ANP 1105A - Anatomy & Physiology I

- Basic Cellular Physiology & the Anatomy and Physiology of the Cardiovascular, Lymphatic & Respiratory Systems

Lecture 9 - Homeostasis: Introduction to the Autonomic Nervous System

Presented by: Dr. Stephen Gee, October 2018

Learning Objectives

3. Homeostasis: Introduction to the Autonomic Nervous and Endocrine Systems

- **3.1**. Define and identify the main characteristics of homeostasis

- **3.2**. Nervous system:
  - 3.2.1. Compare somatic and autonomic nervous systems
  - 3.2.2. Compare the functional differences between the sympathetic and parasympathetic divisions of the ANS

Readings Marieb and Hoehn, 11th Ed.

Chapter 1 (pp. 9-12)

1.4 Homeostasis is maintained by negative feedback

Chapter 14 The Autonomic Nervous System

(pp. 531-535, 545-548)

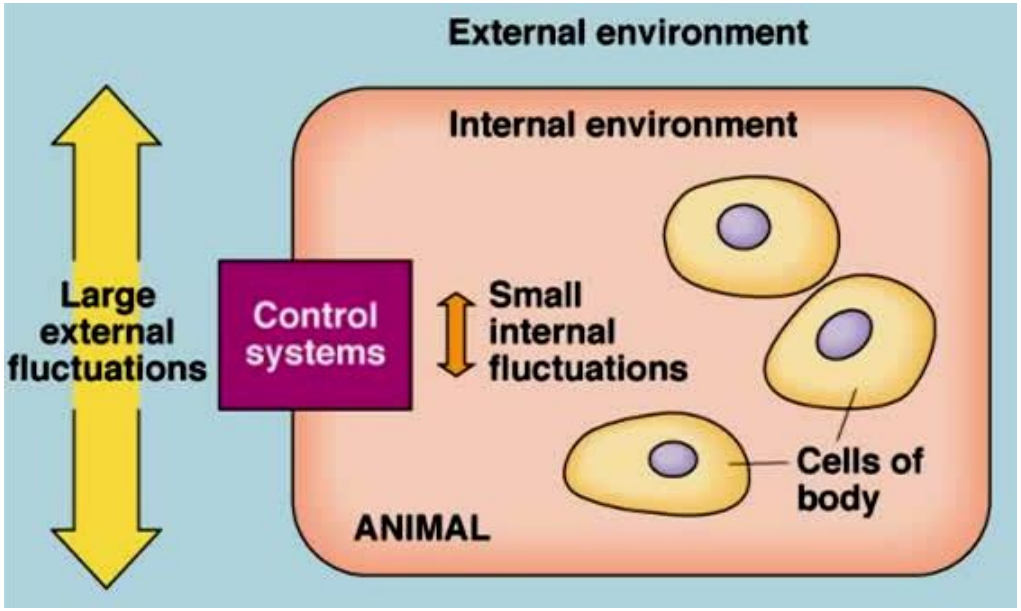
14.1 The ANS differs from the somatic nervous system in that it can stimulate or inhibit its effectors

14.2 The ANS consists of the parasympathetic and sympathetic divisions

14.7 The parasympathetic and sympathetic divisions usually produce opposite effects

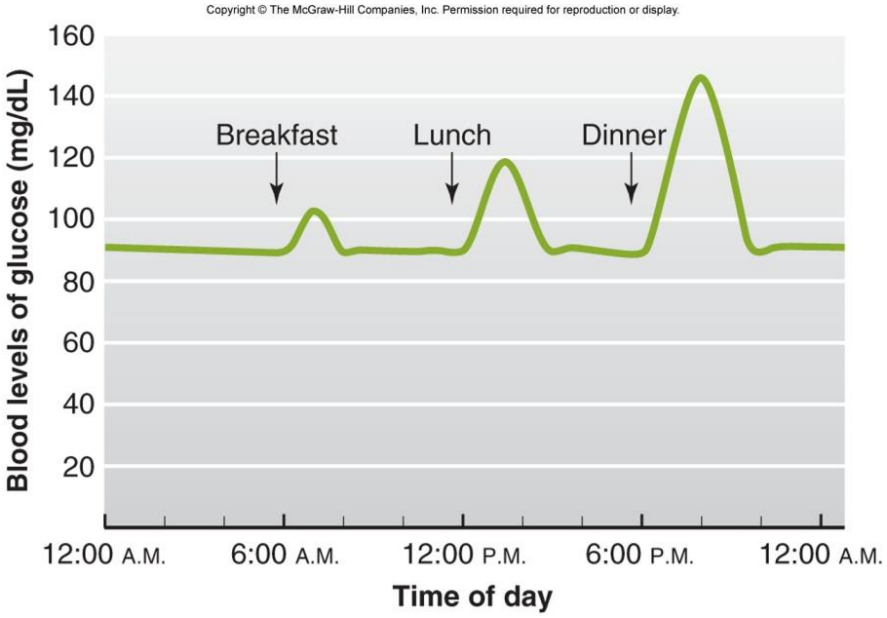
Homeostasis: A defining feature of Physiology

- Cells and components of cells work best when specific conditions are maintained (optimal temperature, pH, O_2, etc.)
- Different organ systems work cooperatively to promote the well being of the entire body and to maintain stable internal conditions
- **Homeostasis:** ability of the body to maintain a relatively constant internal environment with changing external conditions (Walter Cannon)
  - Unifying concept of physiology.



Homeostasis

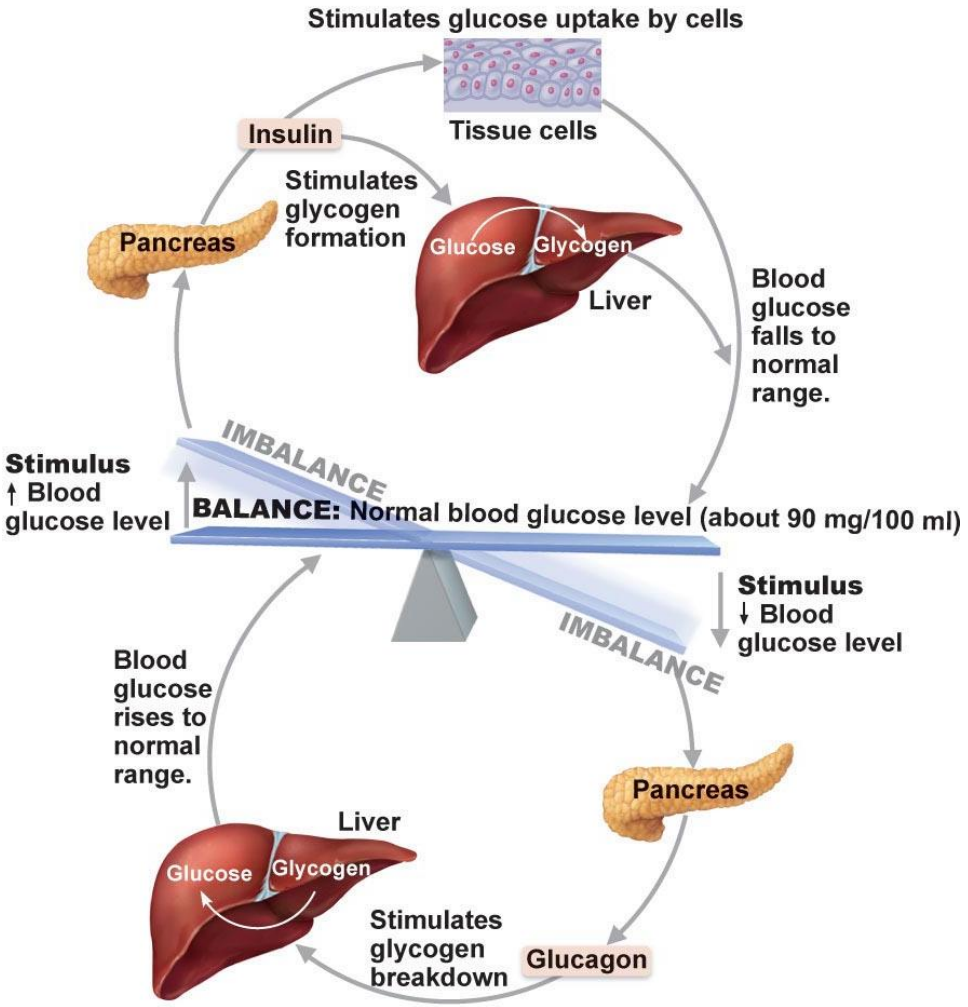
- Homeostasis does not imply that a given physiological function or **variable** is rigidly constant.
- Variables fluctuate within a predictable and often narrow range. When disturbed up or down from the normal range, they are restored to normal.
- Thus, homeostasis is a state of **dynamic constancy**. A variable like blood glucose may vary in the short term, but is fairly constant when averaged over the long term.



