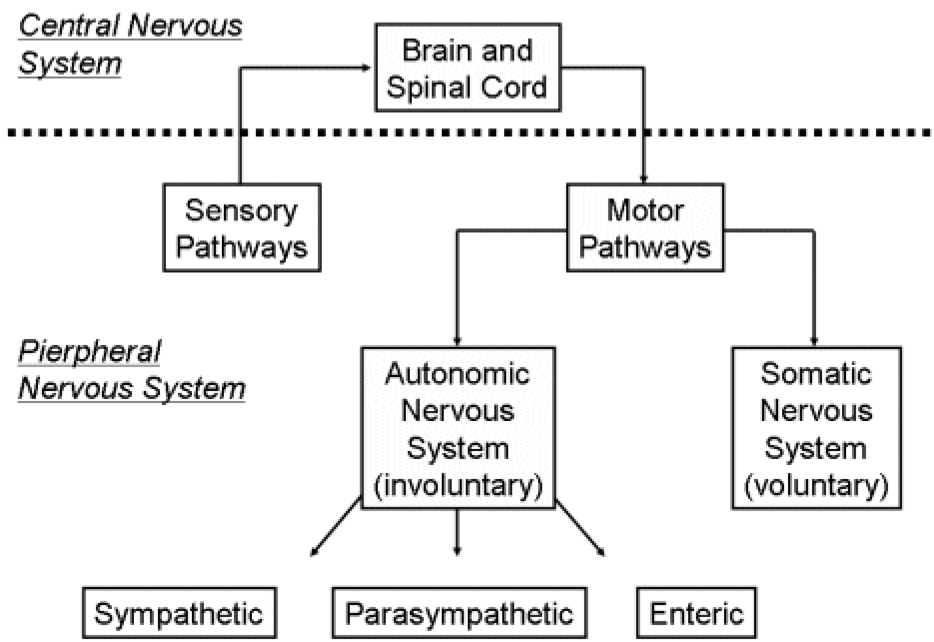
Somatic and Autonomic reflexes

- Differ in the involvement of CNS
- Differ in the targets



https://voer.edu.vn/m/autonomic-reflexes-and-homeostasis/0058b664

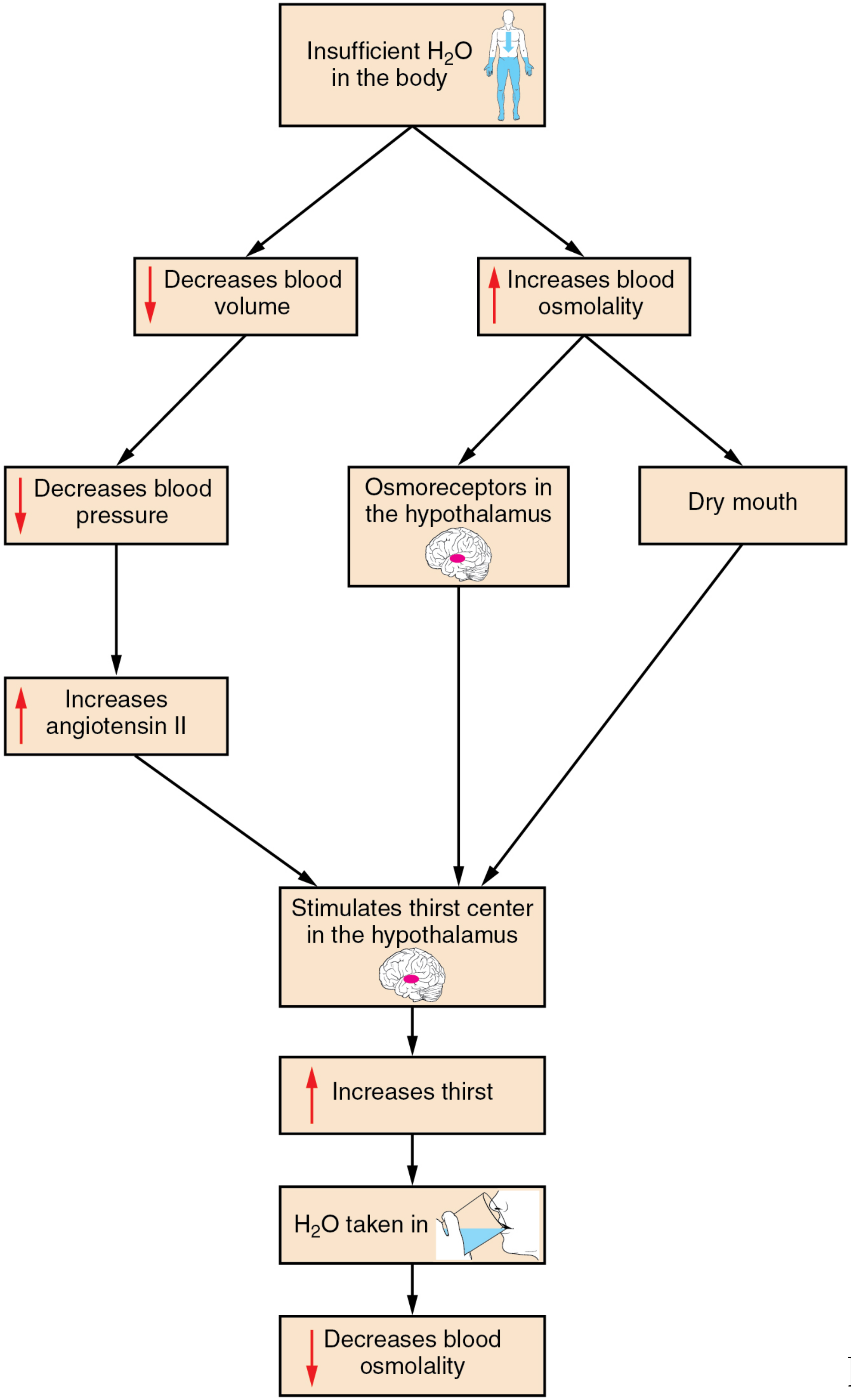
Autonomic nervous system had 3 sub-divisions



- Sympathetic - “Fight or Flight” (Walter Cannon)
- Parasympathetic - “Rest and digest” (Walter Cannon)
- “Homeostasis” - main function to maintain constant internal environment (negative feedback regulation)
- Hypothalamus is the “boss”
- Enteric – related to the gut and mediates digestive reflexes
  - More independent than the other two
  - Very few connections to the rest of the nervous system

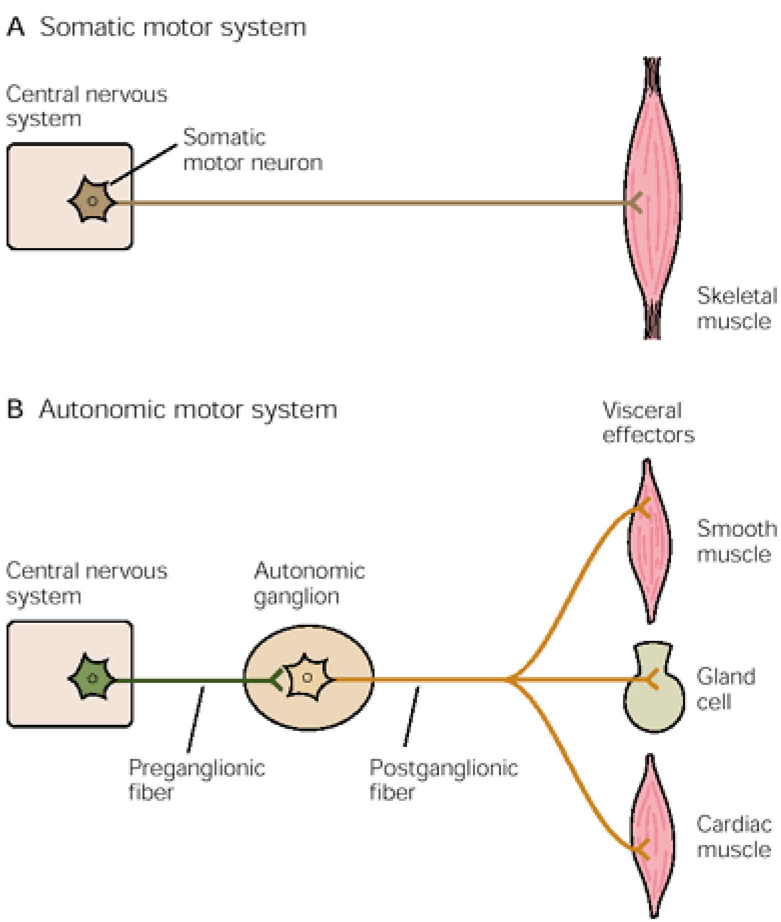
http://faculty.clintoncc.suny.edu/faculty/michael.gregory/files/bio%20102/bio%20102%20lectures/nervous%20system/nervous1.htm

An example of autonomic nervous system function Regulation of water in the body - thirst



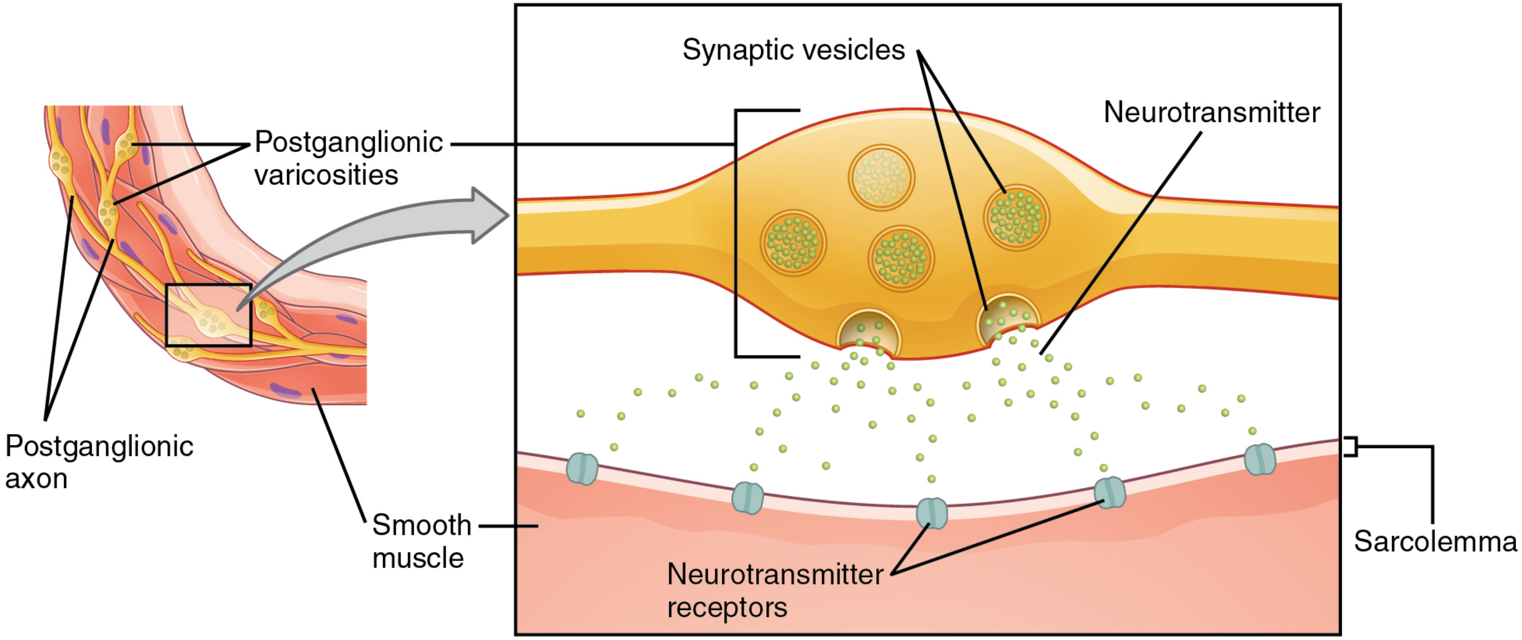
https://voer.edu.vn/c/water-balance/948ed3b1/04a5f05f

Differences between somatic and autonomic motor systems : 1) location of motor neuron



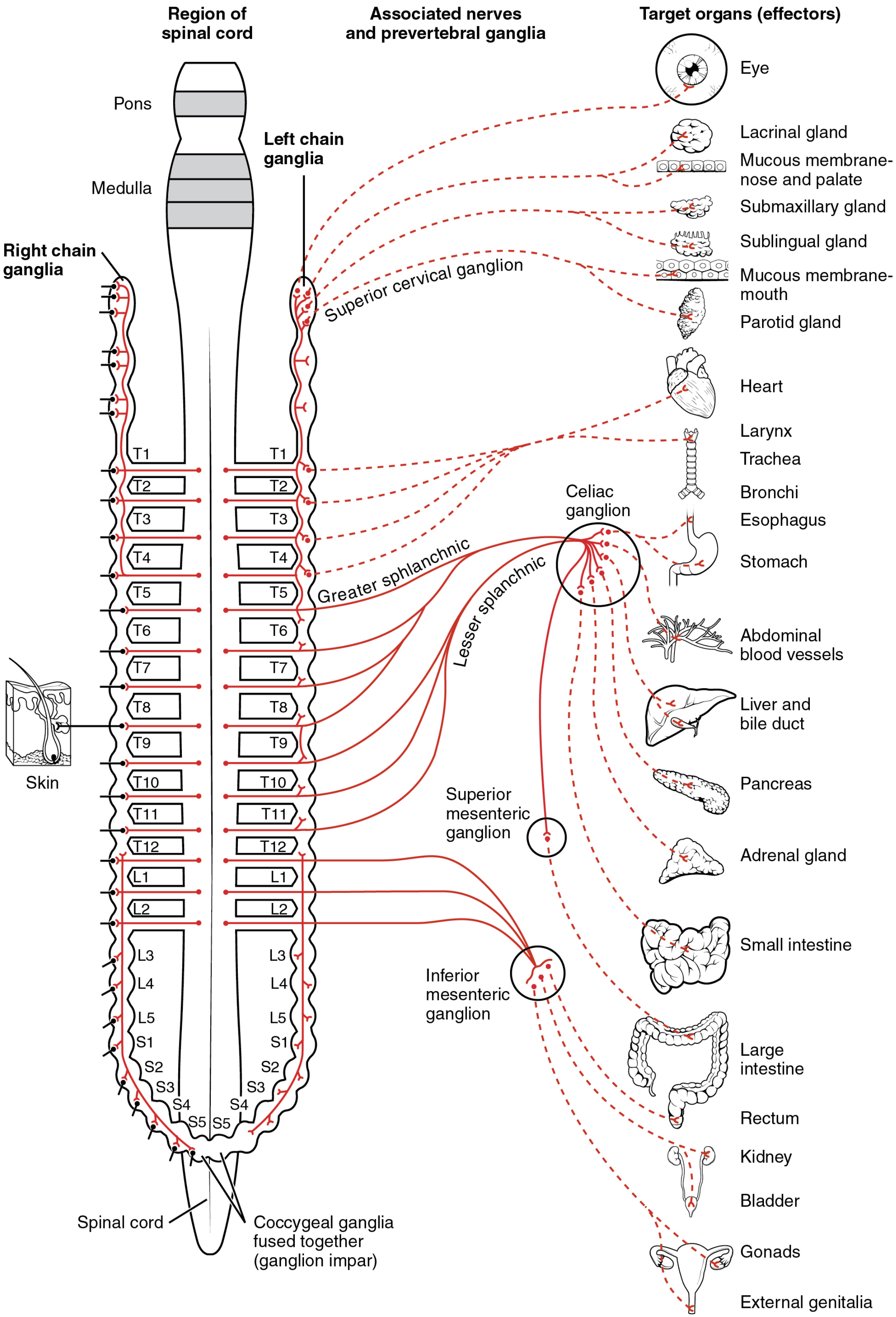
- Motor neurons of autonomic nervous system are outside CNS
  - Preganglionic fiber from CNS
  - Postganglionic fiber to target
- One extra synapse in the path from CNS to peripheral target – autonomous nervous system

