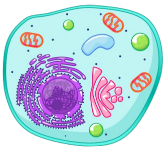
Brain & Integration

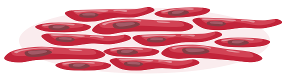
Contents

Levels of an Organism

Cells → **Tissues** → **Organs** → **Systems** → **Organism**

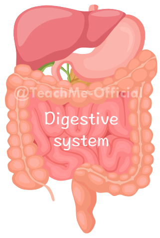


Cells: Each cell has all the DNA, but only some of it used to carry out their specialized function.



Tissues: A GROUP OF CELLS that have similar structure that function together as a unit. There are 4 tissues types.

Organs: A unit that carries out a unique function as a result of the COMBINATION OF TISSUES that it's comprised from.

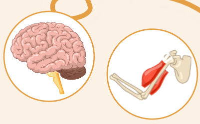


Systems: A COMBINATION OF ORGANS, which carry out RELATED functions, that together serve to carry out a LARGER function.

Organism: Comprised of DIFFERENT SYSTEMS to be able to collectively survive and carry out the functions of life to survive.

Emergent Properties

Those that exist when the sum of all the parts creates features that do not exist within the individual components.



"Muscle can't move without the brain"

Like a band!

"All body systems work in unison. Requires appropriate COORDINATION."

Communication & Integration

The body is controlled by two main systems: The **endocrine system** and the **nervous system**. The communication by these two systems can be CONSCIOUS (AWARE). E.g., Moving your pinky. It can also be UNCONSCIOUS (NOT AWARE). E.g., Digesting your food.

On PAGE 9

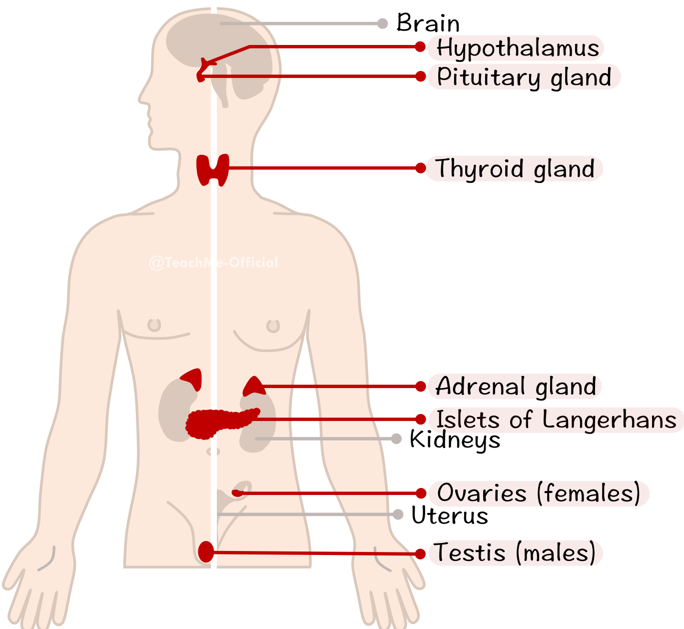
The Endocrine System (Hormones)

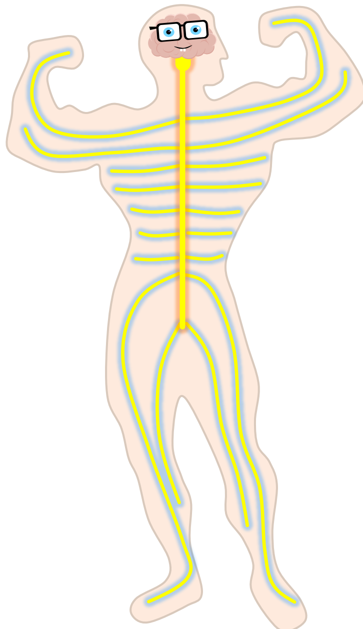
- Endocrine glands (hormone secreting factories).
- Travel through the BLOODSTREAM to target tissue.
- Only INVOLUNTARY functions are controlled.
- Responses are typically SLOW but are LONG LASTING.

On PAGE 2

The Nervous System (Electrical impulses)

- CNS & PNS (Central & Peripheral Nervous System).
- Send messages via NEURONS.
- Control VOLUNTARY OR INVOLUNTARY actions.
- Responses occur QUICKLY but are SHORT LIVED.





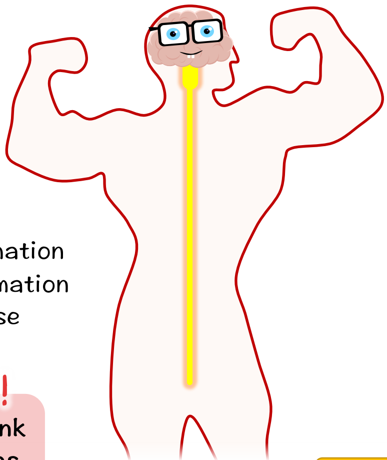
Brain & Integration

I. The Nervous System

The NERVOUS SYSTEM can be further subdivided into two main systems: the central and peripheral nervous systems. Each playing a crucial role in the transmission of signals through the body.

Central Nervous System

"Big Boss" CNS



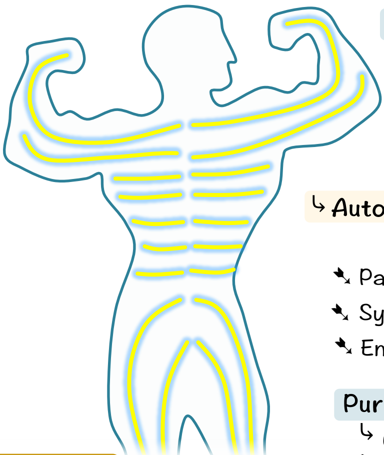
Includes:
- Brain
- Brainstem
- Spinal cord

Purpose:
- Receives information
- Interpret information
- Initiate response

BIG BRAIN TIP!
For the ANS. Think of "Autonomic" as "Automatic"

Peripheral Nervous System

"Worker of Big Boss" PNS



Includes:
- Somatic nervous system (Voluntary/conscious)
  - Motor neurons
  - Sensory neurons
- Autonomic nervous system (ANS) (Involuntary/unconscious)
  - Parasympathetic neurons [Rest & Digest]
  - Sympathetic neurons (Fight or Flight)
  - Enteric nervous system [Digestive...]