Blood glucose levels increase after eating. Levels return to their set point. This is an example of dynamic constancy. Levels change over short periods of time, but remain relatively constant over long periods of time.

Negative Feedback Mechanisms

- Stability of an internal environmental variable achieved by balancing **inputs** and **outputs**.
- In a **negative feedback** control system, a change in the variable being regulated brings about responses that tend to push the variable in the direction opposite to the original change.
- The **set point** is the numerical value of the variable measured at steady state.
- Negative feedback minimizes changes from the set point of the system, leading to stability.

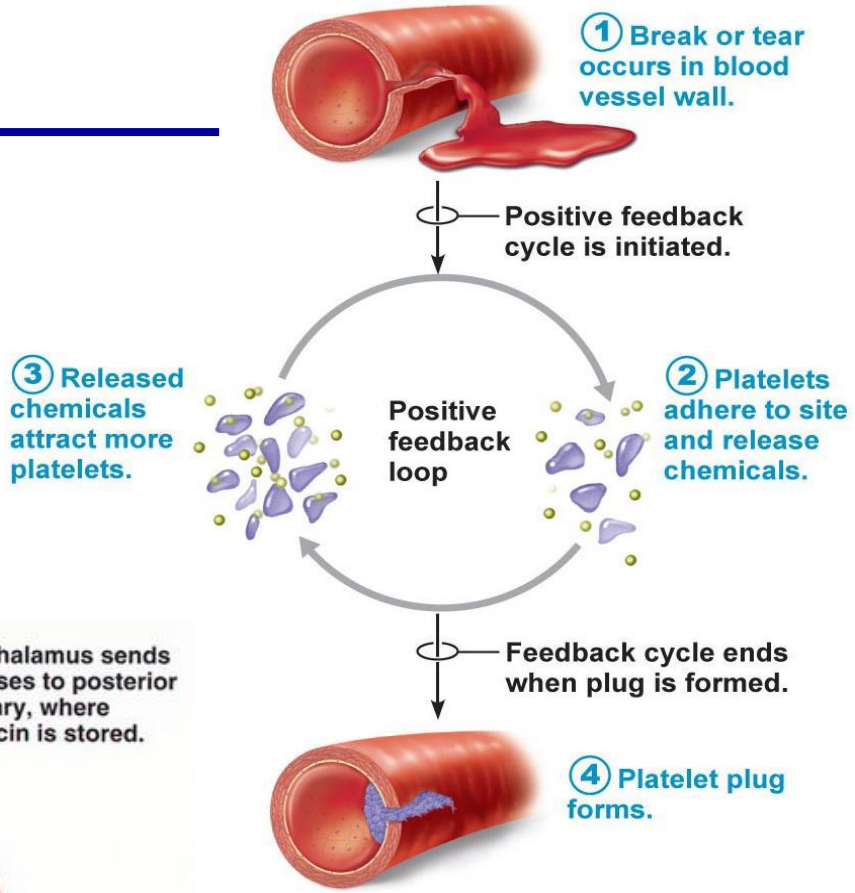


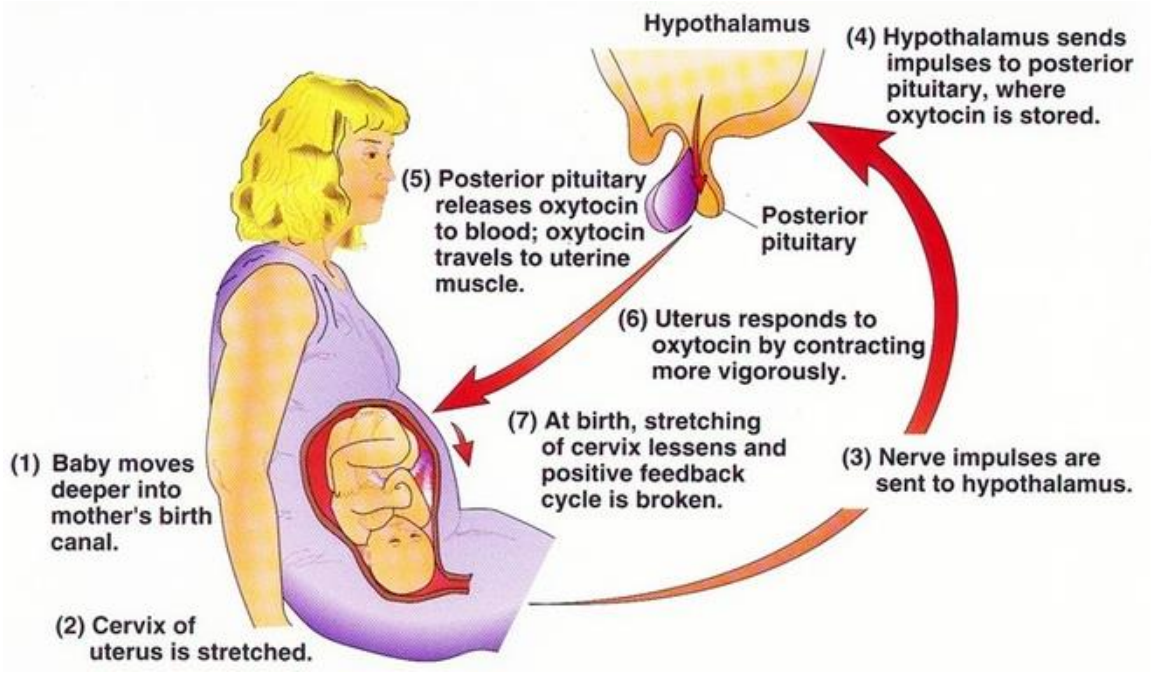
Negative Feedback Mechanisms

- A **steady state** is defined as a system in which a particular variable is not changing, but energy must be added continuously to maintain a constant condition.
- It differs from **equilibrium**, in which a particular variable is not changing but no input of energy is required.

Positive Feedback

- Positive feedback, which accelerates a process, is less common because it pushes values away from the set point.
- Often used when there is a goal to be attained