Differences between somatic and autonomic motor systems : 2) synaptic terminals



- Nerve endings that don't have pre-synaptic boutons
- Rather, presence of multiple varicosities along the length – mutliple release sites

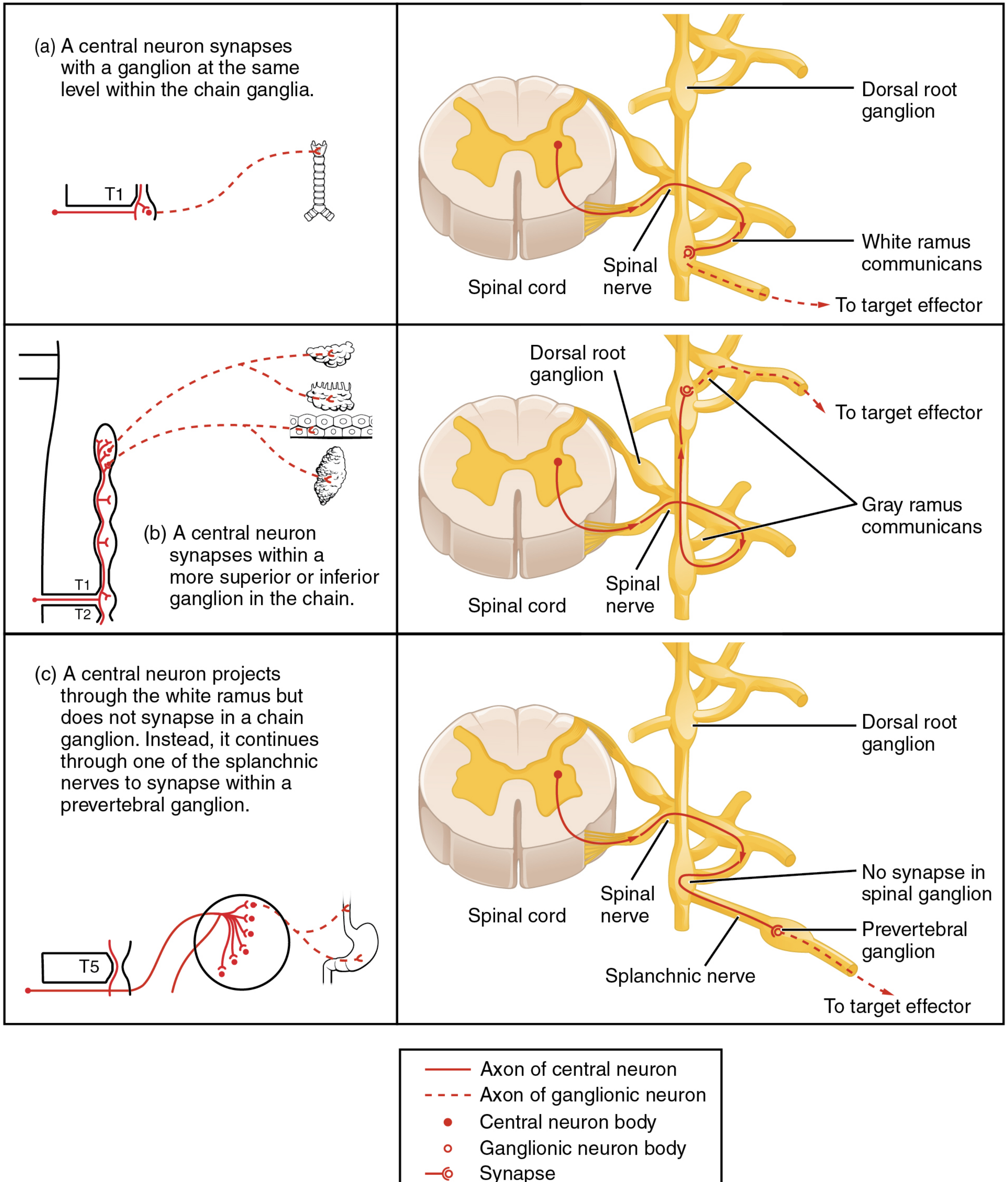
- Small number of fibers providing diffuse innervation – longer range effect than normal neurotransmitters



Organisation of sympathetic nervous system

- Thoracolumbar system
- Originates from thoracic and upper lumbar spinal cord
- Chain of ganglia next to the spinal cord
  - Exceptions – 3 ganglia that control the gut
- Pre-ganglionic fibers – short, myelinated
- Post-ganglionic fibers – long, unmyelinated

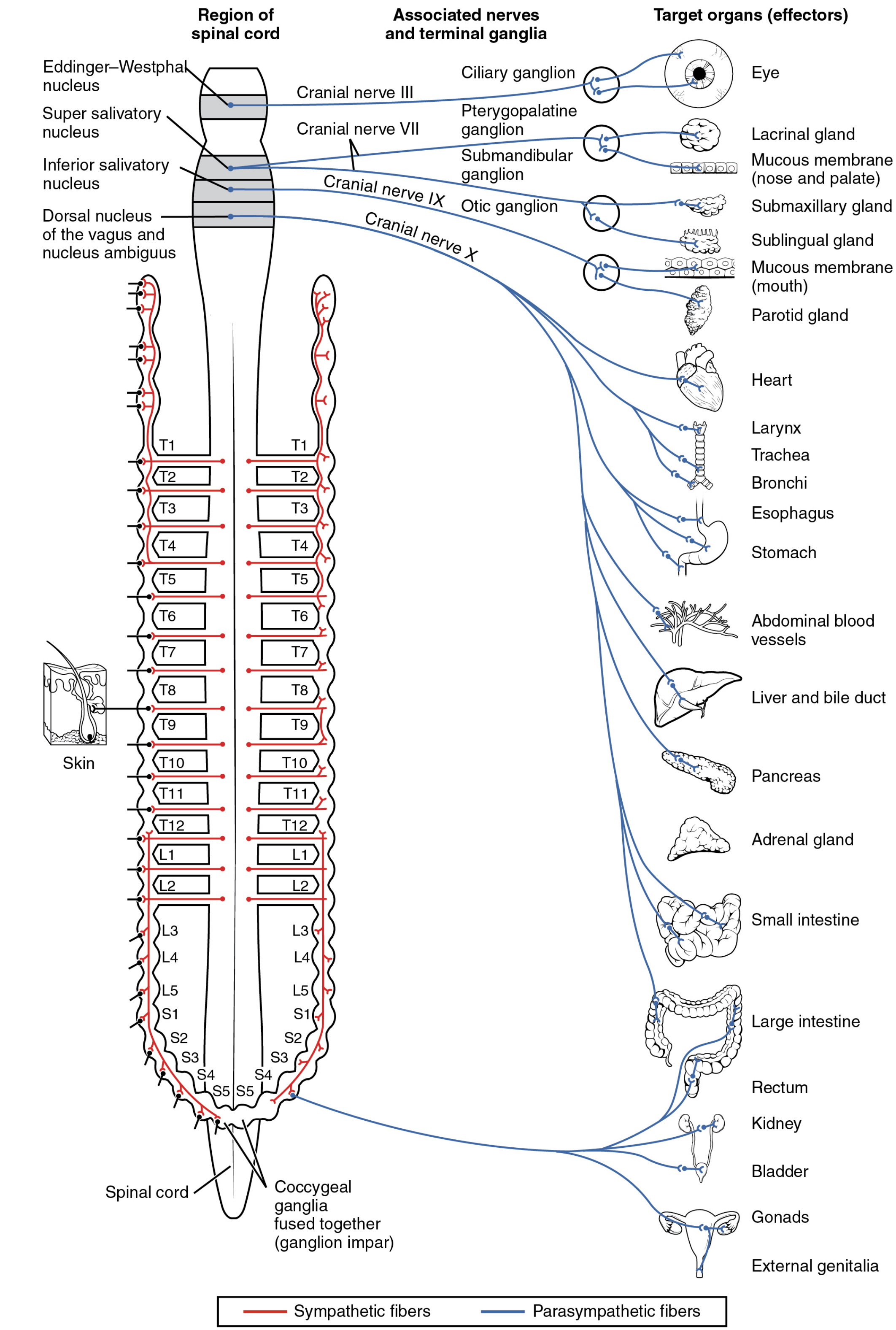
https://voer.edu.vn/m/divisions-of-the-autonomic-nervous-system/1121e1d0#tbl-ch15_01



Organisation of projections to sympathetic system

- 3 major types
- Depends on origin and target or projection

https://voer.edu.vn/m/divisions-of-the-autonomic-nervous-system/1121e1d0#tbl-ch15_01

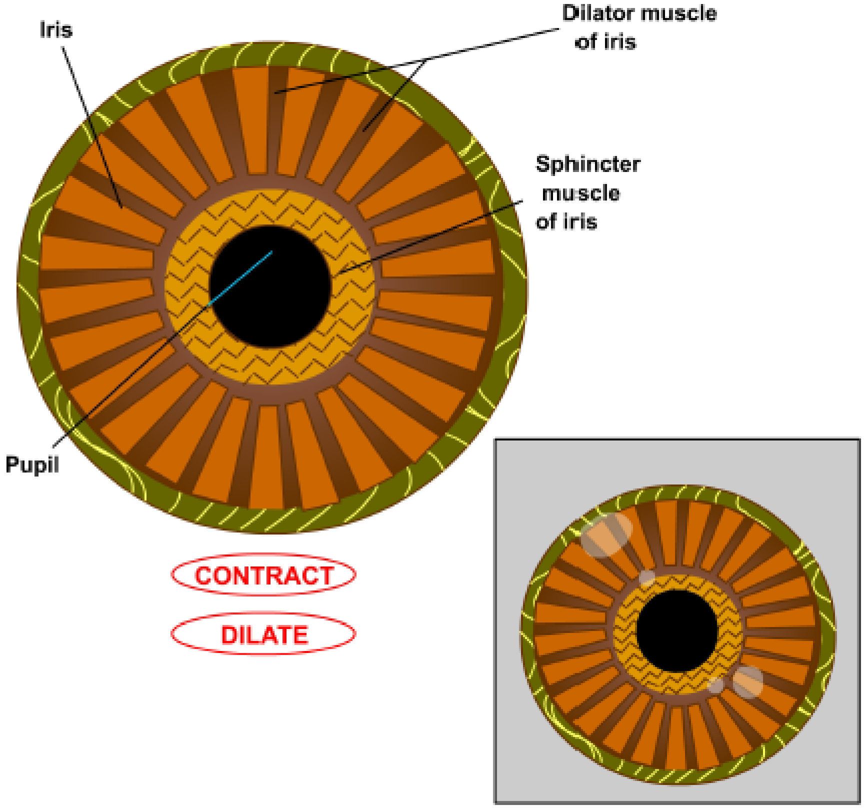


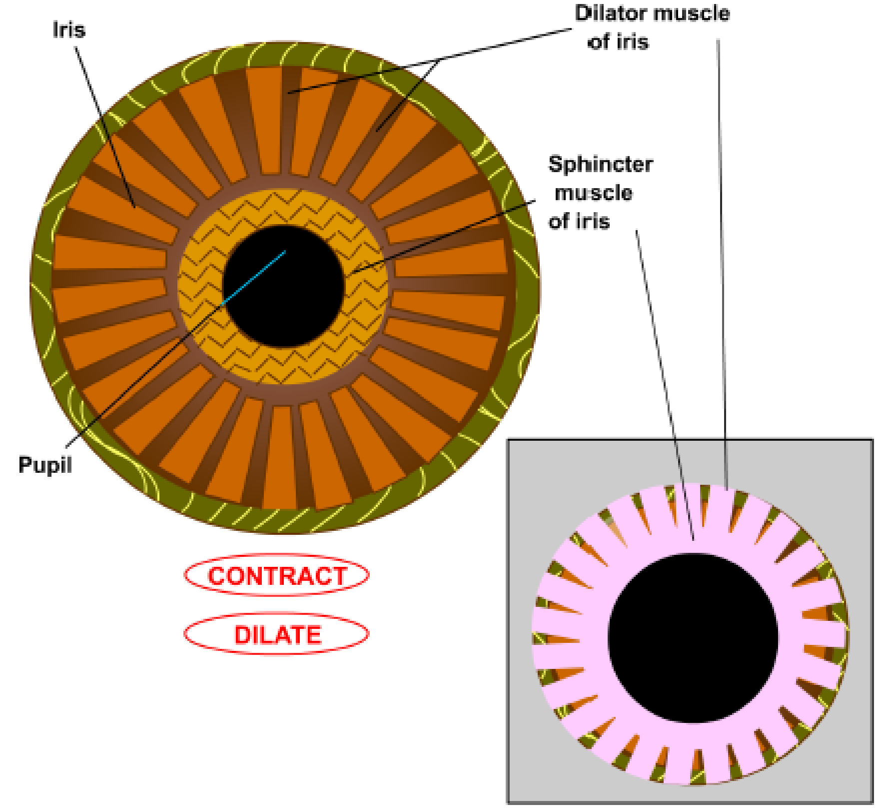
Organisation of parasympathetic nervous system

- Craniosacral system
- Cranial and spinal nerves – origins or preganglionic fibers
- Ganglia are close to targets or within targets
- Preganglionic fibers – long
- Postganglionic fibers - short

https://voer.edu.vn/m/divisions-of-the-autonomic-nervous-system/1121e1d0#tbl-ch15_01