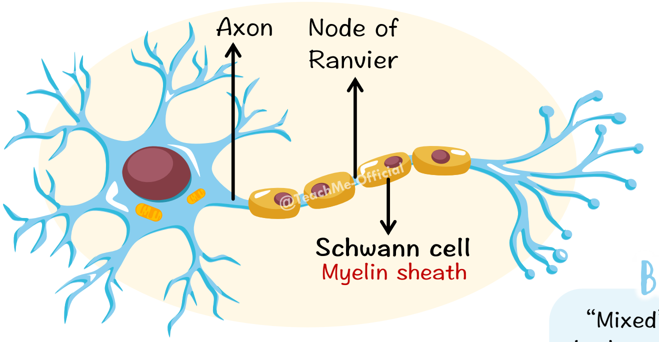
Purpose:
- Carry info to the CNS
- Carry info away from CNS towards muscle & glands etc.

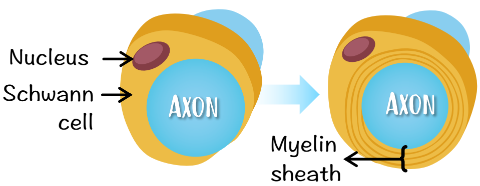
- Nervous System
  - Central Nervous System
    - Brain
    - Brainstem
    - Spinal Cord
  - Peripheral Nervous System
    - Somatic Nervous System
      - Motor Neurons
      - Sensory Neurons
    - Autonomic Nervous System
      - Parasympathetic
      - Sympathetic
      - Enteric nervous system

What cells make up the nervous system?

NEURONS (more in C2.2)

Neurons are individual cells that carries electrical impulses (signals) from one point in the body to another.





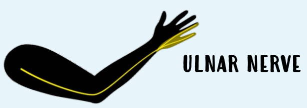
SCHWANN CELLS wrap around the axon forming multiples layers: "MYELIN SHEATH"

Difference between a NERVE & a NEURON?

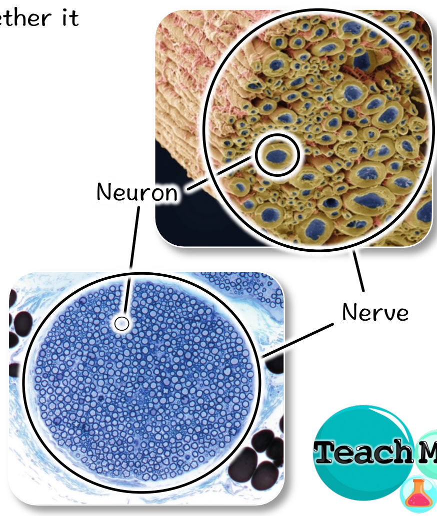
When many individual NEURONS grouped or bundle together it forms a NERVE.

BIG BRAIN TIP!

"Mixed" nerves refers to having both **motor** AND **sensory** neurons. There cannot be a "mixed neuron" only "mixed nerve".



The **ulnar nerve** for example has both sensory and motor abilities in the 4th and 5th fingers of the hand.



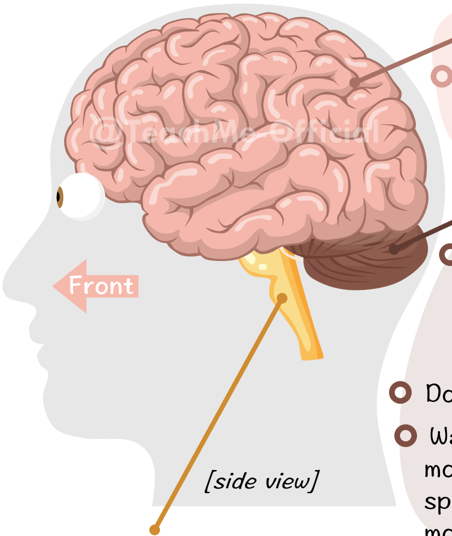
C3.1

Brain & Integration

Within the CENTRAL NERVOUS SYSTEM, we can find a crucial structure which is capable of receiving multiple signals (inputs) and even store them in different places (as memory). This structure is also capable of initiating responses such as muscle movement, initiating the heartbeat and controlling breathing. This structure is the BRAIN!

ANATOMY & FUNCTIONS OF THE BRAIN

The brain is composed of three main components: (1) Cerebrum, (2) Cerebellum, (3) Brainstem.



CEREBRUM

- In charge of CONSCIOUS activities
- Can INITIATE

CEREBELLUM

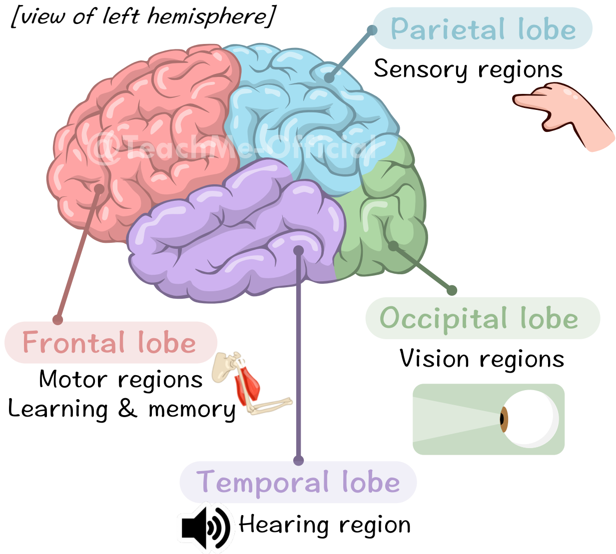
- COORDINATES voluntary movements and controls balance (posture) and equilibrium.
- Does NOT INITIATE. Only modifies.
- Walking, hand and finger movements, eye movements, speech... Allows smooth movements.

BRAINSTEM

- RELAYS between the cerebrum, cerebellum & spinal cord.
- Responsible for most autonomic nervous system (ANS) functions.
- The medulla (or medulla oblongata) regulates both breathing and heart rate. See page 6,7, and 8.