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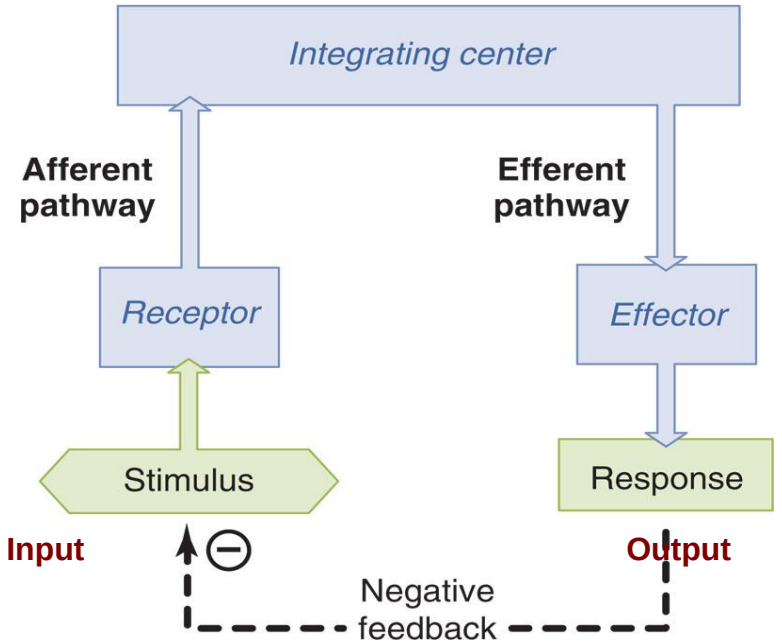
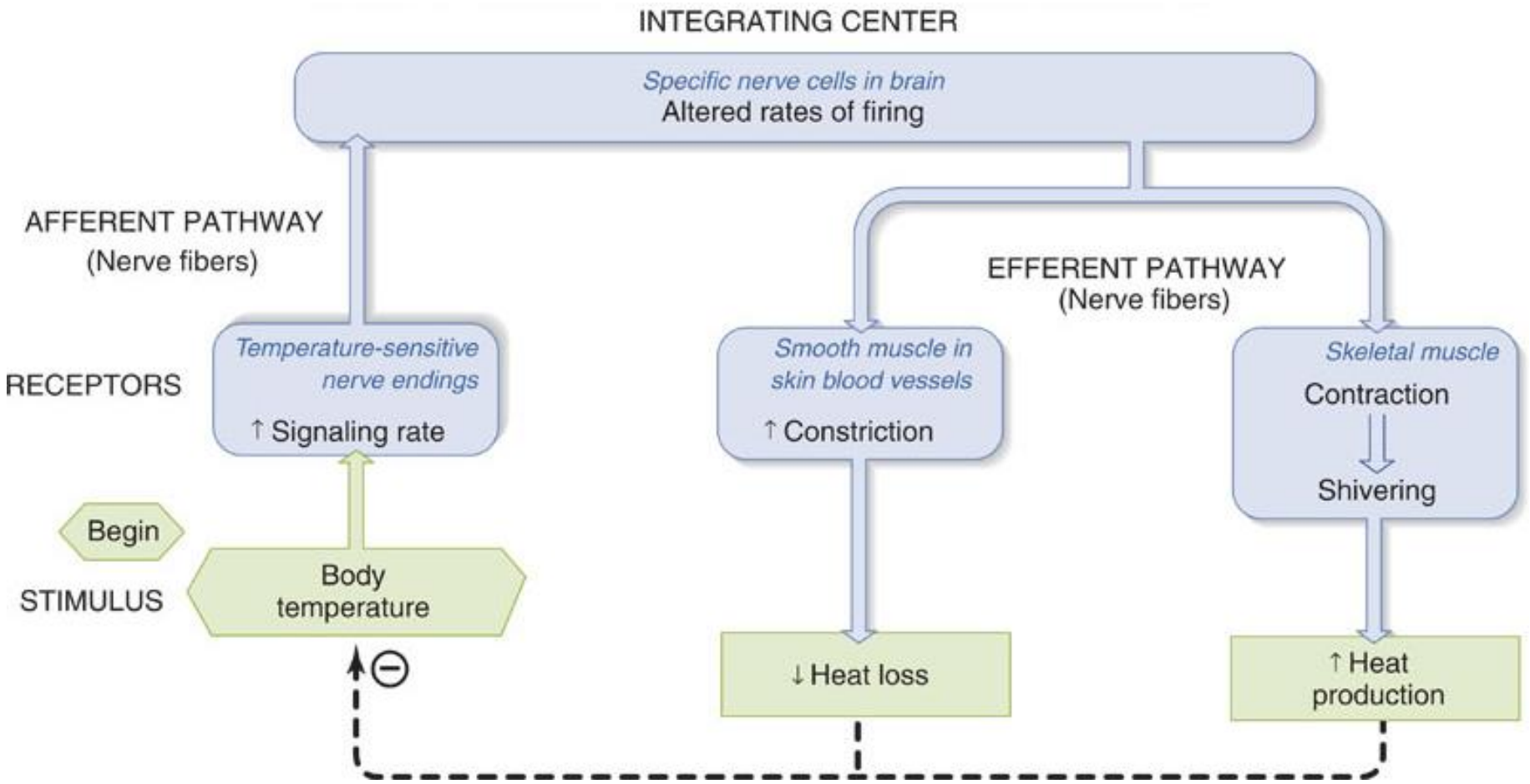
Components of Homeostatic Control Systems

- Multiple organ systems control a single variable. Homeostasis requires communication between different systems.
- Signals relayed by: nervous system and endocrine system (hormones).
- Homeostatic control mechanisms are examples of reflexes.
- A ***reflex*** is an involuntary (built-in) response to a particular stimulus. Many reflexes occur without our awareness.
- A pathway describing a reflex known as a ***reflex arc***.
- **Components of a reflex arc:** receptor, afferent pathway, integrating center, efferent pathway, and effector.



General components of a reflex arc in a negative feedback control system

A Reflex Arc for Body Temperature



Homeostatic Imbalance

- Numerous physiological variables must be maintained homeostatically.
- A person may be homeostatic for one variable but not for another. For (e.g. blood Na^+ may be normal but CO_2 levels may be abnormally high due to a lung disease).
- When homeostasis is lost for one variable, it may trigger a series of changes in other variables. Dramatic changes in just one variable can have life-threatening consequences.
- Certain diseases or illnesses can be characterized as a loss of homeostasis in one or more systems in the body (**homeostatic imbalance**).
- Because so many properties of the internal environment are closely interrelated, it is often possible to keep one property relatively constant only by moving others away from their usual set point. This is referred to as competing or "clashing demands".

Homeostatic Control Systems Review

How does the body react to change?

TABLE 1–2 *Some Important Generalizations About Homeostatic Control Systems*

1. Stability of an internal environmental variable is achieved by balancing inputs and outputs. It is not the absolute magnitudes of the inputs and outputs that matter, but the balance between them.
2. In negative feedback systems, a change in the variable being regulated brings about responses that tend to move the variable in the direction opposite the original change—that is, back toward the initial value (set point).
3. Homeostatic control systems cannot maintain complete constancy of any given feature of the internal environment. Therefore, any regulated variable will have a more-or-less narrow range of normal values depending on the external environmental conditions.
4. The set point of some variables regulated by homeostatic control systems can be reset—that is, physiologically raised or lowered.
5. It is not always possible for homeostatic control systems to maintain constancy in every variable in response to an environmental challenge. There is a hierarchy of importance, so that the constancy of certain variables may be altered markedly to maintain others at relatively constant levels.

CHAPTER 14

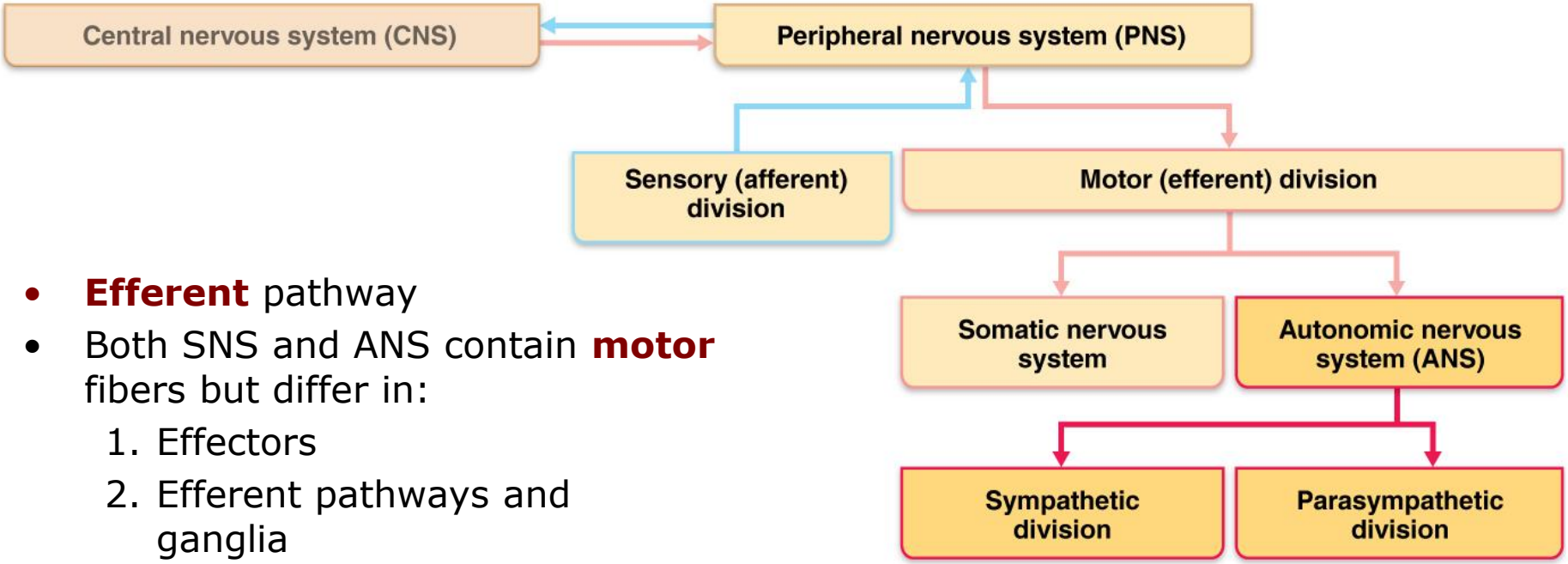
The Autonomic Nervous System

The Autonomic Nervous System

- **ANS** consists of **motor** neurons that:
  - Innervate smooth muscles, cardiac muscle, and glands
  - Makes adjustments to ensure optimal support for body activities
  - Shunts blood to areas that need it, adjusts heart rate, blood pressure, digestive processes, etc.
  - Operates via subconscious control