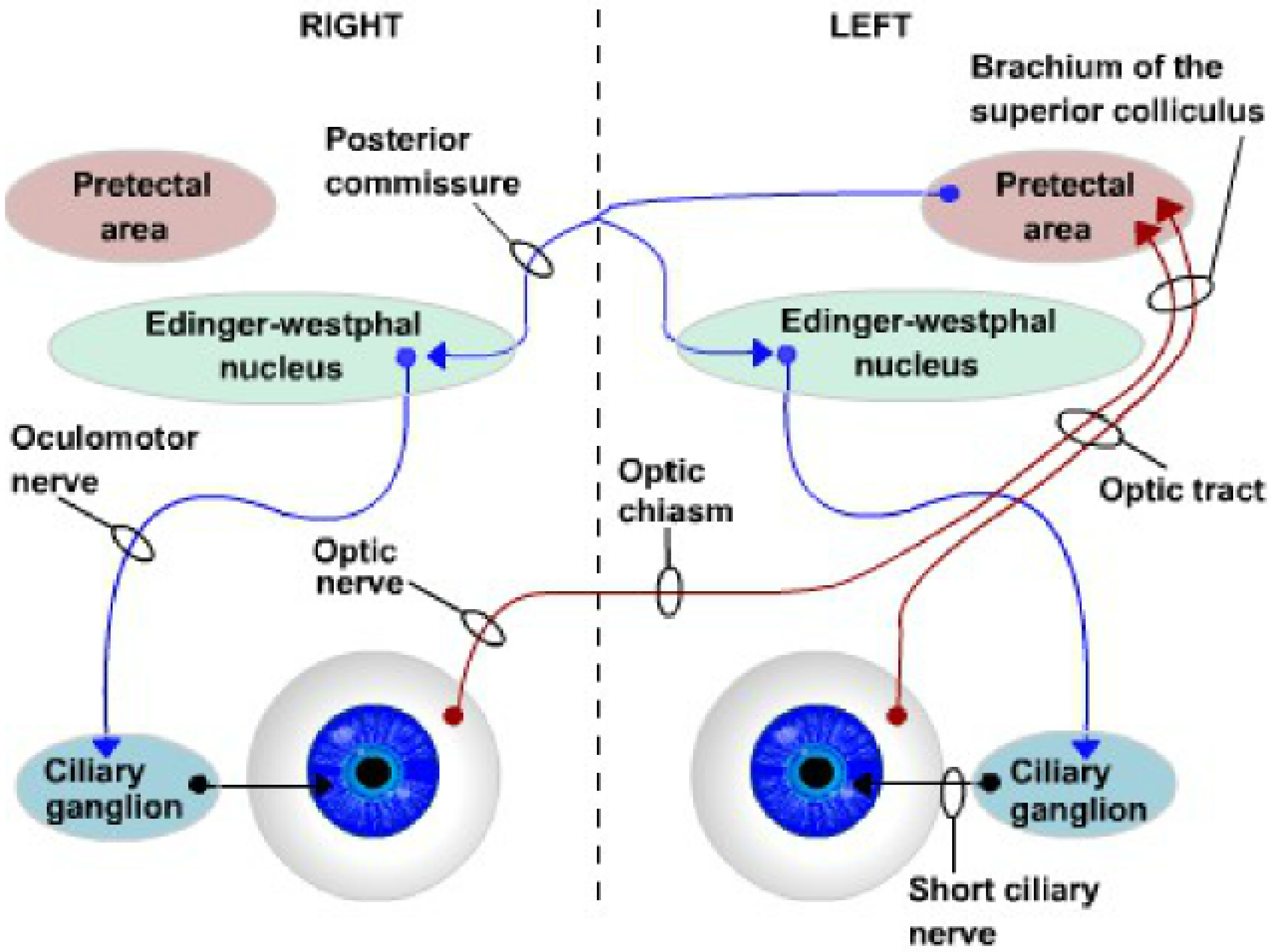
Example of autonomic nervous system – pupil dilation and contraction





http://neuroscience.uth.tmc.edu/s3/chapter07.html

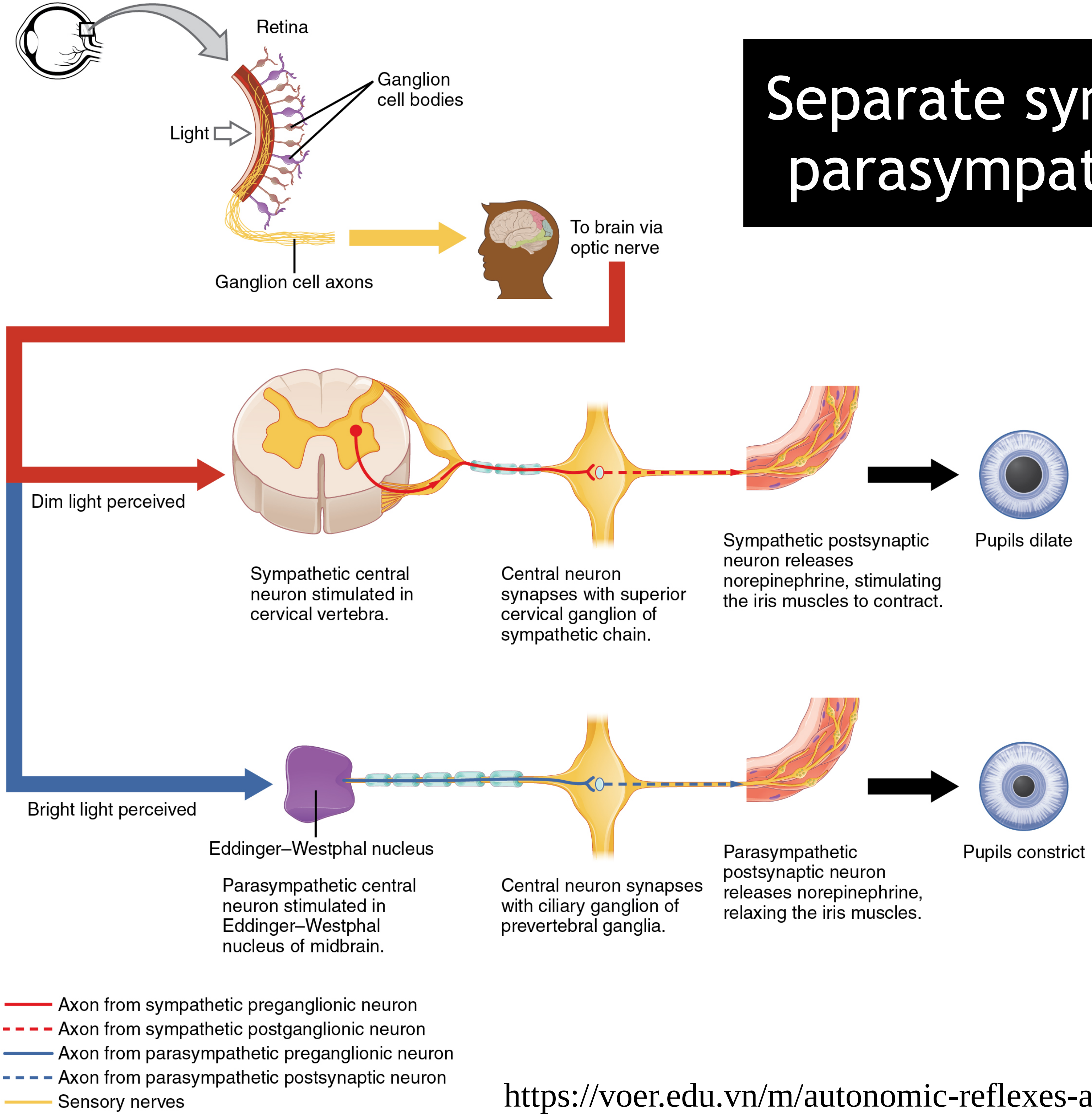
Circuit that controls changes in pupil size



- Only one part of the circuit

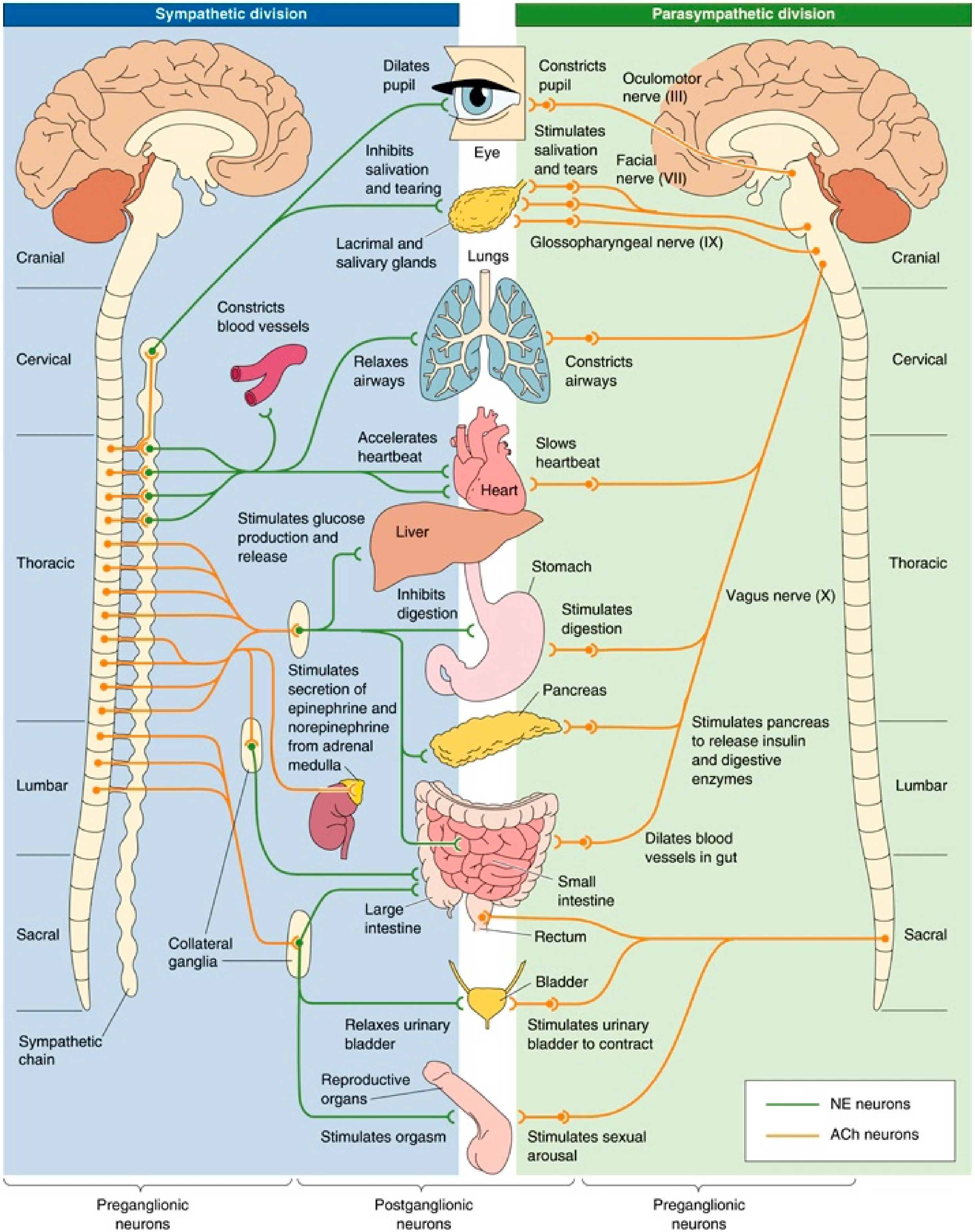
http://neuroscience.uth.tmc.edu/s3/chapter07.html

Separate sympathetic and parasympathetic control



https://voer.edu.vn/m/autonomic-reflexes-and-homeostasis/0058b664

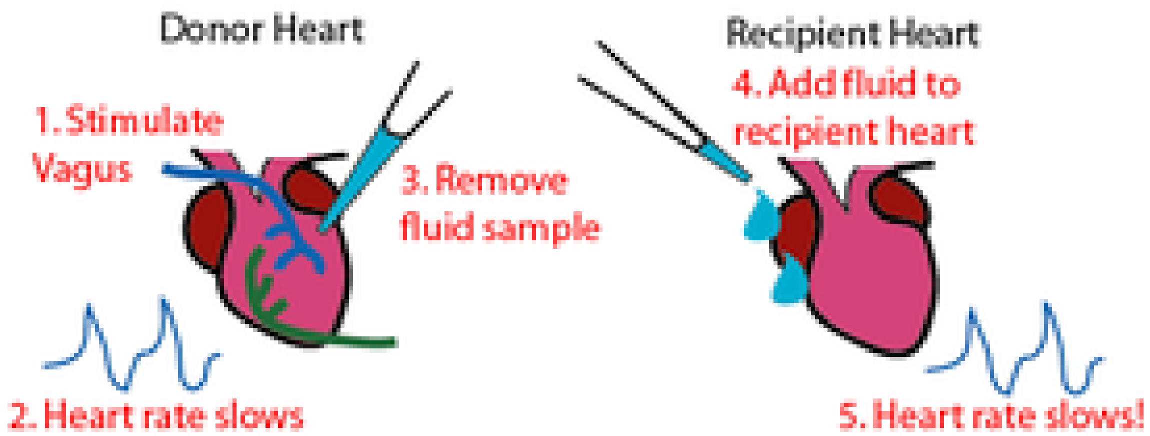
Sympathetic and parasympathetic nervous system – work antagonistically



http://web.stanford.edu/class/cs379c/archive/2012/suggested_reading_list/supplements/figures/sympathetic_parasympathetic.jpg

How do you get different responses in the targets?