The CEREBRUM is composed of the right and left hemispheres, each hemisphere contains four lobes:

[view of left hemisphere]



Conscious

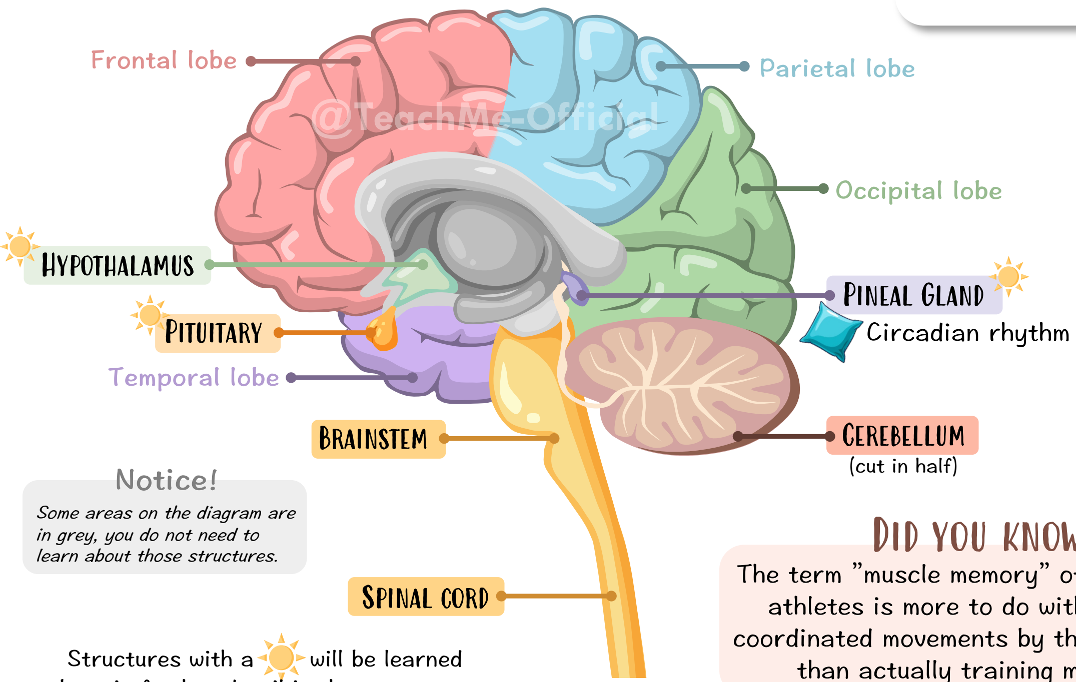
Muscle (coordination), sensations (eye, ear, mouth), emotions, problem solving, memory...

Unconscious

Heart rate, breathing, blood pressure...

If we were to cut the brain in half (in between the eyes), remove the left hemisphere then from the side look at the brain, this is the view we would obtain:

Regions of the brain
[view of right hemisphere]



All the structures work in unison, with a multitude of interactions and connections between them – they do not work independently.

Notice!
Some areas on the diagram are in grey, you do not need to learn about those structures.

Structures with a ☀ will be learned about in further detail in the next pages.

DID YOU KNOW?

The term "muscle memory" often used by athletes is more to do with training coordinated movements by the cerebellum than actually training muscles.

Teach Me

Brain & Integration

Types of Receptors*

All the input received by the brain originates from various types of receptors capable of picking up different types of stimuli. Some of these signals can be picked up CONSCIOUSLY while others are UNCONSCIOUS.

**A neuron capable of transduction (conversion of a physical stimulus into an electrical signal - action potential).*

Conscious

I. CHEMORECEPTORS

Mainly on our tongue for tasting. Other locations (certain vessels).

(Chemicals)

II. PHOTORECEPTORS

Located within the retina of the eyes for visual information.

(Light waves)

III. MECHANORECEPTORS

Located in inner ear and sensitive to sound vibrations.

(Pressure)

IV. THERMORECEPTORS

Located in the skin to provide information on temperature.

(Temperature)

Unconscious

I. BARORECEPTORS

Located in carotid arteries and the aorta.

(Blood pressure)

II. OSMORECEPTORS

Located in carotid arteries and the hypothalamus of the brain.

(Water content & solutes)

III. PROPRIOCEPTORS

Located in muscles and joints.

(Positioning, for balance and coordination)

Receptors we focus on in this chapter

Neural Pathways

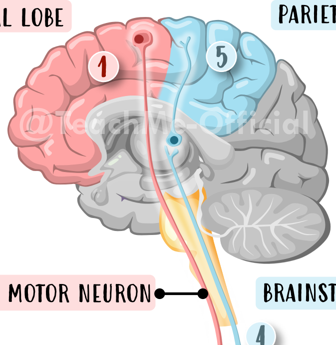
Sensations, motor signals or reflexes follow a different pathway within the nervous system.

Motor Neurons

CNS ➜ Muscle

Summary of steps:

1. Motor cortex (FRONTAL LOBE) sends signal via UMN.
2. UMN synapses with LMN.
3. LMN carries signal to muscle cell.
4. At the NEUROMUSCULAR JUNCTION (motor end plate), ACETYLCHOLINE (neurotransmitter) is released triggering MUSCLE CONTRACTION.