- Also called involuntary nervous system or general visceral motor system

Overview of Nervous System Organization

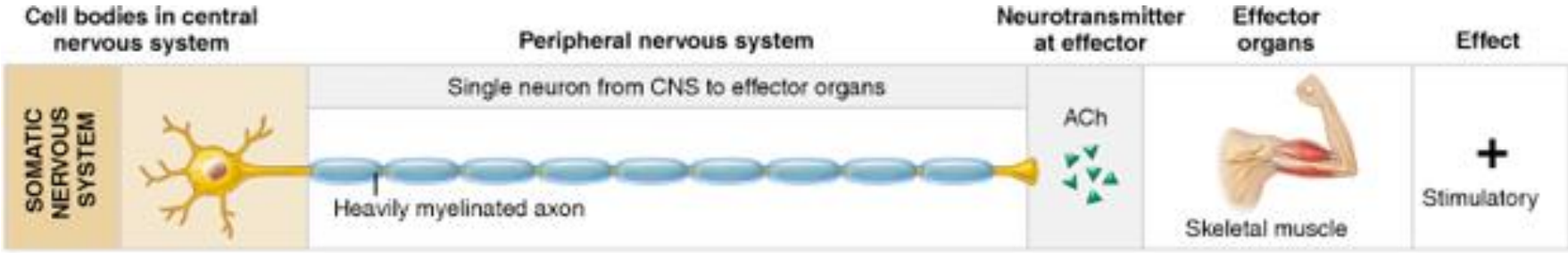


- **Efferent** pathway
- Both SNS and ANS contain **motor** fibers but differ in:
  1. Effectors
  2. Efferent pathways and ganglia
  3. Target organ responses to neurotransmitters

- Two divisions of ANS
  - Sympathetic
  - Parasympathetic

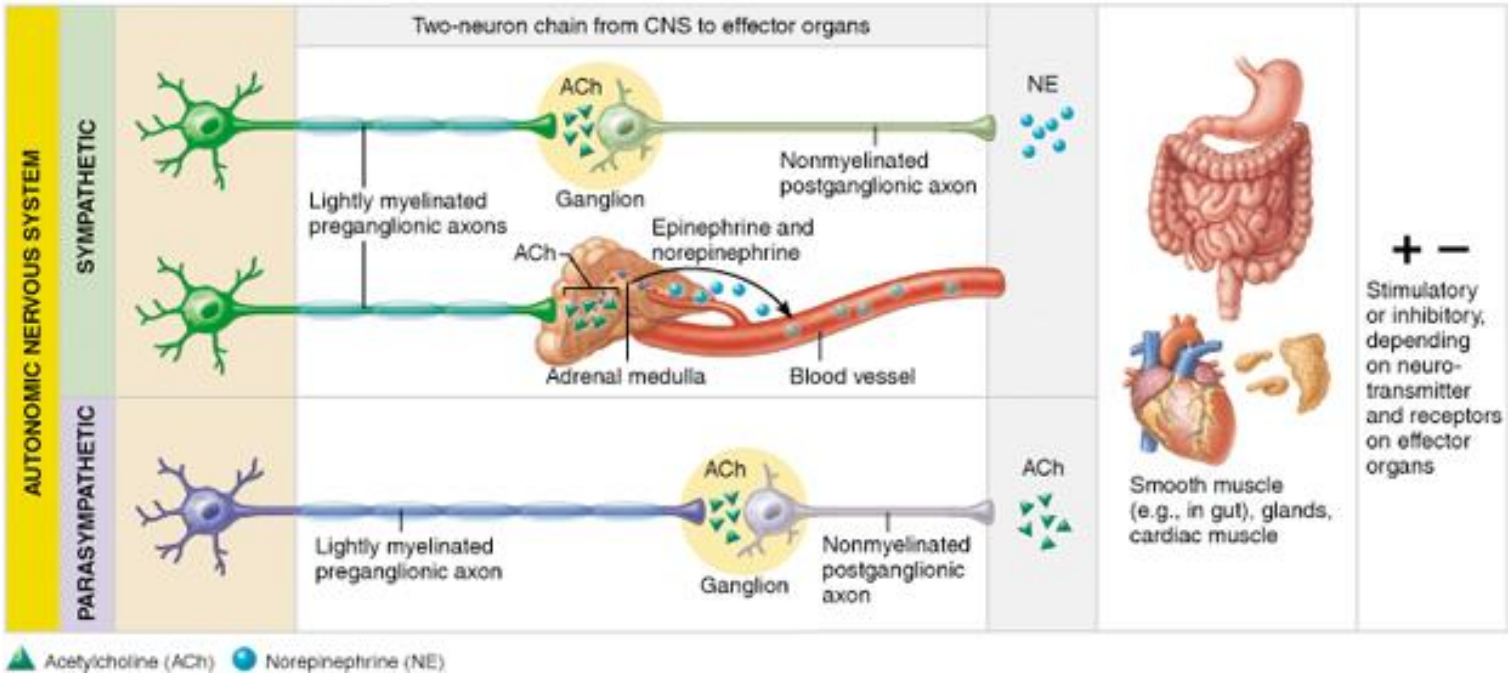
Somatic Nervous System

1. **Effectors -** skeletal muscles
2. **Efferent pathways and ganglia**
   - Cell body is in CNS, and a single, thick myelinated (group A) axon extends in spinal or cranial nerves directly to skeletal muscle
3. **Target organ responses to neurotransmitters**
   - All somatic motor neurons release acetylcholine (ACh)
   - Effect is ALWAYS stimulatory



Autonomic Nervous System

1. **Effectors:** cardiac muscle, smooth muscle, and glands
2. **Efferent pathways and ganglia:** Two-neuron chain
   - Preganglionic neuron: cell body in CNS with thin, lightly myelinated (group B) preganglionic axon extending to ganglion
   - Postganglionic neuron (outside CNS): cell body synapses with preganglionic axon in **autonomic ganglion** with nonmyelinated (group C) postganglionic axon that extends to effector organ
3. **Target organ responses to neurotransmitters**
   - Preganglionic fibers release Ach; Postganglionic fibers release norepinephrine or ACh at effectors; Effect is stimulatory or inhibitory, depending on type of receptor



Divisions of Autonomic Nervous System

- Two branches of ANS:
  - **Parasympathetic** division: promotes maintenance functions, conserves energy
  - **Sympathetic** division: mobilizes body during activity