- Otto Loewi – Nobel prize in 1934 – for the discovery of chemical neurotransmission – ACh (Vagusstoff)
- His experiments were done in 1921 – at a time when it was not clear if neurotransmission was chemical or electrical



http://en.wikipedia.org/wiki/Otto_Loewi

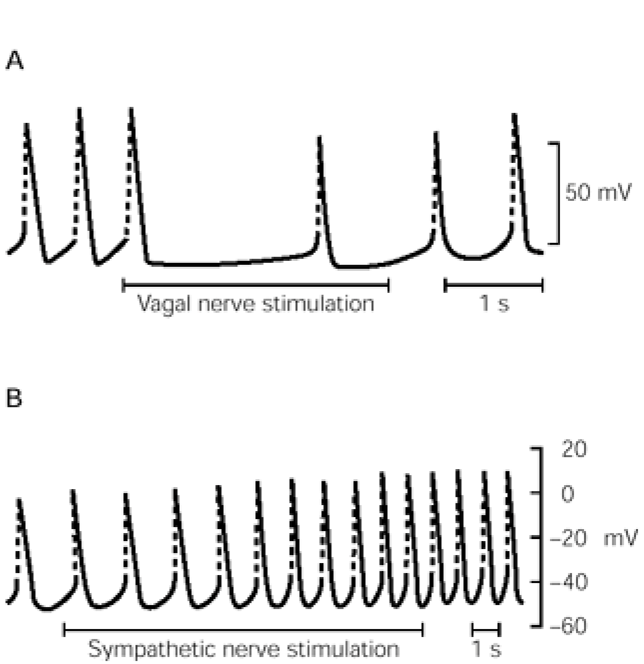
Interesting history pertaining to his discovery

On mature consideration, in the cold light of the morning, I would not have done it. After all, it was an unlikely enough assumption that the vagus should secrete an inhibitory substance; it was still more unlikely that a chemical substance that was supposed to be effective at very close range between nerve terminal and muscle be secreted in such large amounts that it would spill over and, after being diluted by the perfusion fluid, still be able to inhibit another heart. (Loewi 1921)

While it remains unclear how much of Loewi's account is true, Loewi was fortunate in his choice of experimental preparation. In the species of frog used (Rana esculenta), the vagus contains both inhibitory and stimulatory fibers. In the winter, inhibitory fibers predominate, so Loewi was also fortunate to have performed his experiments in February or March. Additionally,acetylcholinesterase activity (the enzyme that degrades acetylcholine) is low, particularly in an unheated laboratory, allowing the neurotransmitter to remain long enough to be collected and applied to a second heart. Thanks to this confluence of events, Loewi was able to describe the existence of vagusstoff and prove the existence of chemical synaptic transmission

http://en.wikipedia.org/wiki/Vagusstoff

Increase and decrease in heart-rate mediated by two different neurotransmitters

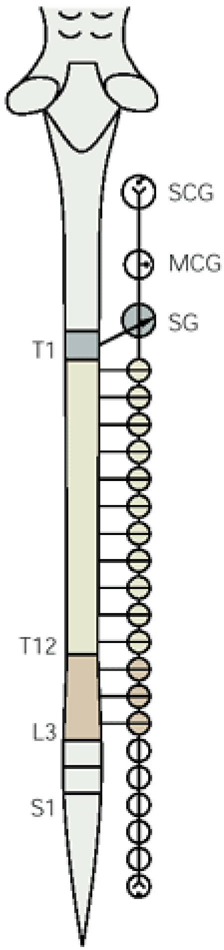


- Two different neurotransmitters
  - NE (norepinephrine)
    - adrenergic receptors – alpha and beta
  - ACh (Acetyl Choline)
    - cholinergic
    - muscarinic receptors

Neurotransmitters typically used by both systems

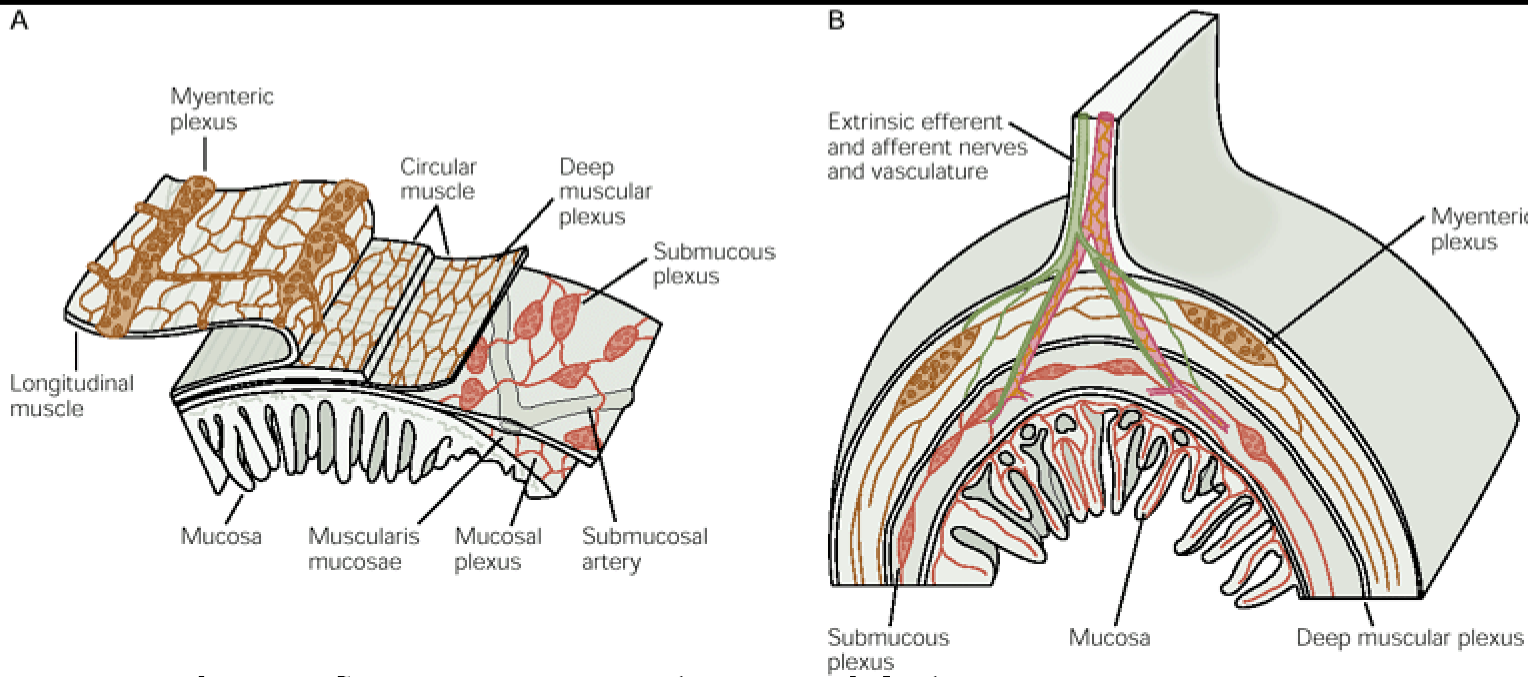
Autonomic System Signaling Molecules		
	Sympathetic	Parasympathetic
Preganglionic	Acetylcholine → nicotinic receptor	Acetylcholine → nicotinic receptor
Postganglionic	Norepinephrine → α- or β-adrenergic receptors Acetylcholine → muscarinic receptor (associated with sweat glands and the blood vessels associated with skeletal muscles only	Acetylcholine → muscarinic receptor

Other neuropeptides also used



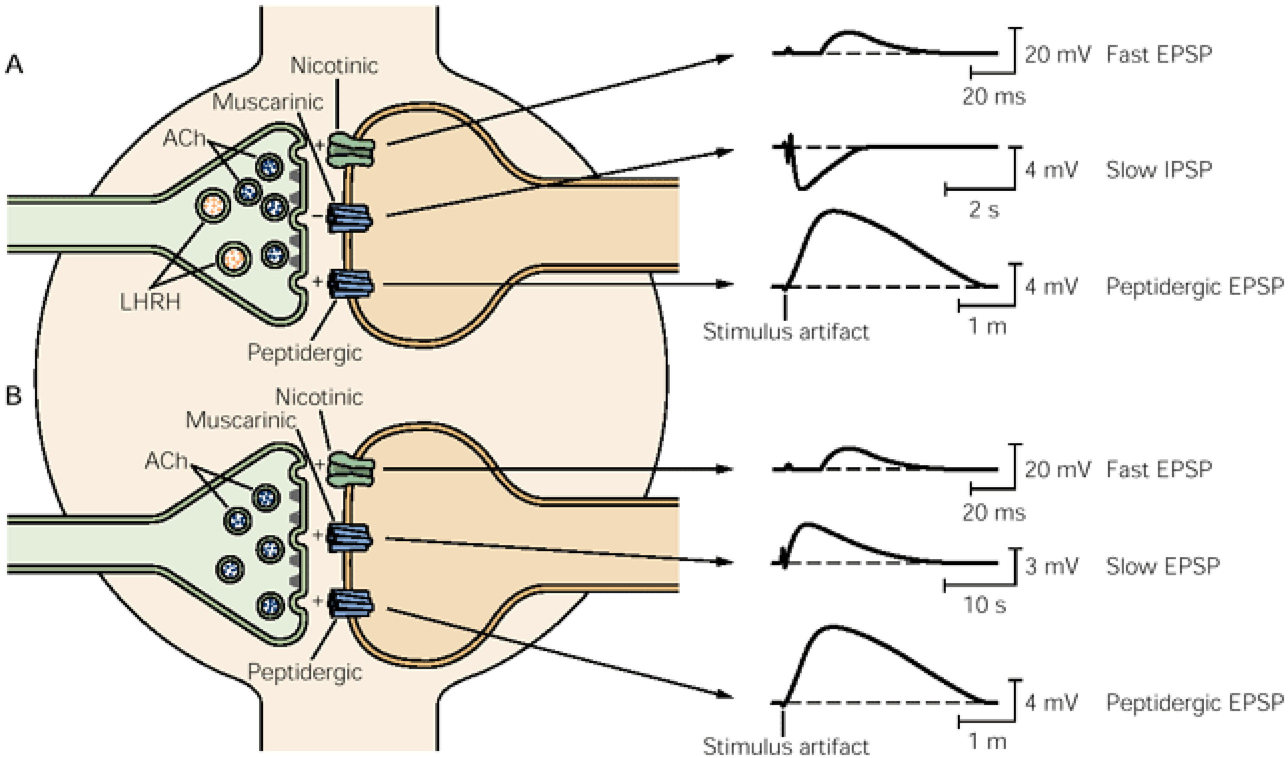
Cat: Noradrenergic	Cat: Cholinergic	Guinea pig: Noradrenergic	Guinea pig: Cholinergic
Neuropeptide Y Somatostatin Enkephalins	Vasoactive intestinal polypeptide Calcitonin gene-related peptide Substance P Neurotensin	Neuropeptide Y Neuropeptide Y + dynorphin Dynorphin Somatostatin Enkephalins	Vasoactive intestinal polypeptide Vasoactive intestinal polypeptide + neuropeptide Y
Neuropeptide Y	Vasoactive intestinal polypeptide	Neuropeptide Y	Vasoactive intestinal polypeptide
Neuropeptide Y Neuropeptide Y + galanin Galanin Neurotensin	Vasoactive intestinal polypeptide Vasoactive intestinal polypeptide + calcitonin gene-related peptide + substance P Neurotensin	Neuropeptide Y Neuropeptide Y + dynorphin Dynorphin	Vasoactive intestinal polypeptide Vasoactive intestinal polypeptide + neuropeptide Y

Enteric nervous system



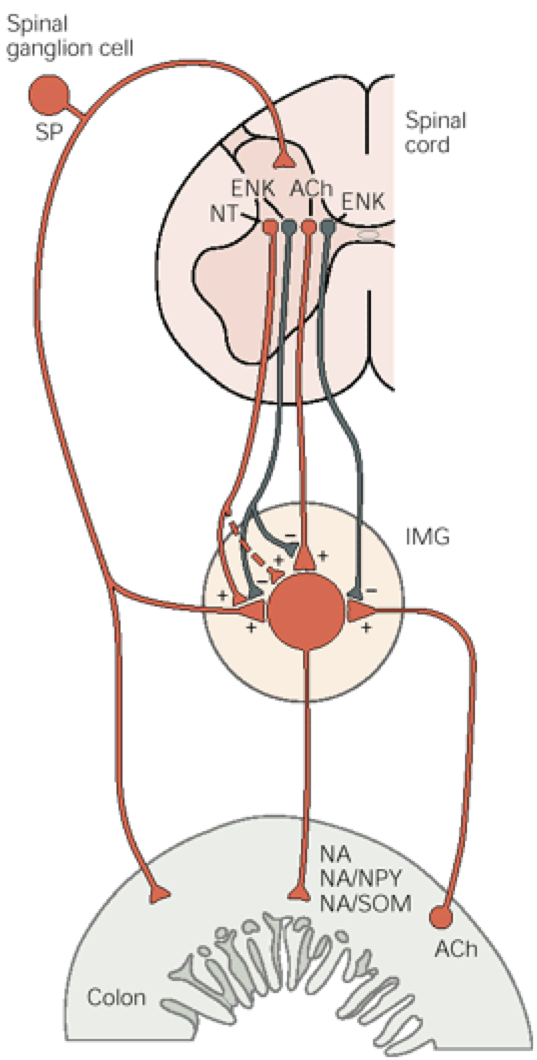
- Very large number of sensory, motor and interneurons
- Controls smooth muscles of the gut, local blood vessels and secretions of the mucosa
- Two major networks of nerves and vessels
  - Myenteric plexus – gut motility
  - Submucous plexus – secretions of mucous

Multiple time-scales of responses mediated by the different transmitters and different receptors



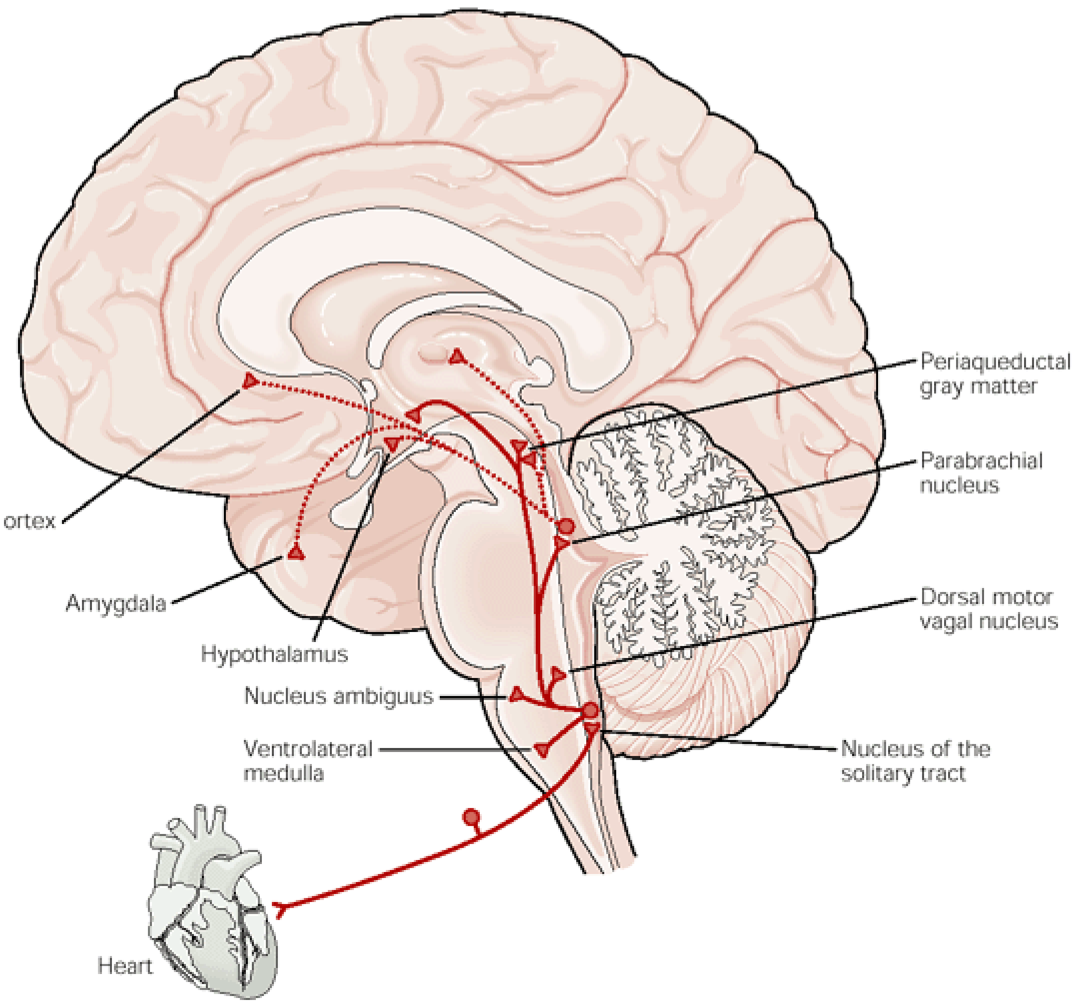
- Synapses in the sympathetic chain ganglia of bullfrog
- Single pre-synaptic stimulation in both evokes fast EPSPs
- Repetitive stimulation evokes different responses in both
- Peptidergic EPSP evoked in second synapse only when first one is stimulated