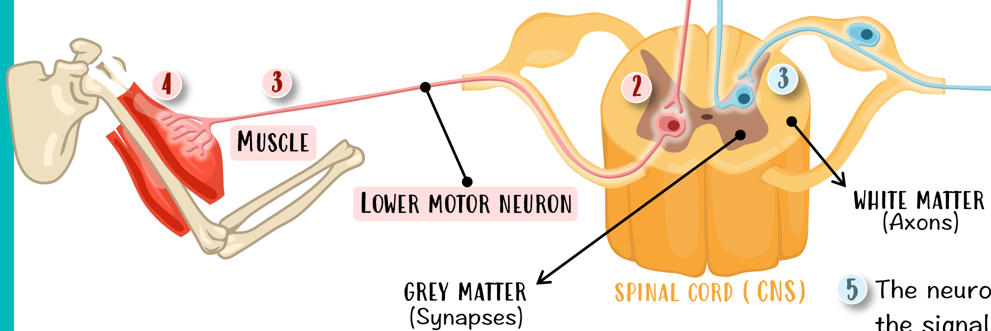


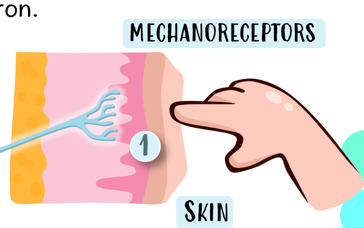
Sensory Neurons

Receptor ➜ CNS

Summary of steps:

1. Skin of the body contain sensory RECEPTORS. (mechanoreceptors) that is stimulated (touch).
2. Receptors converts & sends signal via ACTION POTENTIALS through your nerve to join a SPINAL NERVE eventually.
3. Enter spinal cord (CNS) GREY MATTER. Synapse with another neuron.





4. This neuron carries signal up the WHITE matter and up spinal cord through the BRAINSTEM.
5. The neuron synapses once more, and the signal is sent to the PARIETAL LOBE (cerebrum). Sensation is perceived. (Consciousness).

*UMN = Upper Motor Neuron

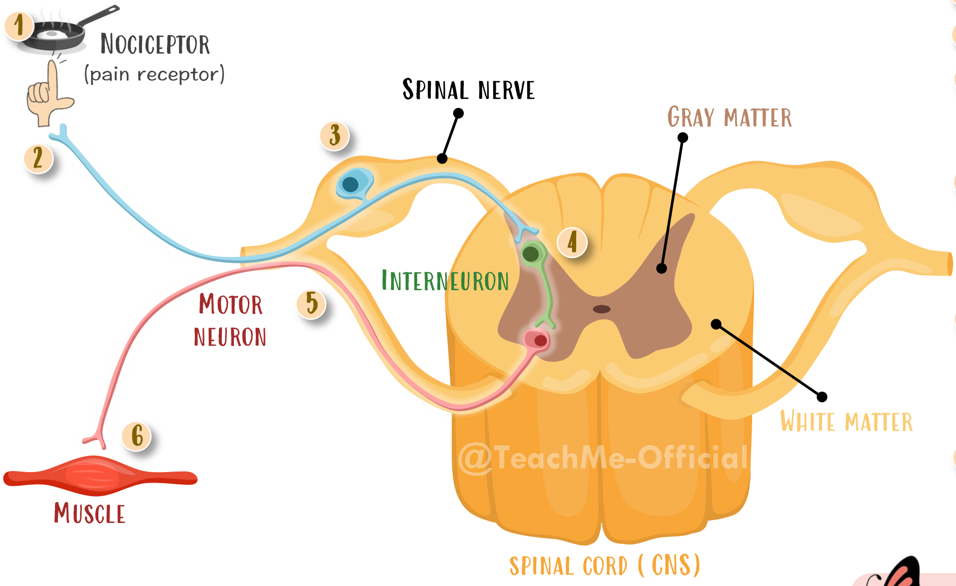
*LMN = Lower Motor Neuron

Brain & Integration

Pain Reflex Arc

What: Immediate, involuntary response to painful stimulus

Components: Three neurons (sensory neuron, interneuron, motor neurons).



Summary of steps:

1. Encounter a painful stimulus.
2. NOCICEPTORS stimulated.
3. Action potentials travels through the nerve and eventually joins one of the SPINAL NERVES.
4. After entering the spinal cord, the AFFERENT neurons synapses with a short INTERNEURON (relay neuron) located within the GREY MATTER.
5. The interneuron synapses with a motor neuron and the resulting action potentials go directly to arm muscles (the EFFECTOR).
6. Resulting in muscle movement that removes you from the painful stimulus.

Big Brain Tip!

Notice how the shape of grey matter in the spinal cord is similar to that of a butterfly.

Key considerations:

- Pulling finger away from painful stimulus occurs FASTER than sensing the pain.
- To sense pain the signal must first travel to CEREBRUM. Then a sensation is felt and a motor response formulated voluntarily. The pain reflex arc NEVER goes to the cerebrum.
- PURPOSE: Limit damage to body (quick reaction).

INTERNEURON – Located between a sensory and motor neuron. Only found in the CNS.

AFFERENT neurons – Neuron going towards the spinal cord.

EFFERENT neurons – Neuron going away from the spinal cord.