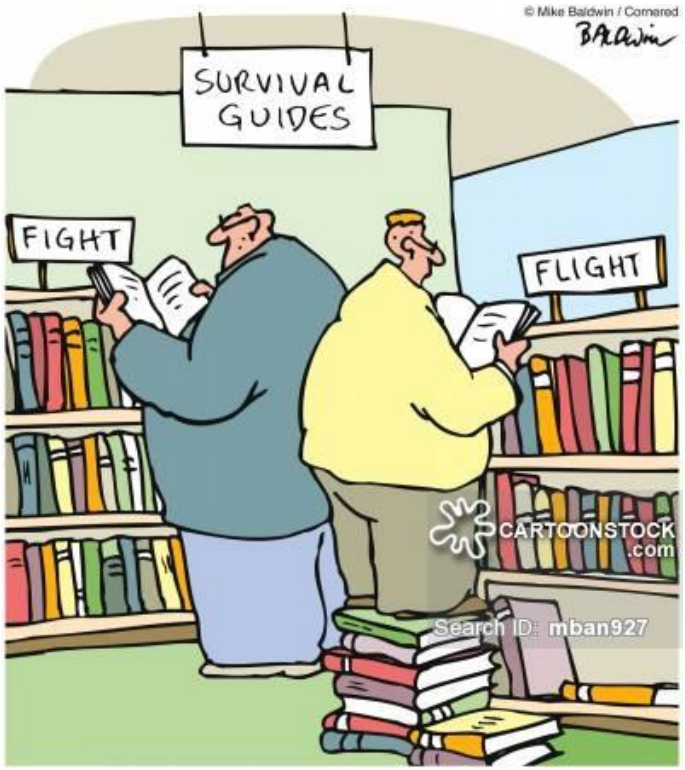
- **Dual innervation**: all visceral organs are served by both divisions, but these divisions cause opposite effects

Role of the Parasympathetic Division

- Referred to as "rest-and-digest" system
- Keeps body energy use as low as possible, even while carrying out maintenance activities
  - Directs digestion, diuresis, defecation
- Example: person relaxing and reading after a meal
  - Blood pressure, heart rate, and respiratory rates are low
  - Gastrointestinal tract activity is high
  - Pupils constricted, lenses accommodated for close vision

Role of the Sympathetic Division

- Mobilizes body during activity
- Referred to as "fight-or-flight" system
- Exercise, excitement, emergency, embarrassment (and exams!) activate sympathetic system
  - Increased heart rate; dry mouth; cold, sweaty skin; dilated pupils
  - Think more clearly
- During vigorous physical activity:
  - Shunts blood to skeletal muscles and heart
  - Dilates bronchioles
  - Causes liver to release glucose



Key Anatomical Differences between ANS Divisions

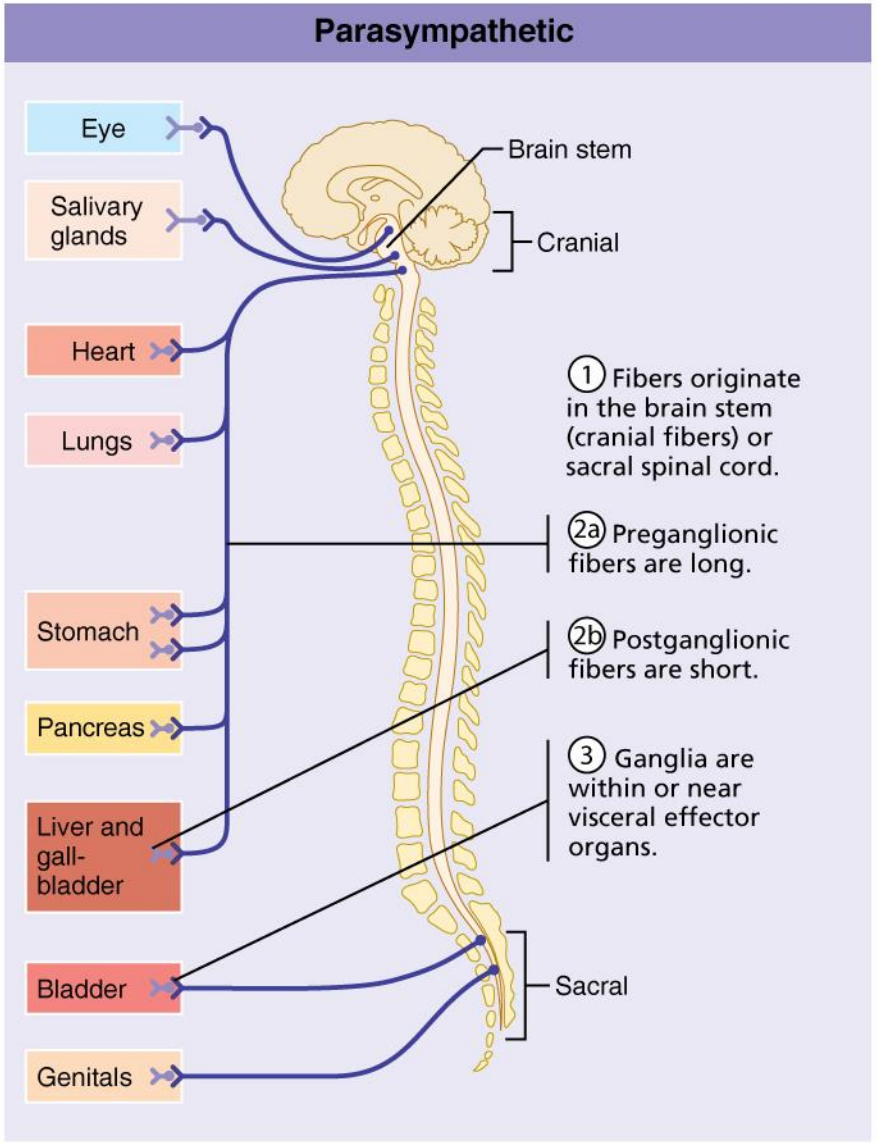
Three main anatomical differences between sympathetic and parasympathetic divisions:

Parasympathetic:

1. **Sites or origin**
   - Parasympathetic fibers are craniosacral; originate in brain stem and sacral spinal cord

2. **Relative lengths of fibers**
   - Parasympathetic has long preganglionic and short postganglionic fibers

3. **Location of ganglia**
   - Parasympathetic ganglia are located in or near the their visceral effector organ



Key Anatomical Differences between ANS Divisions

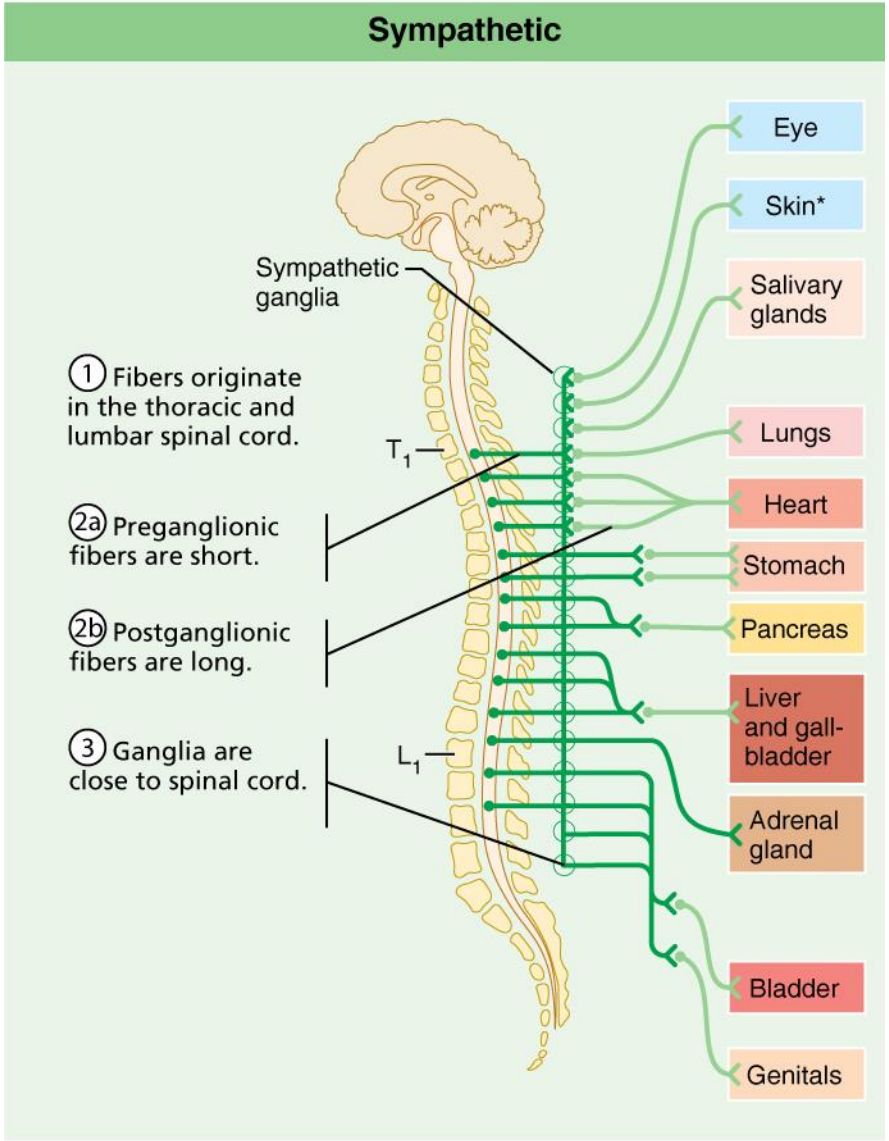
Three main anatomical differences between sympathetic and parasympathetic divisions:

Sympathetic:

1. **Sites or origin**
   - Sympathetic fibers are thoracolumbar; originate in thoracic and lumbar regions of spinal cord

2. **Relative lengths of fibers**
   - Sympathetic has short preganglionic and long postganglionic

3. **Location of ganglia**
   - Sympathetic ganglia lie close to spinal cord



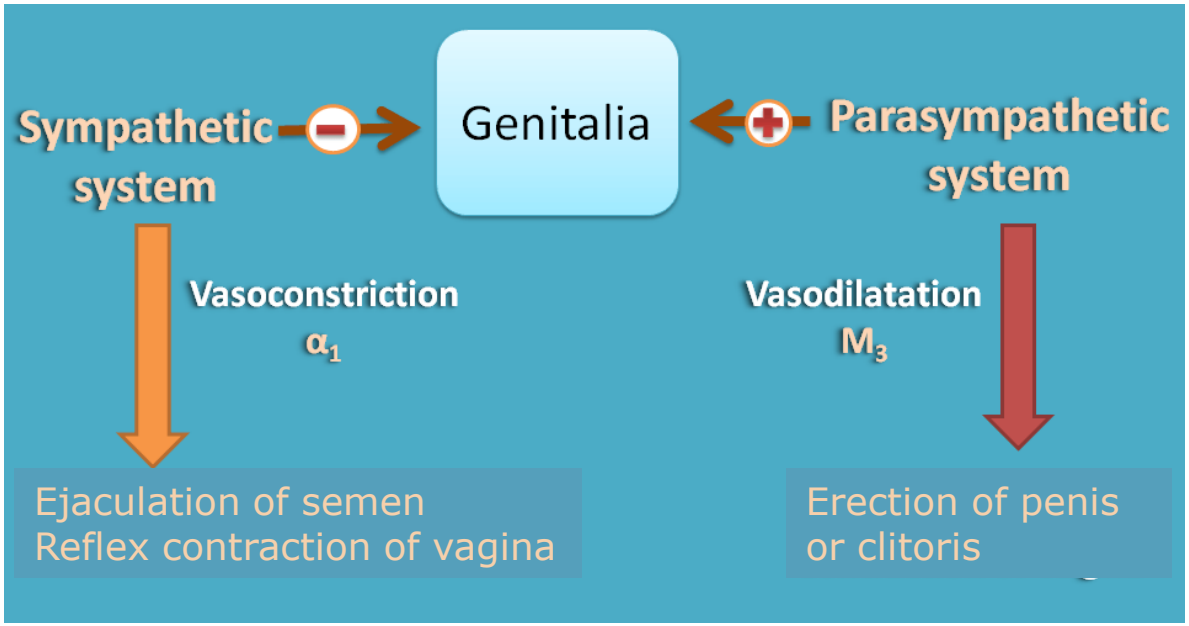
Antagonistic Interactions

- Most visceral organs have *dual innervation*
- Action potentials continually fire down axons of both divisions, producing a dynamic **antagonistic interaction**
  - Works to precisely control visceral activity

- Dynamic antagonism allows for precise control of visceral activity
  - Sympathetic division increases heart and respiratory rates and inhibits digestion and elimination
  - Parasympathetic division decreases heart and respiratory rates and allows for digestion and discarding of wastes
  - One division usually predominates, but in a few cases, divisions have a **cooperative effect**

Cooperative Effects

- Best example of cooperation between two divisions seen in control of external genitalia
- Parasympathetic fibers cause vasodilation and are responsible for erection of penis or clitoris
- Sympathetic fibers cause ejaculation of semen in males and reflex contraction of a female's vagina

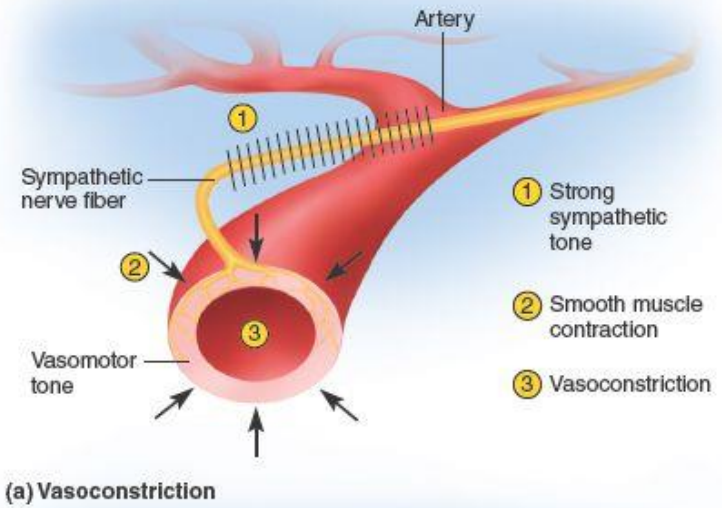


Sympathetic and Parasympathetic Tone

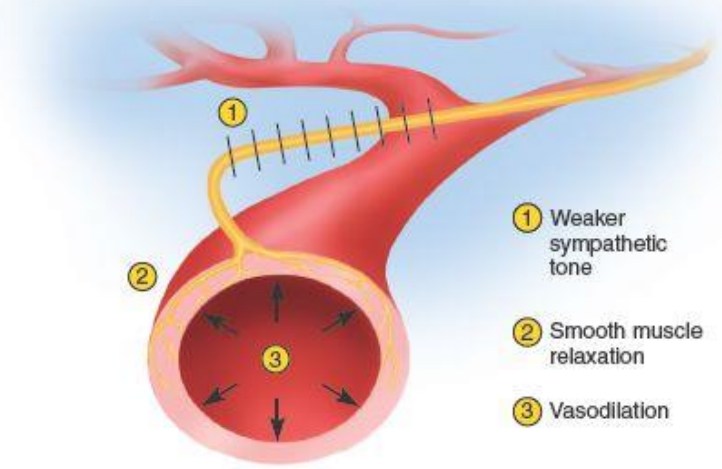
- Both ANS divisions are partially active, resulting in a basal sympathetic and parasympathetic tone

Sympathetic (vasomotor) tone:

- Blood vessel smooth muscle is innervated by sympathetic fibers only, so this division controls blood pressure, even at rest
- Continual state of partial constriction of blood vessels
  - Blood pressure ↓, sympathetic fibers fire faster - ↑ constriction - blood pressure ↑
  - Blood pressure ↑ ↑, sympathetic fibers fire less - ↓ constriction (dilation) - blood pressure ↓
  - Allows sympathetic system to shunt blood where needed, for example, to heart and skeletal muscles during emergency
  - Vasoconstriction of skin blood vessels to minimize bleeding if injury occurs during stress or exercise