Another example of the influence of neuropeptides



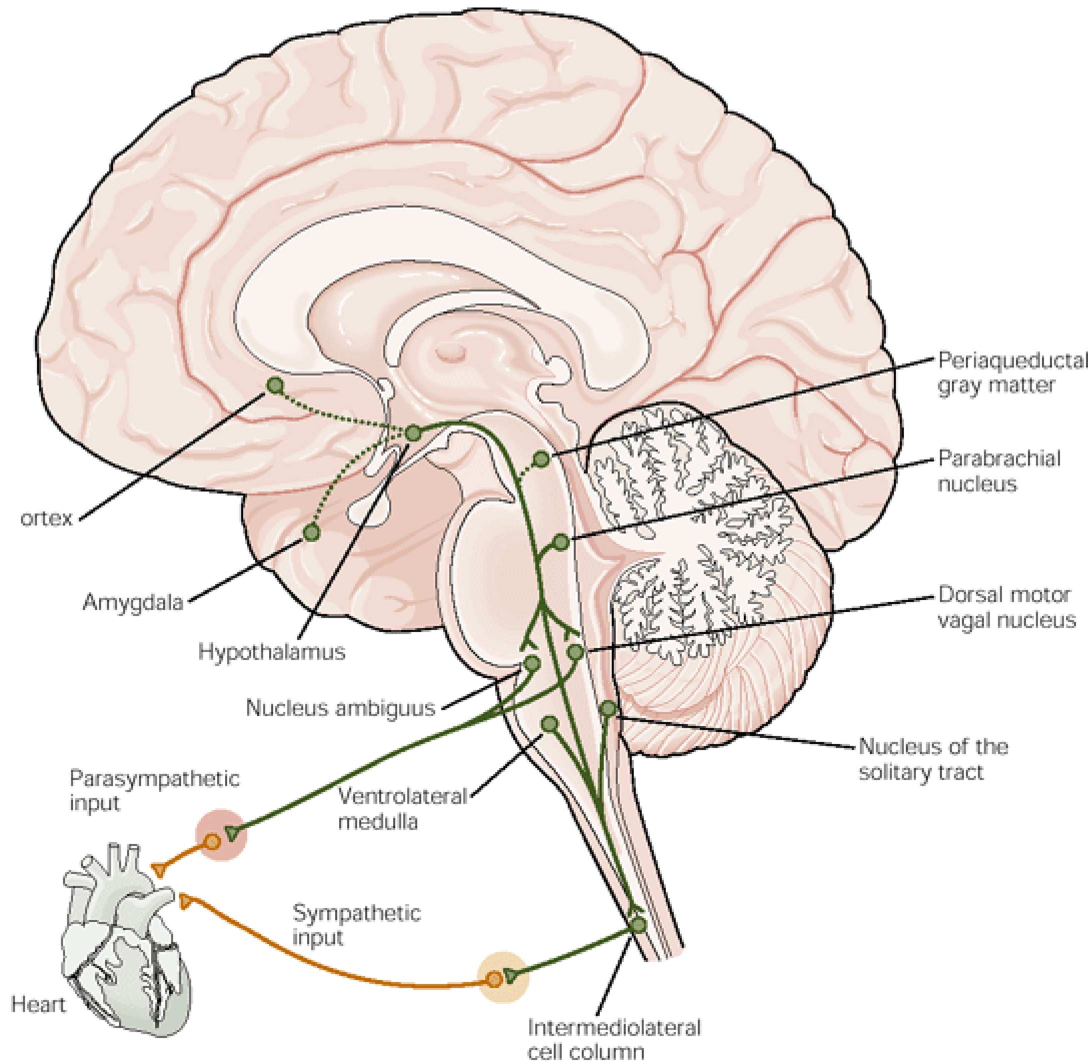
- Different neuropeptides add to the complexity

Central autonomic networks - input

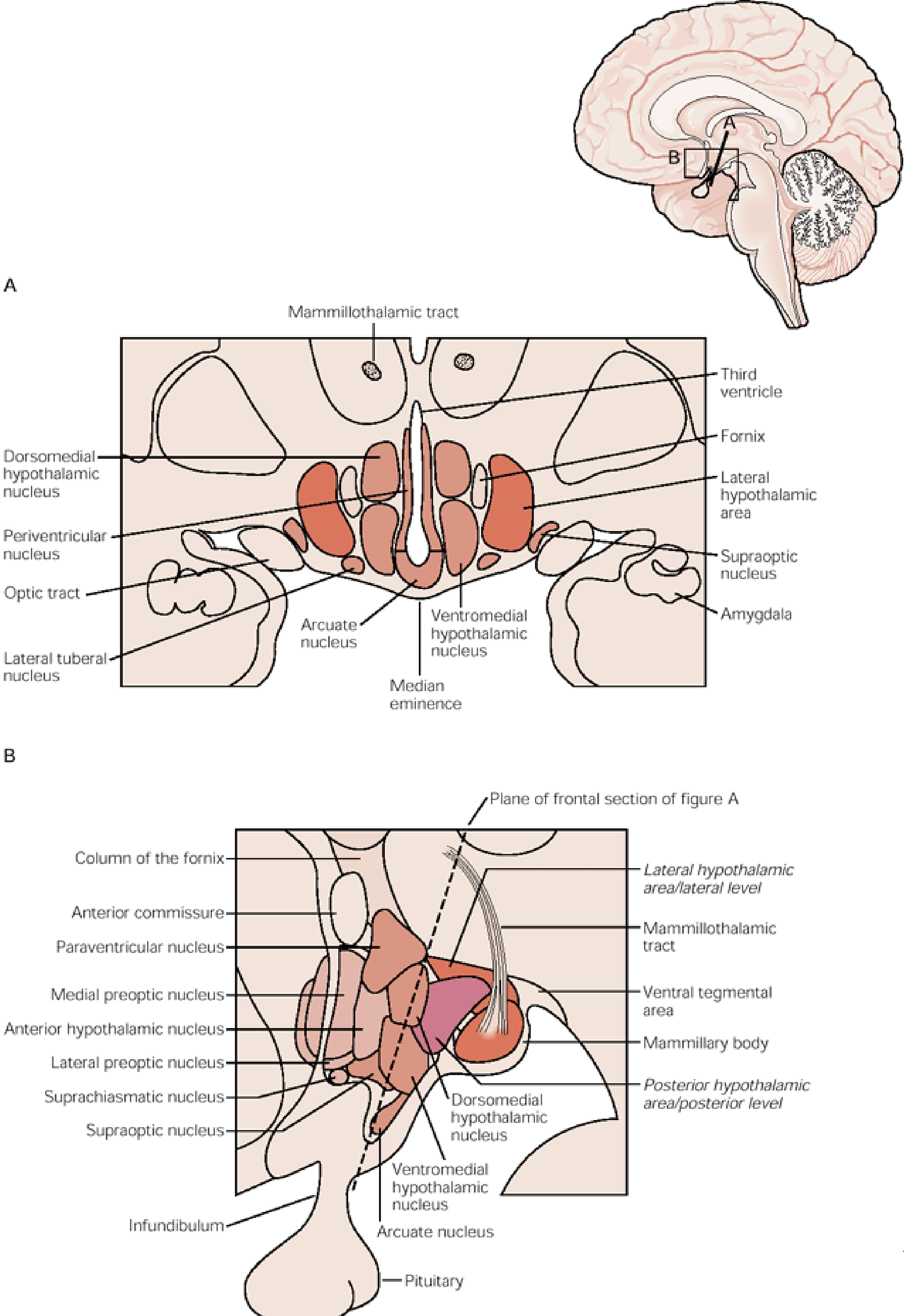


- Cranial nerves VII, IX and X convey information to the brainstem - NST (nucleus of the solitary tract)

Central autonomic network - outputs



- NST, and other nuclei in the brainstem and medulla provide direct outputs to sympathetic ganglion
- A number of other forebrain and midbrain nuclei are also connected to this system
- Anterior insula – visceral sensory cortex – gets information about internal state
  - Topographic map of internal organ systems
  - Lesions cause loss of appreciation of visceral sensations
- Infralimbic area – part of cingulate cortex – visceral motor cortex
  - Lesions – abulia – loss of emotional responses to external stimuli

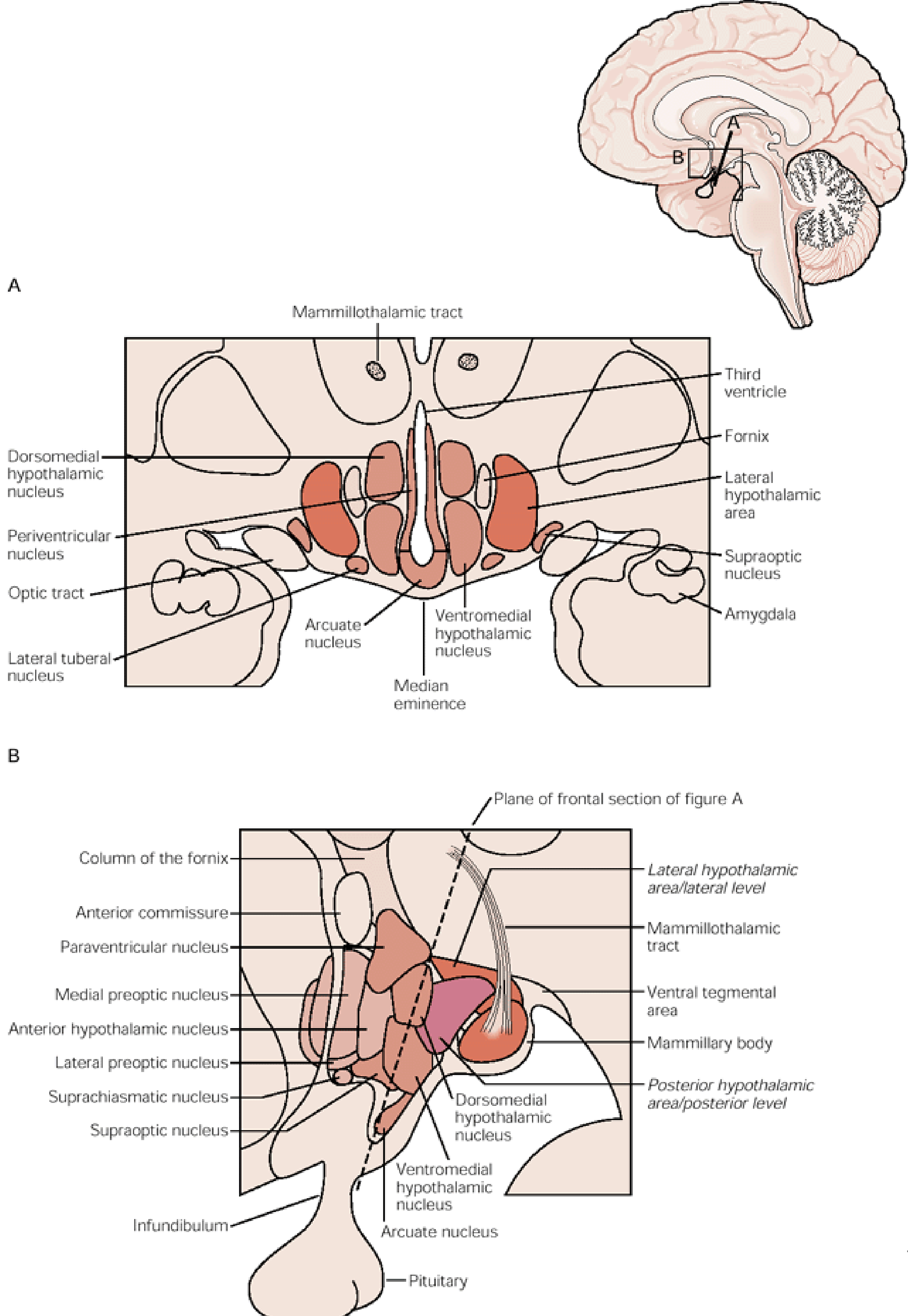


Hypothalamus

- Integrates autonomic responses and endocrine function with behavior
  - Controls blood pressure and electrolyte composition
  - Regulates body temperature
  - Controls energy metabolism
  - Regulates reproduction
  - Controls emergency responses to stress