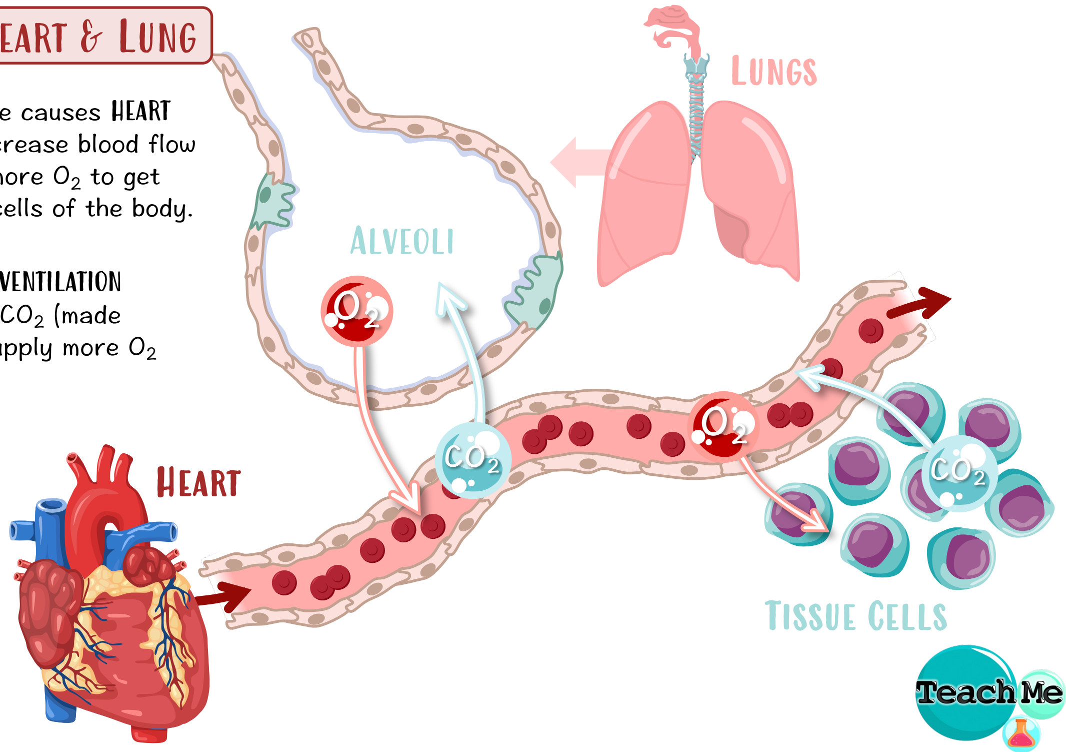
II. Control of the Heart & Lung

Compaired to at rest, exercise causes HEART RATE TO INCREASE in order to increase blood flow to the lungs. This allows for more O_2 to get picked up and delived to the cells of the body.

At the same time, the RATE OF VENTILATION INCREASES to get rid of excess CO_2 (made during cell respiration) and supply more O_2 to meet demand.

How does the heart know it needs to INCREASE HEART RATE?

How do the lungs know to INCREASE RATE OF VENTILATION?



Brain & Integration

Control of the Heart

The heart can be controlled in three different ways: **sensory information**, **baroreceptors** and **chemoreceptors**. The locations of the latter two may be seen on the diagram below.

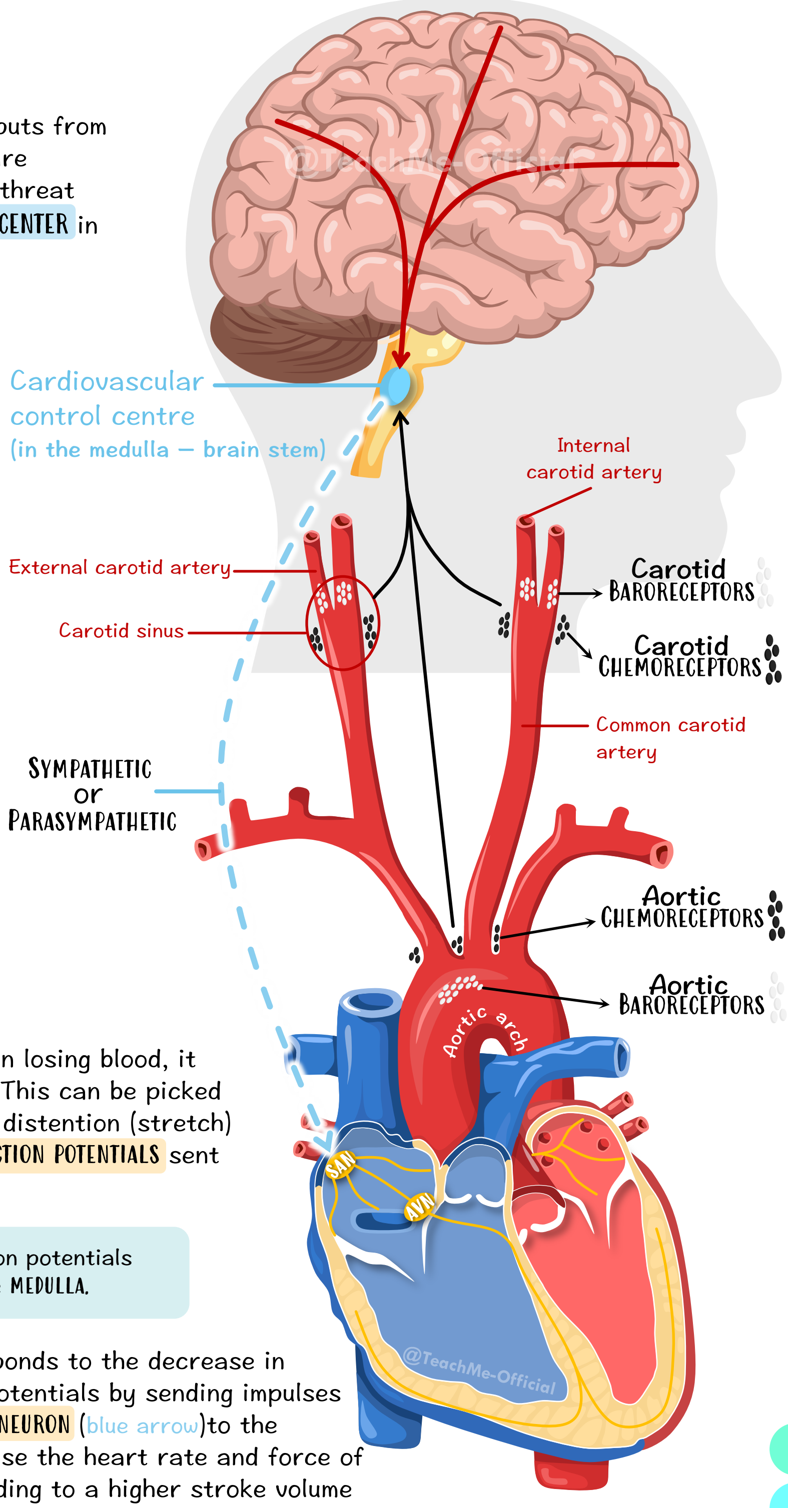
1 Sensory Information

When a person perceives a scary situation, sensory inputs from the special senses—such as sight, hearing, or smell—are processed by the brain and interpreted as a potential threat (red arrows). These influence the CARDIOVASCULAR CONTROL CENTER in the medulla.

This center will then stimulate SYMPATHETIC NEURONS (blue arrow) which target the SA node in the heart, to increase the heart rate. This allows for more blood to be pumped throughout the body in this situation of stress.

Inversely, at times of rest, the cardiovascular control center will stimulate PARASYMPATHETIC NEURONS (blue arrow) which would decrease the heart rate.