(a) Vasoconstriction



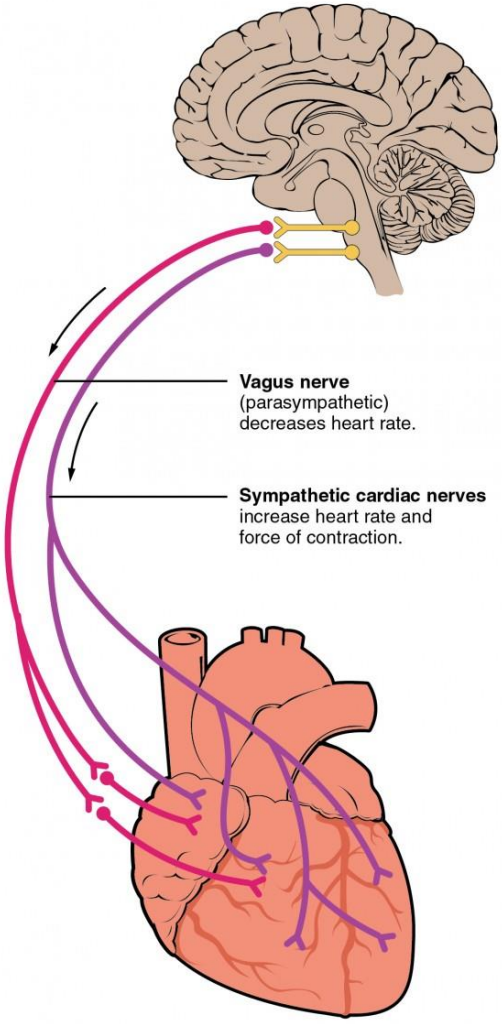
(b) Vasodilation

Sympathetic and Parasympathetic Tone

- Parasympathetic division normally dominates heart and smooth muscle of digestive and urinary tract organs, and it activates most glands except for adrenal and sweat glands
  - Slows the heart and dictates normal activity levels of digestive and urinary tracts
  - These organs also exhibit **parasympathetic tone** where they are always slightly activated

- The sympathetic division can override these effects during times of stress

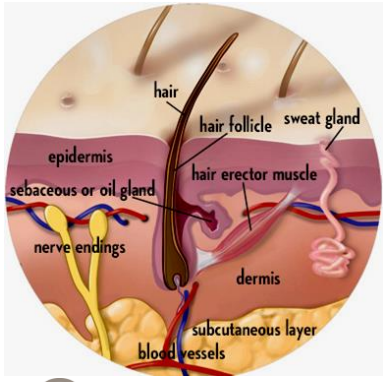
- Drugs that block parasympathetic responses increase heart rate and cause fecal and urinary retention (e.g. **atropine**: anti-cholinergic)



Unique Roles of the Sympathetic Division

- Adrenal medulla, sweat glands, arrector pili muscles, kidneys, and almost all blood vessels receive only sympathetic fibers

- Other unique functions of sympathetic division include:
  - **Thermoregulatory responses to heat**
    - When body temperatures rise, sympathetic nerves:
      1. Dilate skin blood vessels, allowing heat to escape
      2. Activate sweat glands
    - When body temperatures drop, blood vessels constrict
  - **Release of renin from kidneys**
    - Sympathetic system causes release of renin from kidneys that in turn activates a system that increases blood pressure
  - **Metabolic effects**
    - Increases metabolic rates of cells
    - Raises blood glucose levels
    - Mobilizes fats for use as fuels
    - Increased mental alertness
    - Increased speed/strength of muscle contraction



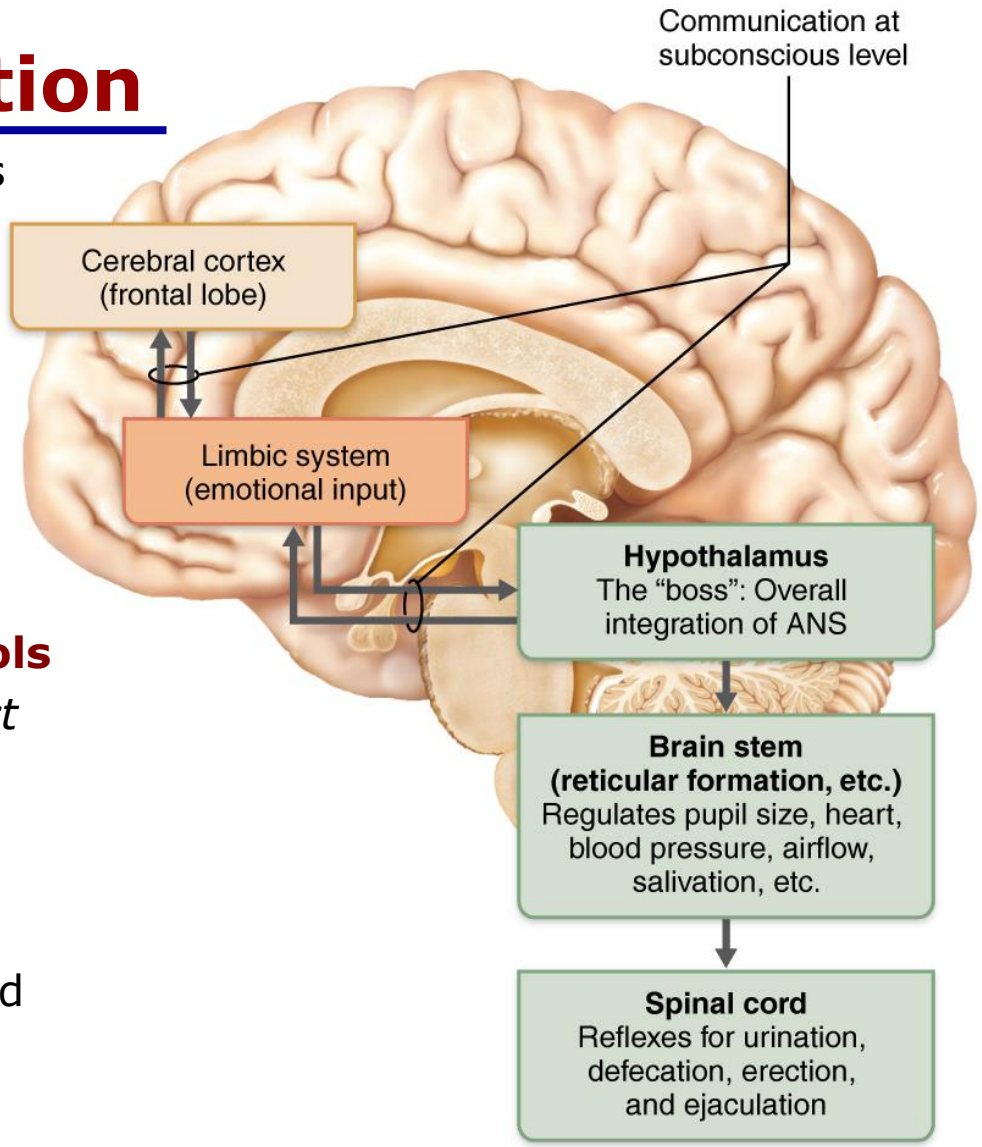
Localized Versus Diffuse Effects

- Parasympathetic division tends to elicit short-lived and highly localized control over effectors
  - ACh is quickly destroyed by acetylcholinesterase
- Sympathetic division tends to be longer-lasting with bodywide effects
  - NE is inactivated more slowly than ACh
  - NE and epinephrine hormones from adrenal medulla have prolonged effects that last even after sympathetic signals stop
  - Takes time to "come down" after traumatic event

Control of ANS Function

Three levels of control of ANS by centers in:

1. **Brain stem and spinal cord**
2. **Hypothalamus,**
3. **Cerebral cortex**



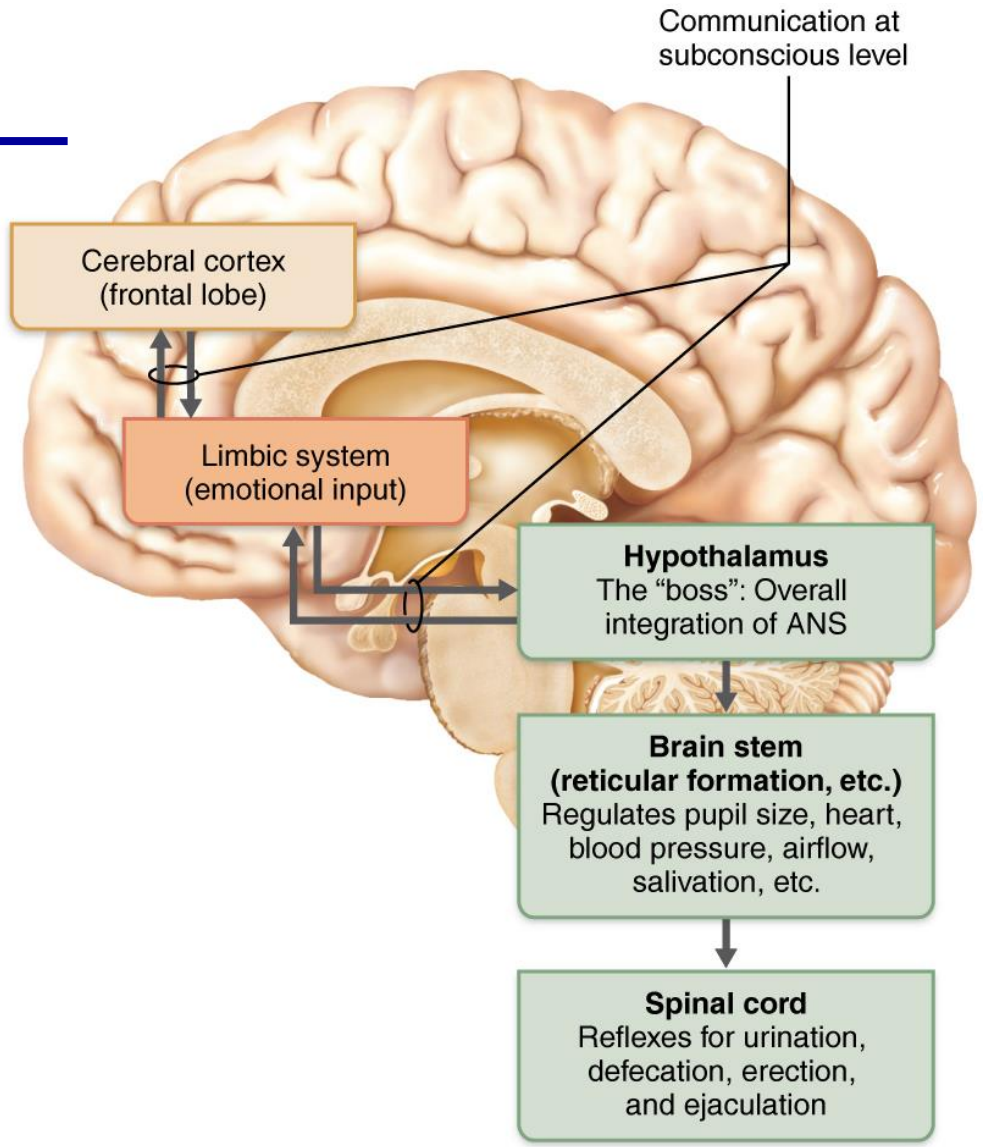
1. Brain stem and spinal cord controls

- Brain stem reticular formation - *direct* influence over ANS
- Medullary centers regulate heart rate and blood vessel diameter; gastrointestinal activity
- Midbrain controls muscles of pupil and lens
- Spinal cord controls defecation and micturition (peeing) - subject to conscious override

Levels of ANS Control

Hypothalamic controls

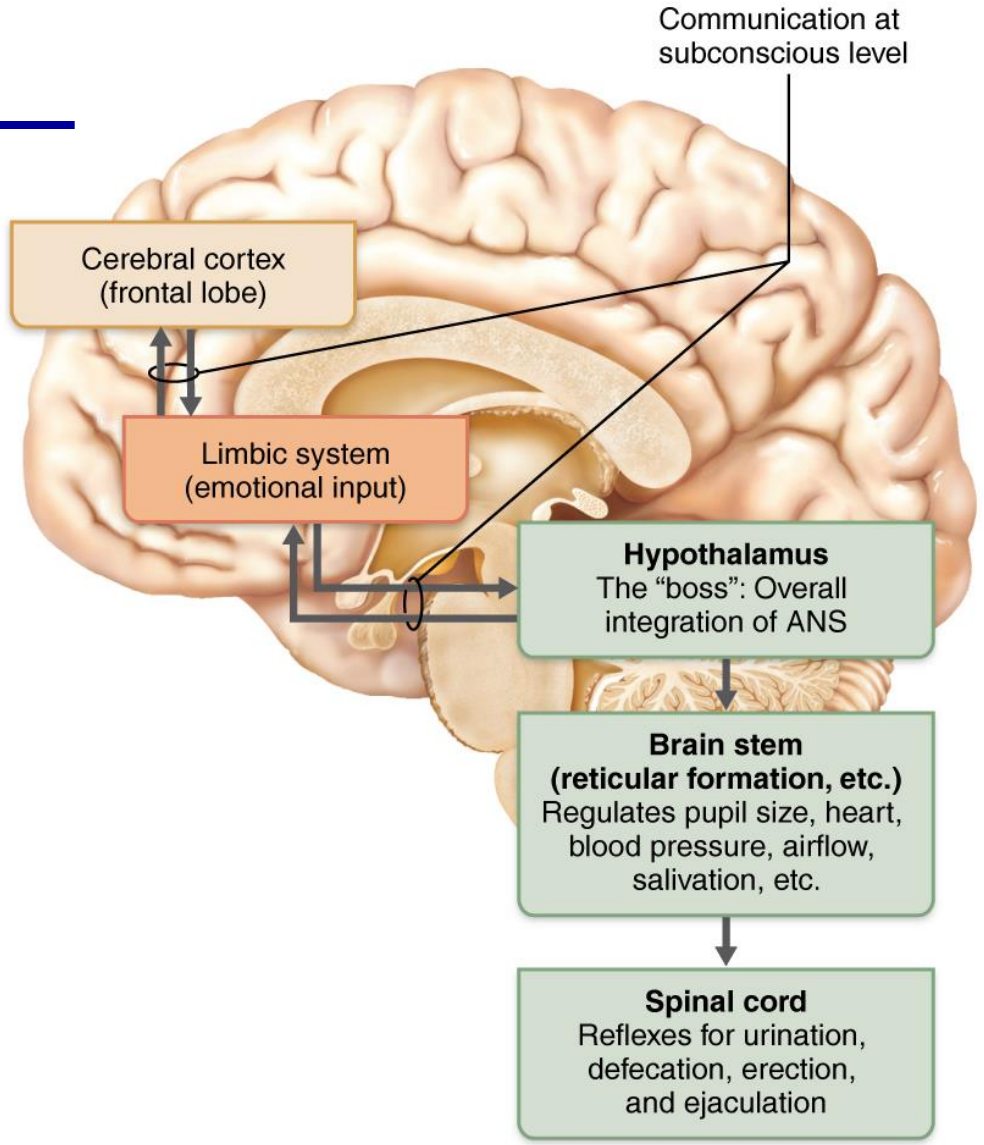
- Main integrative center of ANS activity
- Anterior - parasympathetic functions; posterior – sympathetic
- Direct or indirect control through reticular system or spinal cord
- Centers of hypothalamus control:
  - Heart activity, blood pressure, body temperature, water balance, and endocrine activity
  - Emotional responses (rage, fear, pleasure) activated through limbic system signal hypothalamus to activate fight-or-flight system



Levels of ANS Control

Cortical controls

- Cortical input may modify ANS but does so subconsciously
  - Works through limbic system structures on hypothalamic centers
- Voluntary cortical control of some visceral activities is possible
  - Biofeedback or meditation
    - Awareness of physiological conditions with goal of consciously influencing them
    - Biofeedback training allows some people to control migraines and manage stress



Clinical – Homeostatic Imbalance 14.1

- **Autonomic neuropathy**: damage to autonomic nerves that is a common complication of diabetes mellitus
- Early signs include sexual dysfunction (75% of males)
- Other frequent symptoms include dizziness after standing suddenly (poor blood pressure control), urinary incontinence, sluggish eye pupil reactions, and impaired sweating
- Best way to prevent diabetic neuropathy is to maintain good blood glucose levels

Disorders of the ANS

- Many ANS disorders involve deficient control of smooth muscle activity
  - ***Hypertension*** (high blood pressure)
    - Overactive sympathetic vasoconstrictor response to **stress**
    - Heart must work harder, and artery walls are subject to increased wear and tear
    - Can be treated with adrenergic receptor-blocking drugs (beta-blockers)
  - **Ulcers**
    - Increased sympathetic vasoconstrictor response to stress
    - Decreases blood flow to stomach wall