Three main mechanisms used by the hypothalamus to function

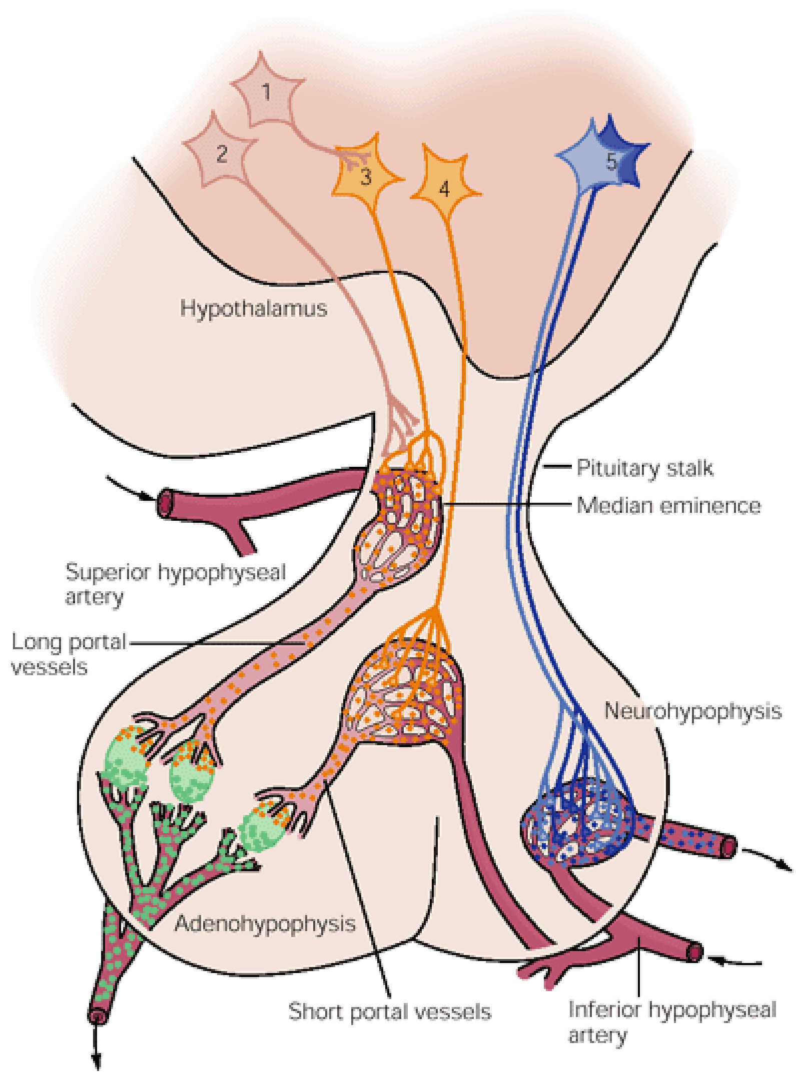
- Gets all sensory input
  - From all sense organs (direct or indirect)
    - visual input used to send information to suprachiasmatic nucleus to regulate circadian rhythm
  - Has internal sensory neurons that respond to changes in temperature, glucose, etc.
  - Circulating hormones can also enter near the margin and directly interact with hypothalamic neurons
- Compares sensory information with biological set points
- If there is a deviation from set point, it triggers various behavioral, autonomic and endocrine responses to restore homeostasis



Hypothalamus – many divisions

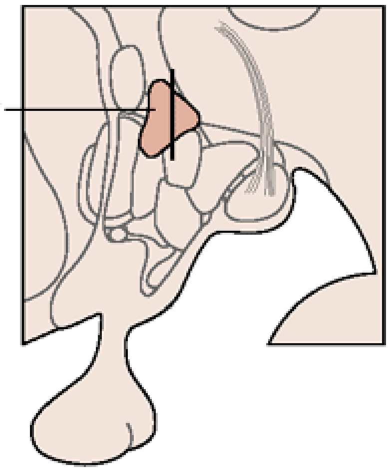
- Anterior third – preoptic area
  - integration of sensory information needed to judge deviation from set point
- Middle third – Dorsomedial, ventromedial, paraventricular, supraoptic, arcuate
  - control of growth, feeding, maturation, reprduction
- Posterior third – mamillary body, posterior hypothalamus
  - regulating wakefulness and arousal
  - other function not known

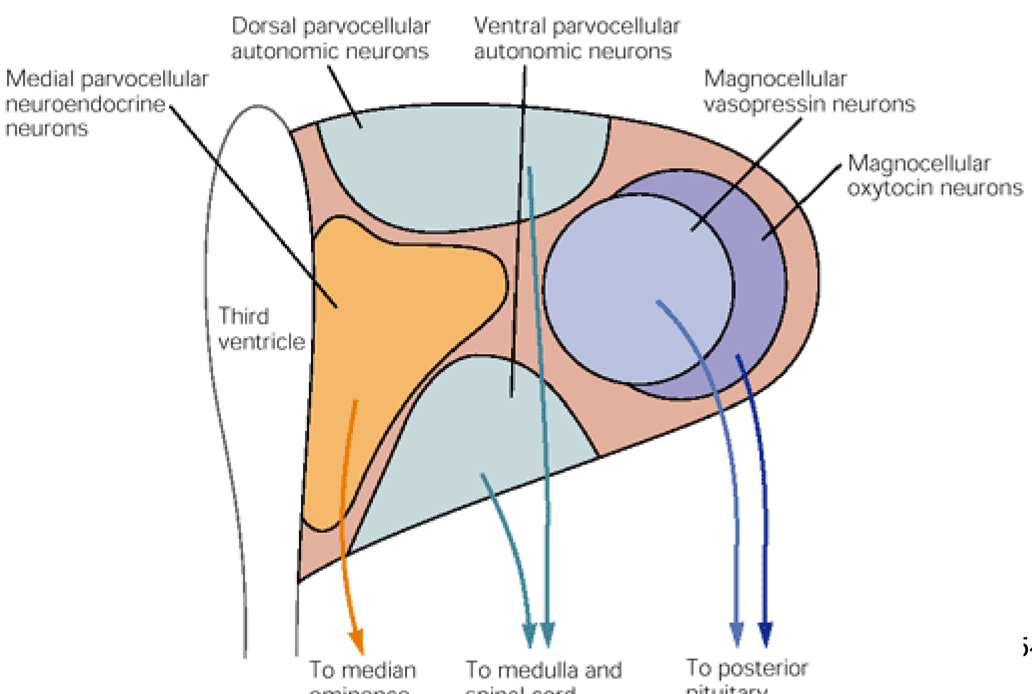
Also controls endocrine system through the pituitary



- Peptidergic neurons (5) release hormones into circulation through posterior pituitary
- Anterior pituitary control – two types of neurons
  - Peptidergic neurons (3, 4) release hormones into the hypophyseal-portal circulation
  - Monaminergic neurons (1,2) link the rest of the brain with peptidergic neurons – can contact at axon terminals or cell body

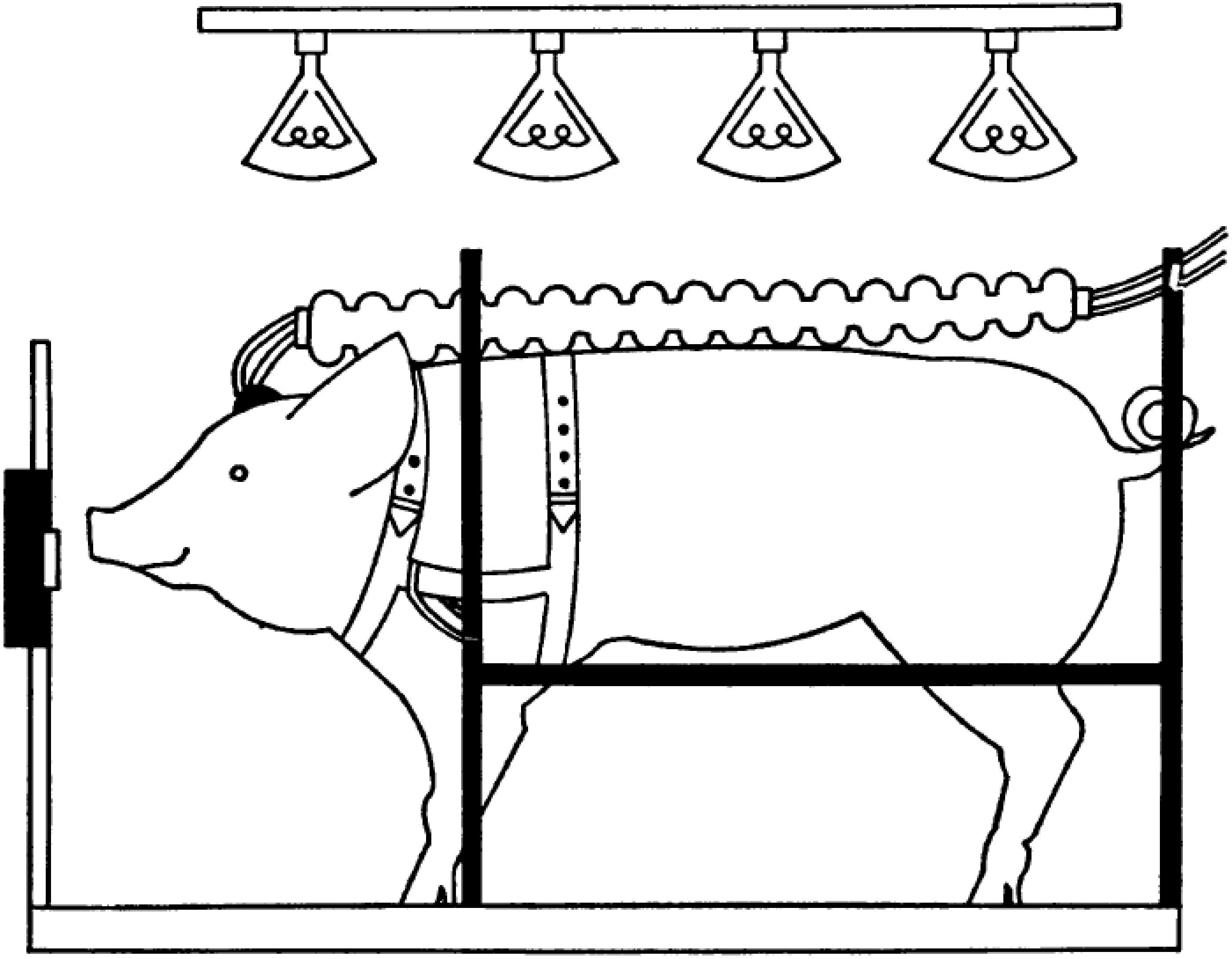
The paravenricular nucleus is a part of the complex control of autonomous and endocrine functions





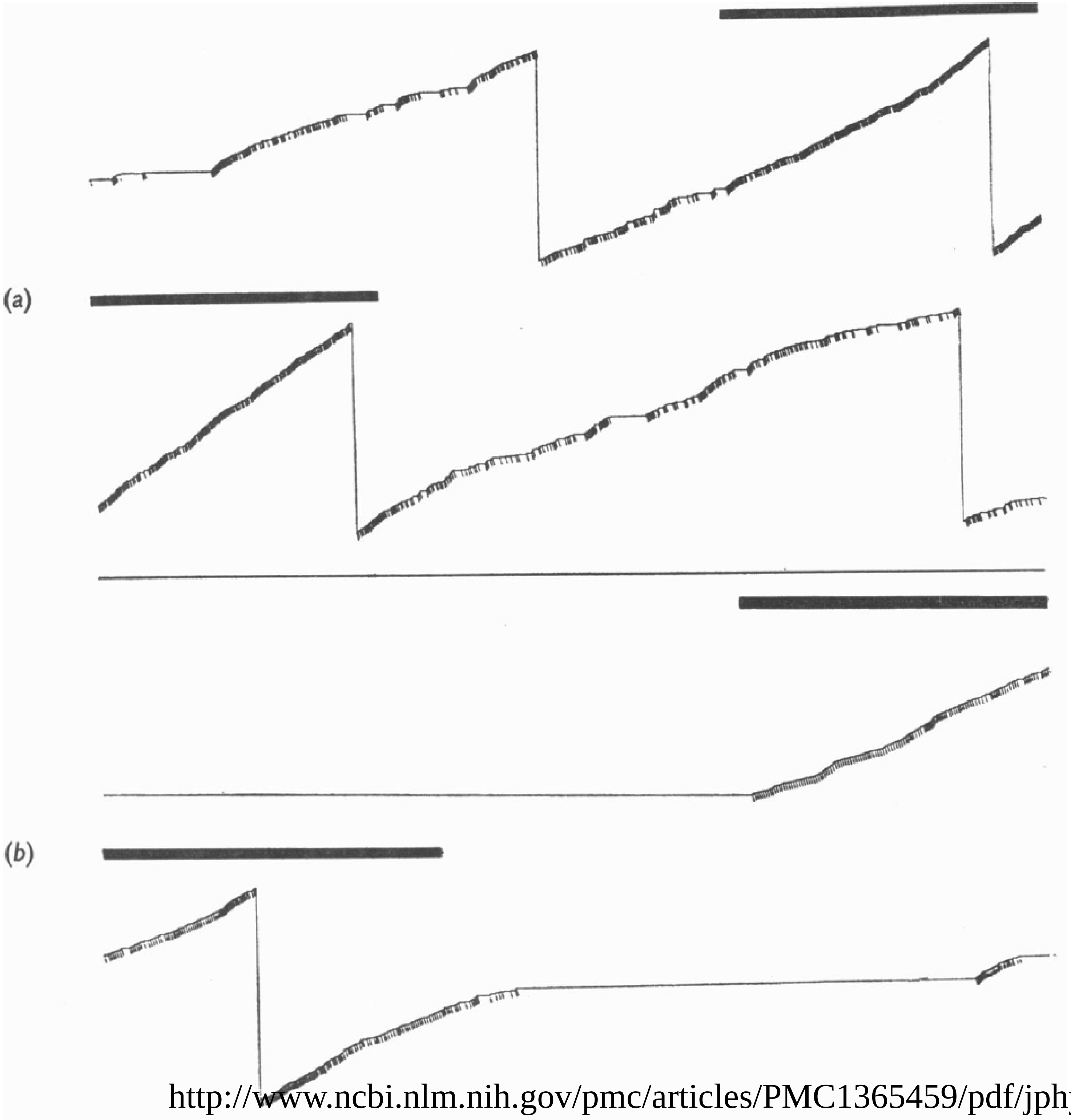
- Magnocellular hormone releasing neurons

Eg: regulation of body temperature



- Pigs can be trained to switch on IR heaters
- Thermodes to cool or heat the hypothalamus