> **Sympathetic**
> system used to increase heart rate
> **Parasympathetic**
> system used to decrease heart rate

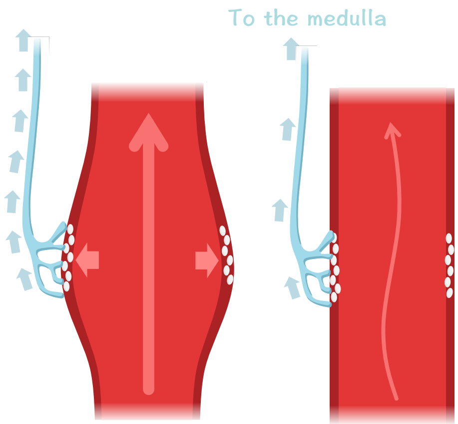


2 Baroreceptors

What	Specialized receptors to detect blood **pressure** in arterial blood vessels.
Where	Aortic arch and carotid sinus – within the wall of blood vessels.

If a person is for instance dehydrated or they have been losing blood, it causes the pressure within the blood vessels to be low. This can be picked up by the baroreceptors which sense a decrease in the distention (stretch) of the artery wall. This causes a DECREASE IN THE RATE OF ACTION POTENTIALS sent to the medulla (black arrows).

↓ Blood pressure → ↓ Distention (stretch) of artery wall → ↓ Rate of action potentials sent to the MEDULLA.



The MEDULLA responds to the decrease in rate of action potentials by sending impulses by a SYMPATHETIC NEURON (blue arrow) to the SA NODE to increase the heart rate and force of contraction, leading to a higher stroke volume (blood volume pumped by each heartbeat). Leads to blood pressure increase back to normal (negative feedback).

Vice versa **If blood pressure is high:**

Increased stretch of the artery wall increases the rate of action potentials sent to the medulla. Medulla responds by sending impulses to **parasympathetic** neurons to decrease heart rate.

Brain & Integration

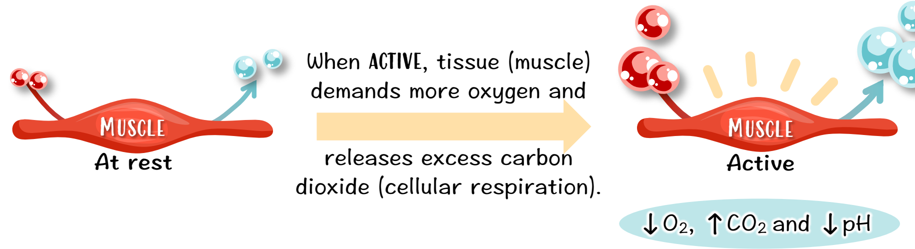
3 Chemoreceptors

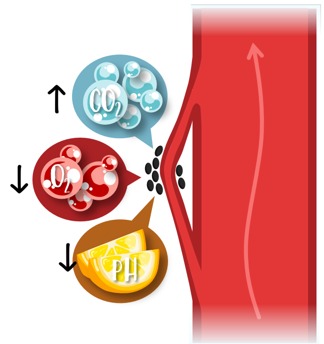
What Specialized receptors to detect blood:

- Oxygen levels
- pH levels
- Carbon dioxide levels

Where Near baroreceptors, but OUTSIDE the blood vessels.

When doing exercise or being active, tissues (especially muscles) demand more oxygen and release an excess of carbon dioxide in comparison to at rest. This is due to increased cellular respiration to produce ATP:





* Refer to the diagram on page 6

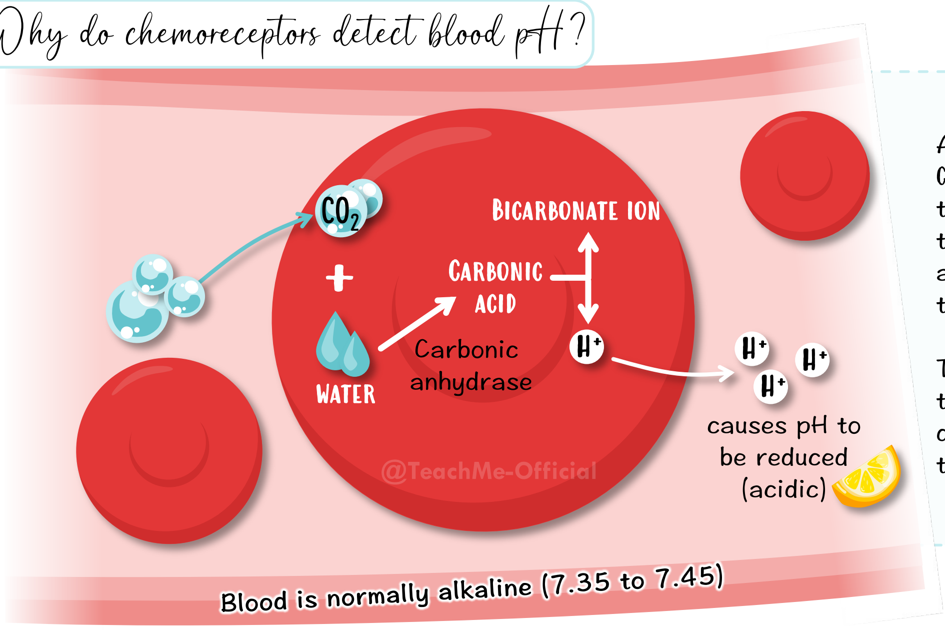
Increased cellular respiration is seen as a decrease in oxygen (↓O_2), an increase in carbon dioxide (↑CO_2) and a decrease in pH (↓pH) in the blood. Such changes can be detected by chemoreceptors and lead to a signal being sent to the CARDIOVASCULAR CENTER in the MEDULLA (black arrow). The center responds by sending SYMPATHETIC impulses (blue arrow) to the SA NODE to increase the heart rate and force of contraction, leading to higher stroke volume (blood volume pumped by each heartbeat). More blood sent to lungs to increase blood O_2 & reduce CO_2.

SYMPATHETIC system used to increase heart rate
PARASYMPATHETIC system used to decrease heart rate

Vice versa **If at rest:**

Increase oxygen, decreased carbon dioxide and increased pH lead to a signal being sent to the medulla which sends **parasympathetic** impulses to the SA node to decrease heart rate.