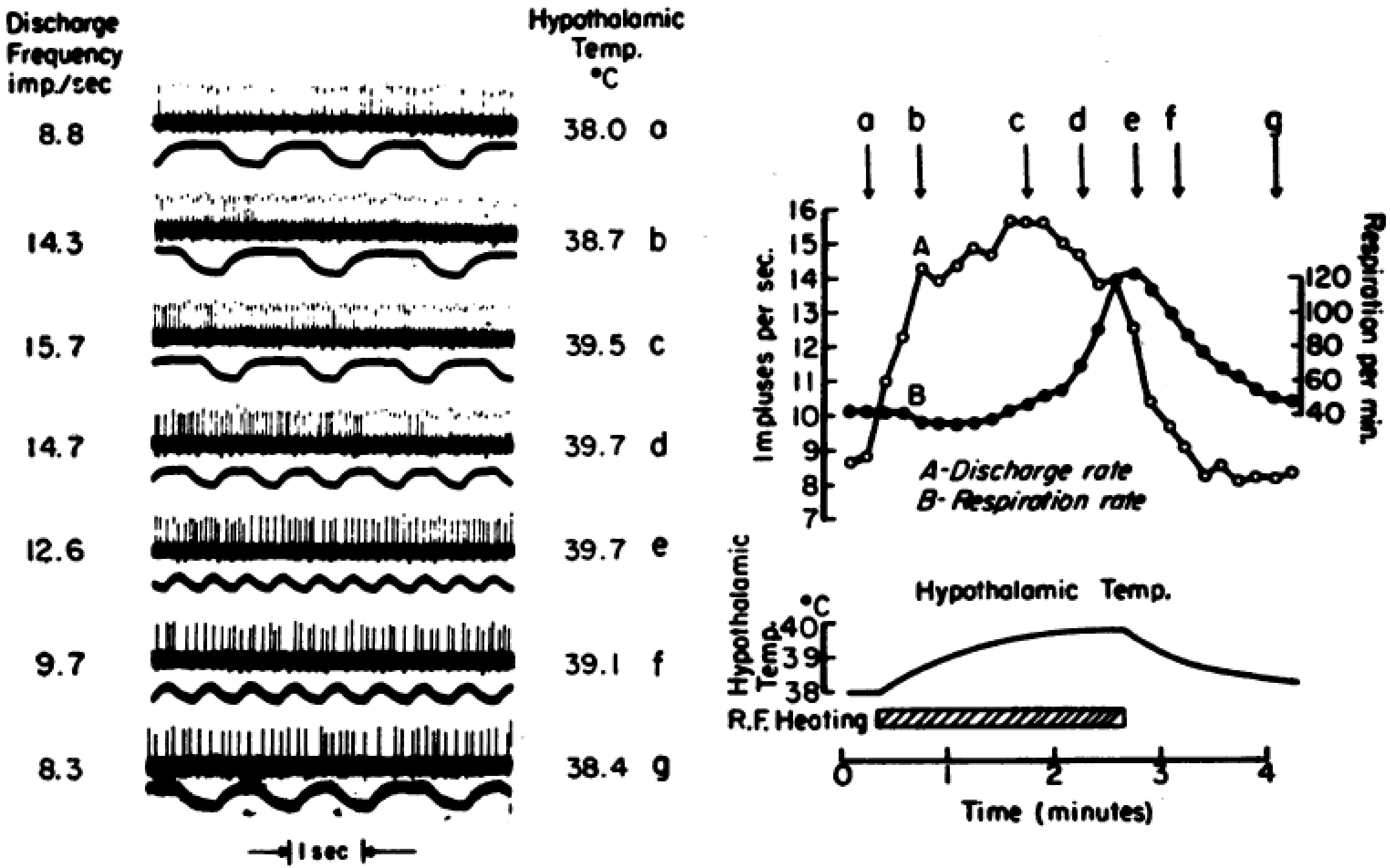
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1365459/pdf/jphysiol01120-0154.pdf



Both ambient temperature and hypothalamus temperature influence warmth seeking behavior

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1365459/pdf/jphysiol01120-0154.pdf

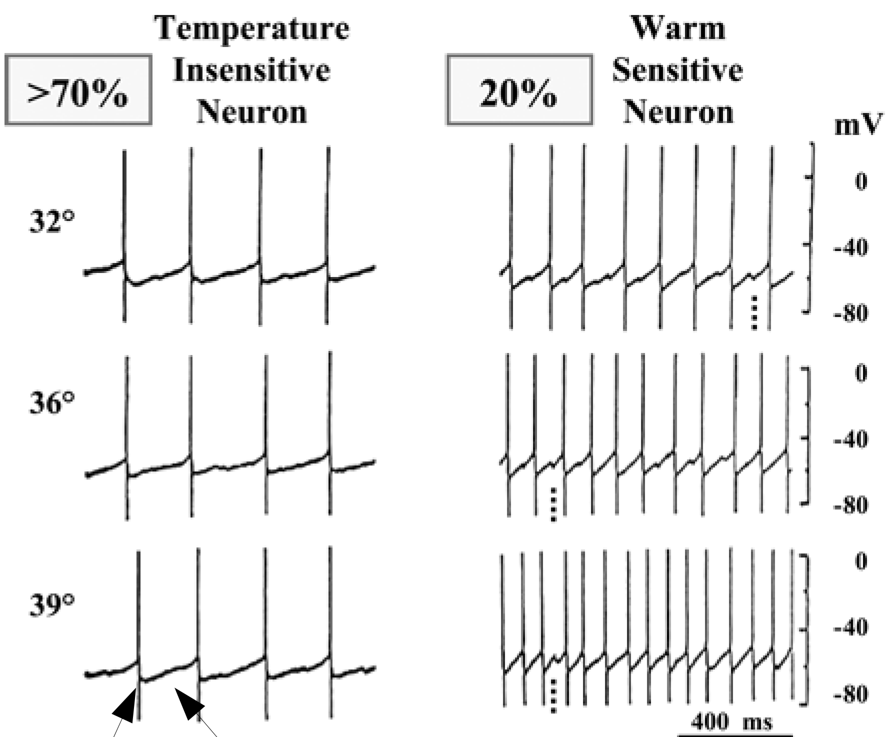
Neurons in the hypothalamus respond to changes in temperature



- A large number of neurons are temperature insensitive (> 70%)
- About 20% of the neurons change their firing rate with changes in temperature

http://www.sciencemag.org/cgi/pmidlookup?view=long&pmid=13727681

Ionic basis of these responses



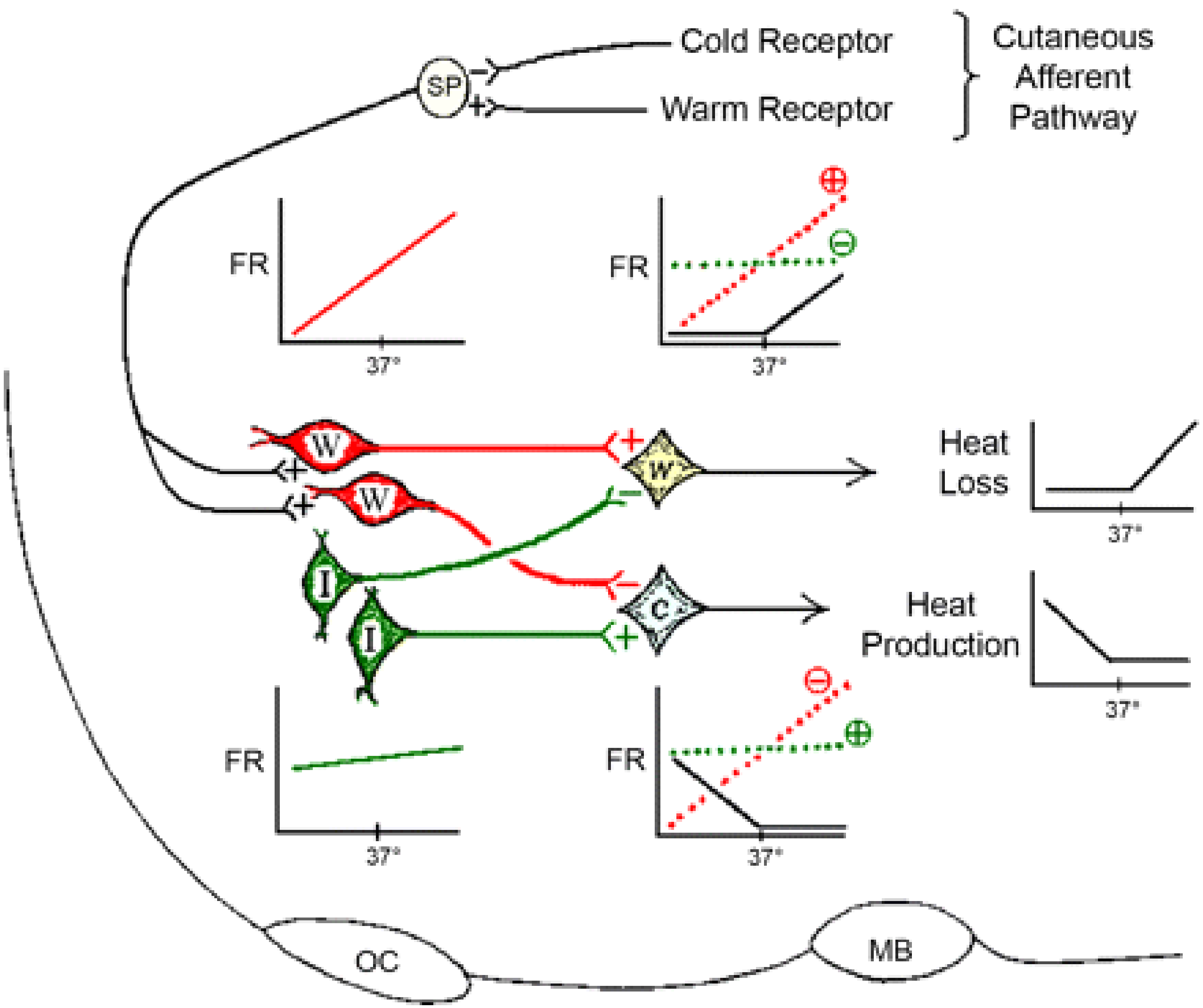
Fast after hyperpolarisation

Slow depolarising pre-potential

- Preoptic neurons in Rat hypothalamic tissue slices
- Temperature insensitive neurons
- Warm sensitive neurons – IA (K+ current) – rates of inactivation are made faster at warmer temperatures

http://jap.physiology.org/content/100/4/1347

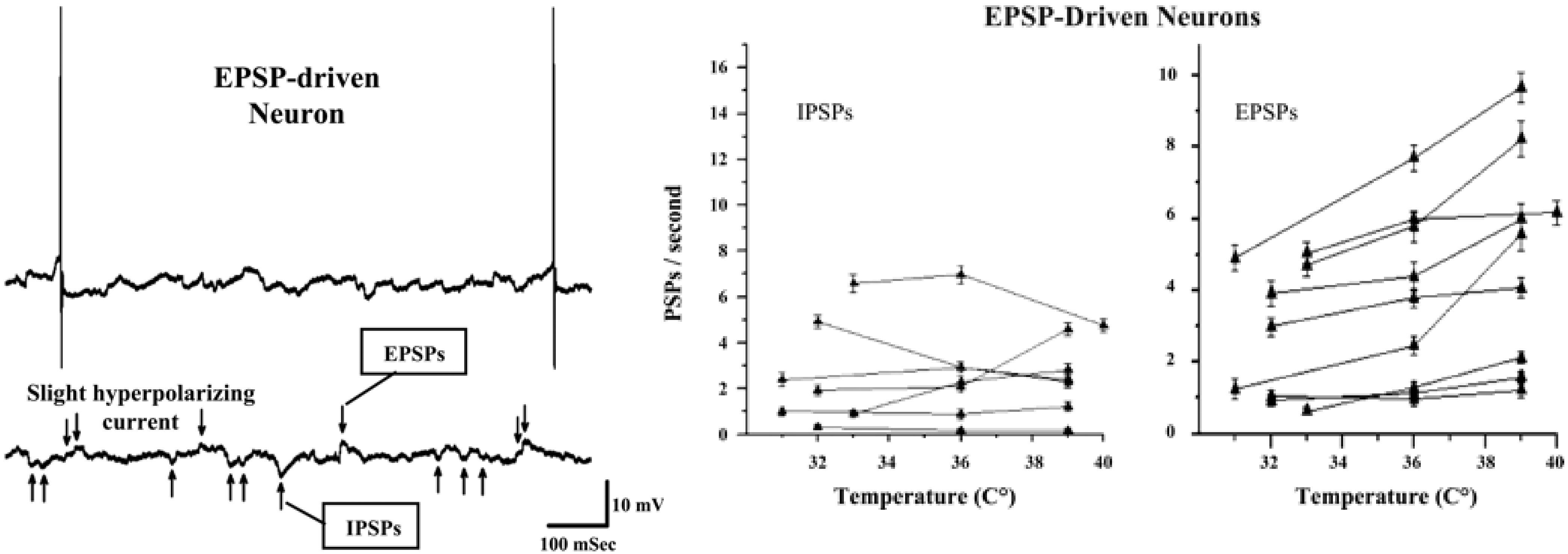
Model for thermoregulation and neuronal basis



- Heat loss effector neurons
- Heat production effector neurons

http://jap.physiology.org/content/100/4/1347

Putative heat-effector neurons



- Recording from EPSP driven neurons
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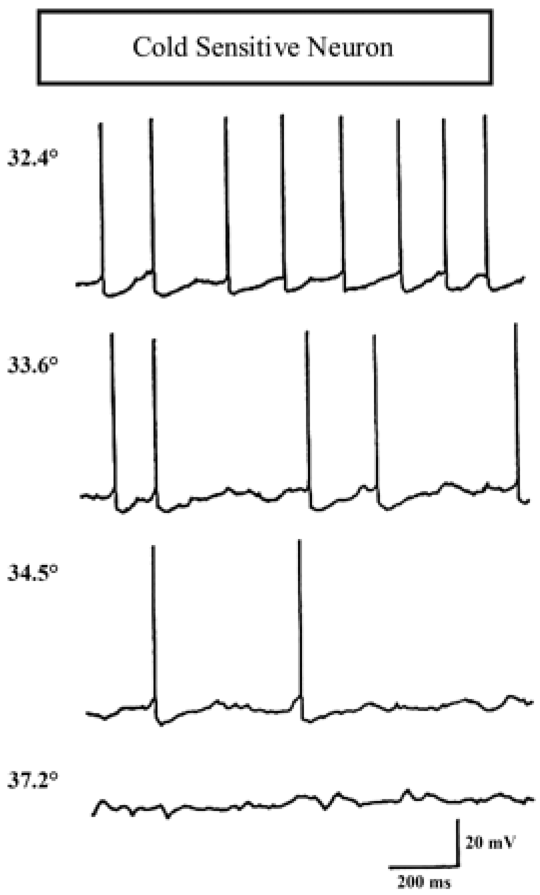
http://jap.physiology.org/content/100/4/1347

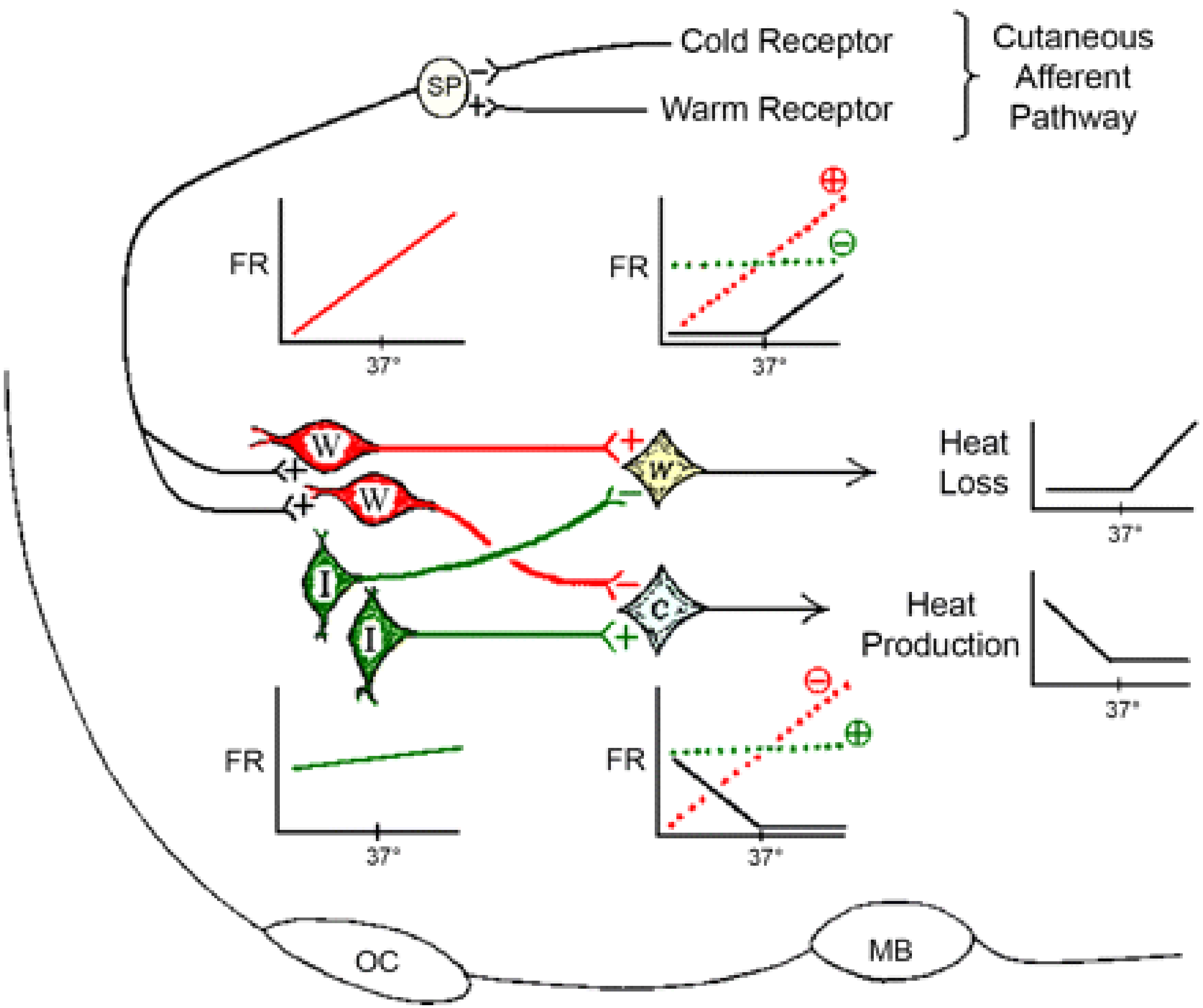
Putative heat production effector neurons



- Cold-sensitive neurons
- Synaptic blockade makes them lose their cold-sensitivity

http://jap.physiology.org/content/100/4/1347

Model for thermoregulation and neuronal basis



- Heat loss effector neurons
- Heat production effector neurons

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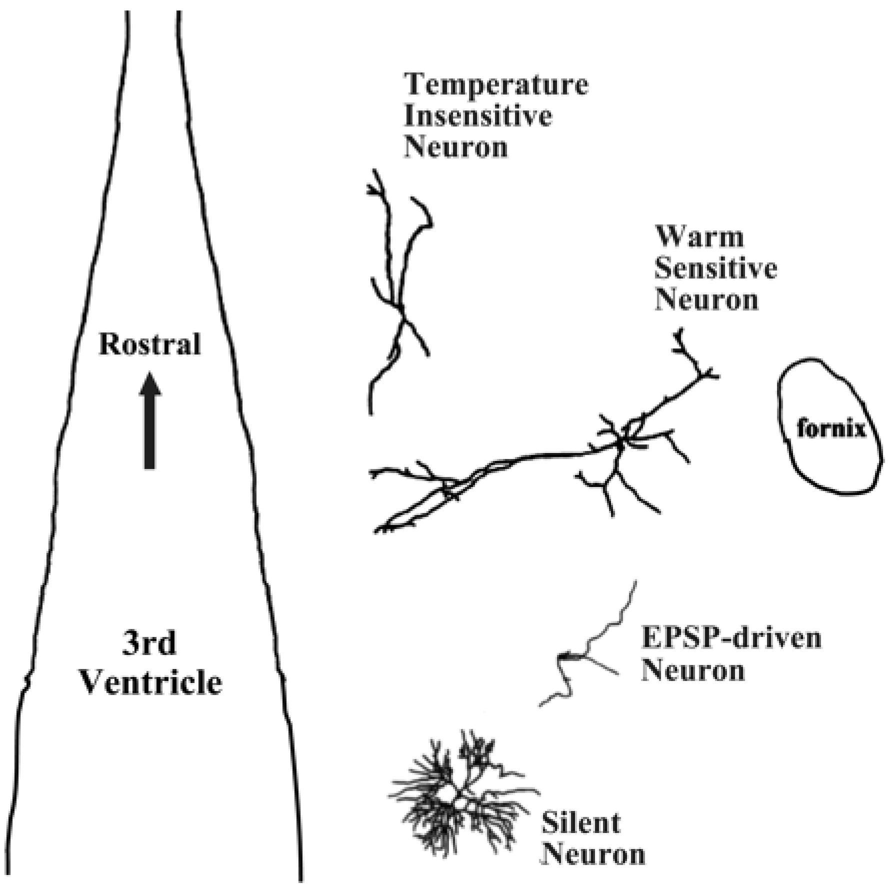
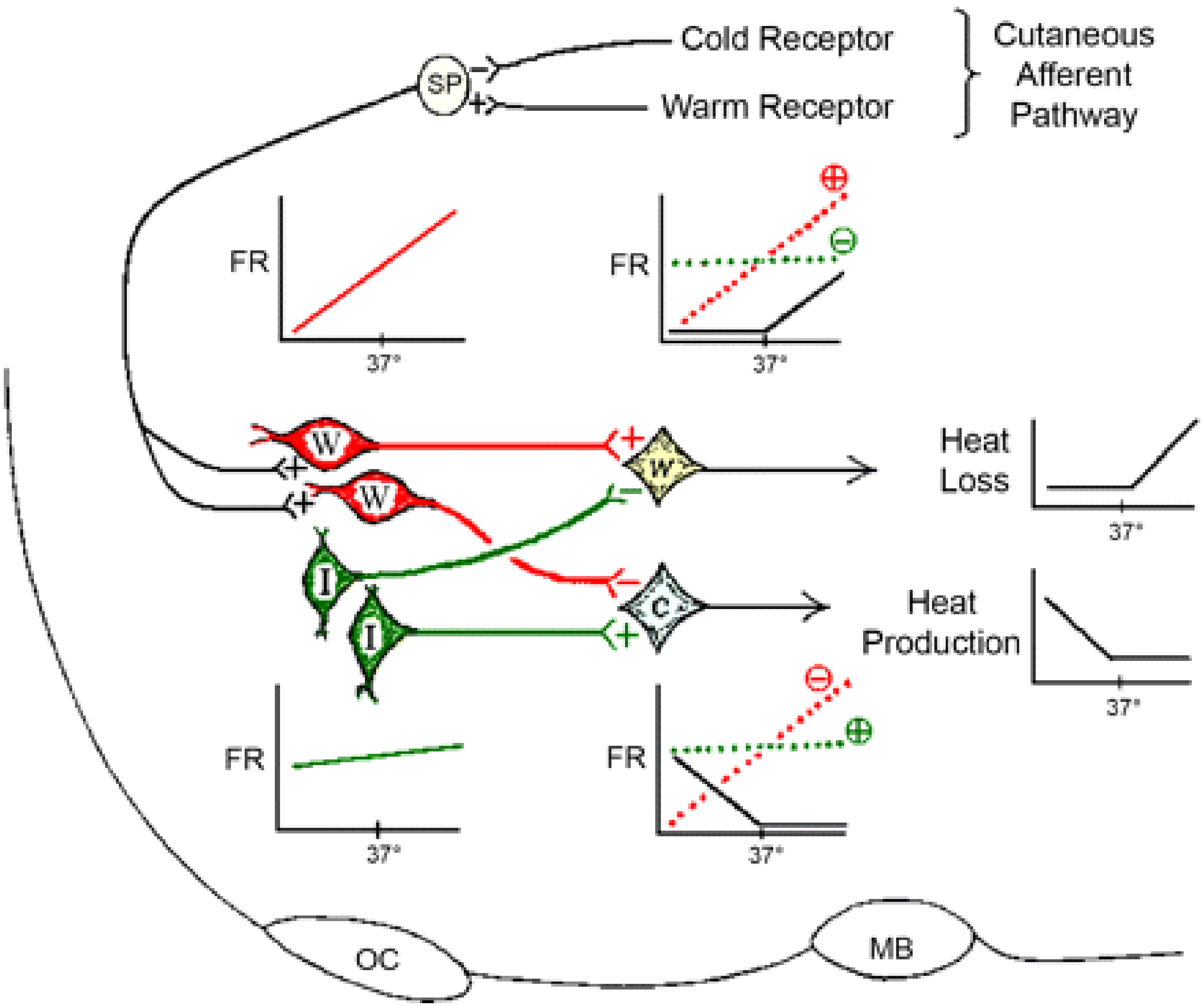
Different neuronal morphologies in the preoptic nucleus



- The different dendritic orientations fits with the known anatomy of peripheral inputs
- Silent neurons can only be driven by current injection
- Receive IPSPs from warm-sensitive neurons
- May be an EPSP-driven neuron – synaptic input from afferents or remote neural sites

http://jap.physiology.org/content/100/4/1347

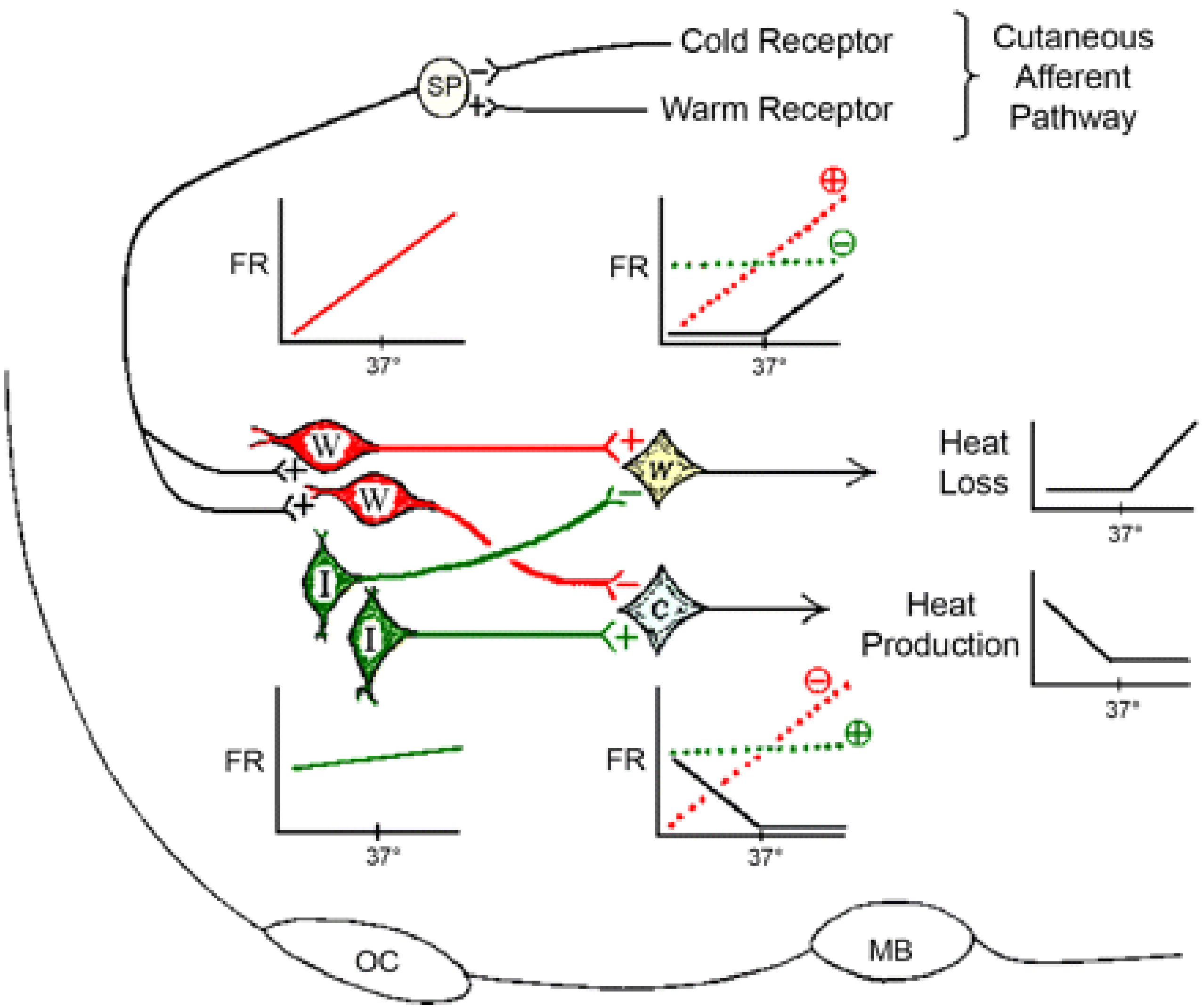
Important differences between earlier models



- Temperature insensitive neurons do not respond to peripheral temperature changes (thought to respond to cold-sensitive peripheral inputs)
- Warm-sensitive neuron is potentially a sensor as well as an integrator (thought to respond to warm-sensitive peripheral inputs)

http://jap.physiology.org/content/100/4/1347

General model for regulation of different body parameters with a set-point



- Set-point is the balance between synaptic inhibition and synaptic excitation
- Can be moved around by changing firing rates of either neuronal type

http://jap.physiology.org/content/100/4/1347

What is the function of the autonomic nervous system?

- "Fight or Flight"
-
- Largely co-ordinates visceral and reflexive actions
- Mostly not under conscious control (there are exceptions)
- Senses the internal environment of the body and acts accordingly
  - Consists of both visceral sensory and motor neurons
- Also called "involuntary nervous system"
- Pretty complex
- Has a number of specializations that help co-ordinate a variety of responses with small set of fibers
- Important for homeostasis – maintenance of constant internal environment of the body