Why do chemoreceptors detect blood pH?



An enzyme found in red blood cells, CARBONIC ANHYDRASE, is responsible for the conversion of CO_2 and water into the final products bicarbonate ions and hydrogen ions. The H^+ ions cause the blood pH to decrease.

Therefore, the more CO_2 in the blood, the more acidic it will become. So, detecting pH allows to indirectly know there is too much CO_2 present.

Brain & Integration

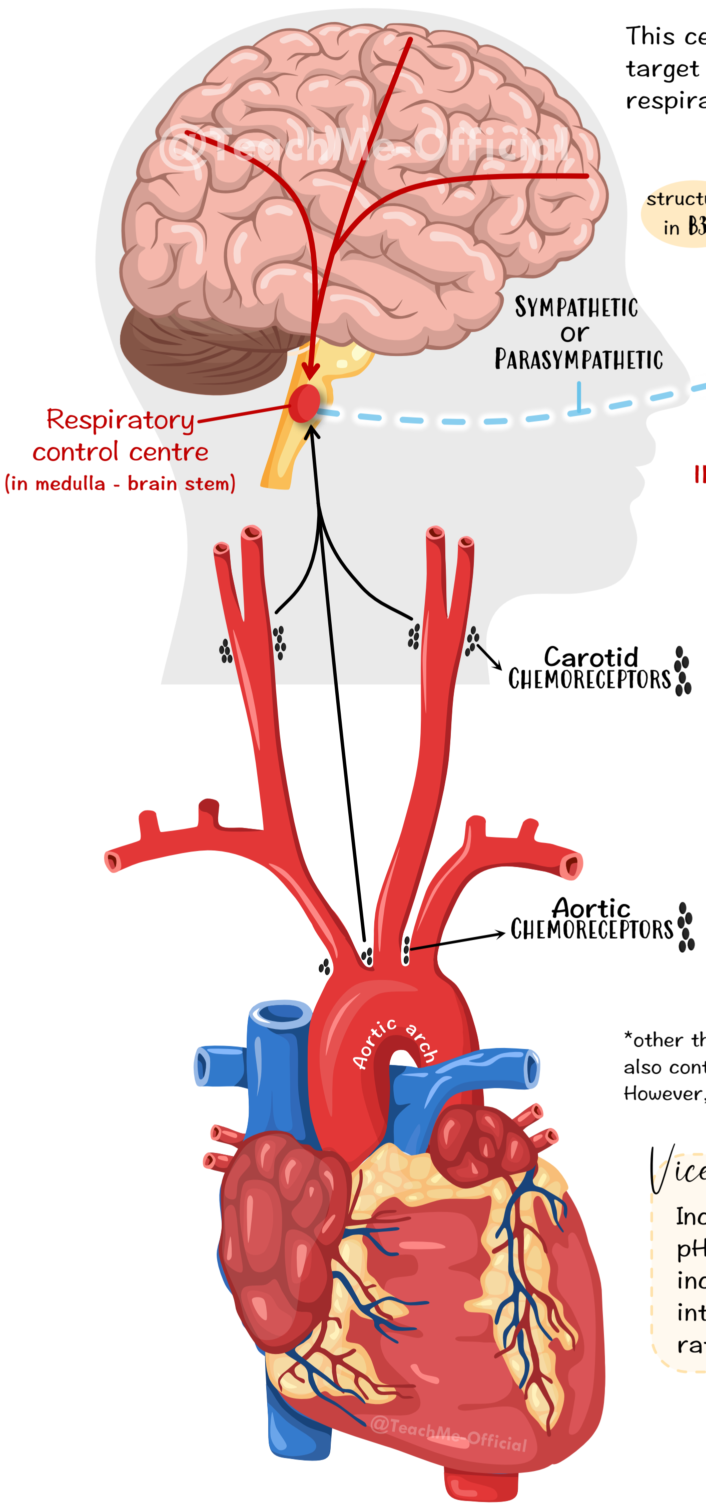
Control of the Lungs

Ventilation rate is controlled by the RESPIRATORY center (in medulla). **Spontaneous** action potentials are released by these cells to signal your DIAPHRAGM and INTERCOSTAL MUSCLES to maintain breathing at a relatively slow and controlled pace.

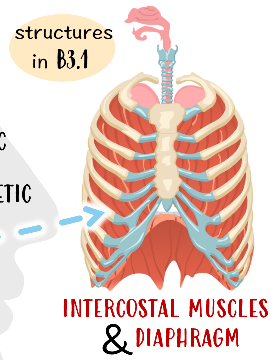
The lungs can be further controlled in two different ways: **sensory information** and **chemoreceptors**. The locations of the chemoreceptors may be seen on the diagram below (same location as for heart control).

1 Sensory Information

Similar to the control of the heart, at times of stress, sensory inputs from the special senses can be processed by the brain and interpreted (red arrows) then can influence the RESPIRATORY CONTROL CENTER in the medulla.



This center will then stimulate SYMPATHETIC NEURONS (blue arrow) which target the intercostal muscles and diaphragm to increase the respiratory rate and depth of each breath.



Inversely, at times of rest, the respiratory control center will stimulate PARASYMPATHETIC NEURONS (blue arrow) which would decrease respiratory rate and depth of each breath.

SYMPATHETIC system used to increase respiratory rate

PARASYMPATHETIC system used to decrease respiratory rate

2 Chemoreceptors

When doing exercise or being active, increased cellular respiration is seen as a decrease in oxygen ($\downarrow O_2$), an increase in carbon dioxide ($\uparrow CO_2$) and a decrease in pH ($\downarrow$ pH) in the blood. Such changes can be detected by chemoreceptors* and lead to a signal being sent to the RESPIRATORY CENTER in the MEDULLA (black arrow). The center responds by sending an increased number of SYMPATHETIC impulses (blue arrow) to the intercostal muscles and diaphragm to increase the ventilation rate and volume. Allows to meet O_2 demands and rids of excess CO_2 produced as waste product.

*other than the carotid and aortic chemoreceptors, the medulla also contains chemoreceptors (called central chemoreceptors). However, they only respond to pH changes.

pH levels

Vice versa **If at rest:**

Increased oxygen, decreased carbon dioxide and increased pH lead to a signal being sent to the medulla which sends an increased number of **parasympathetic** impulses to the intercostal muscles and diaphragm to decrease ventilation rate and volume.

Brain & Integration

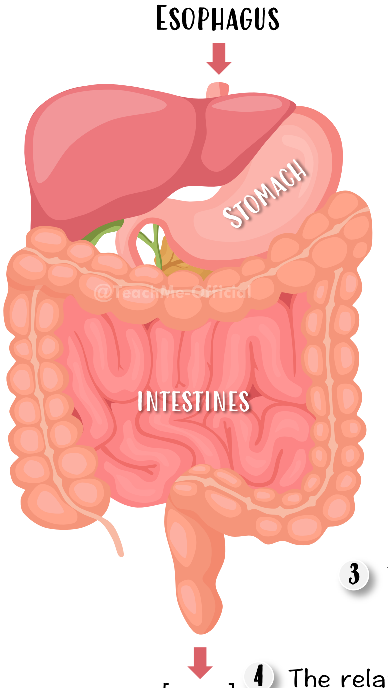
III. Control of the Alimentary Tract

Swallowing food is a voluntary action (controlled by CNS) and so is defecation (passing of stools). However, the involuntary movement of food through the alimentary canal (through the stomach and intestines) is controlled by the **Enteric Nervous System (ENS)**, a part of the **Autonomic System**. This process is called **Peristalsis**.

Series of a smooth muscle contractions that occur along the entire length of the alimentary canal to keep foods moving.
This process is slow and controlled to ensure most nutrients get absorbed.

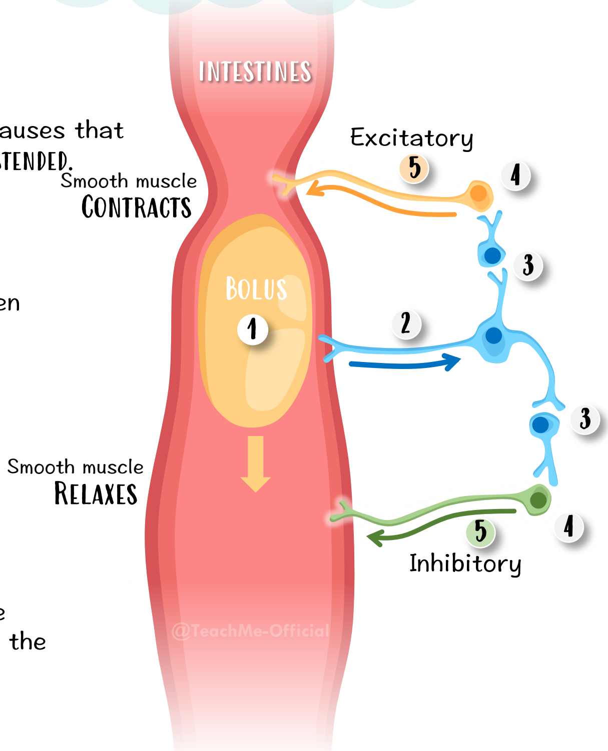
How can such muscle contractions be so well coordinated?

We want to make sure the bolus (partially digested food) moves forward and not move back up the wrong way!



Summary of steps:

1. **Bolus** in the alimentary canal, causes that area of the tube to becomes **distended**.
2. Stimulating **stretch receptors** in the ENS.
3. These (sensory) stretch receptors then synapse with nearby **relay neurons**.
4. The relay neuron then synapses with two different types of **motor neurons**.
5. One type releases an **excitatory** neurotransmitter to smooth muscle "behind" the bolus. Stimulates contraction, pushing the bolus along.
5. One type releases an **inhibitory** neurotransmitter to smooth muscle "ahead" of the bolus. Stimulates relaxation, opening the lumen for the bolus to slide through.

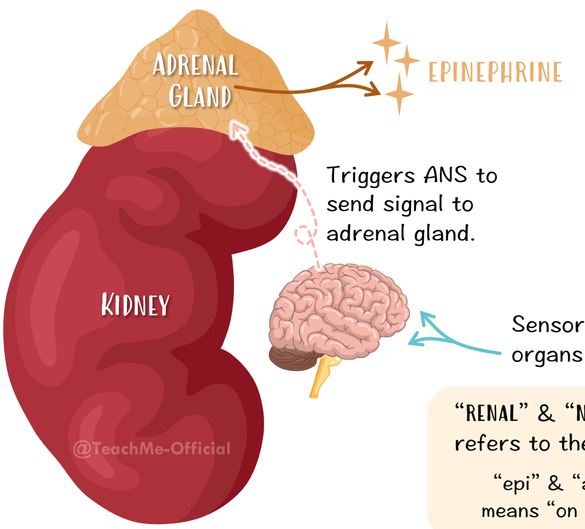


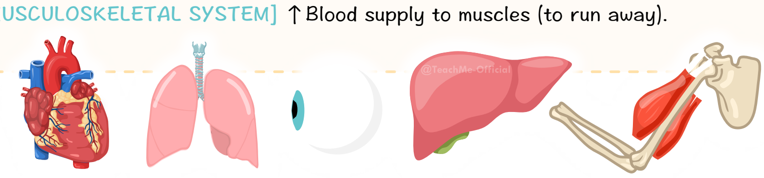
IV. Control by Hormones

A. Adrenal Gland

When sensory organs sense danger (eye, ear, smells etc), the **adrenal gland** releases a hormone called **epinephrine** (also called **adrenaline**). This hormone has various uses:

- [CARDIOVASCULAR SYSTEM] ↑ Heart rate and ↑ Blood pressure.
- [RESPIRATORY SYSTEM] ↑ Diameter (dilation) of air passages (more air in lungs).
- [SPECIAL SENSES] ↑ Dilation (increased size) of the pupils of the eyes (more light in).
- [LIVER] ↑ Blood sugar levels by stimulating glycogen conversion to glucose in the liver.
- [MUSCULOSKELETAL SYSTEM] ↑ Blood supply to muscles (to run away).





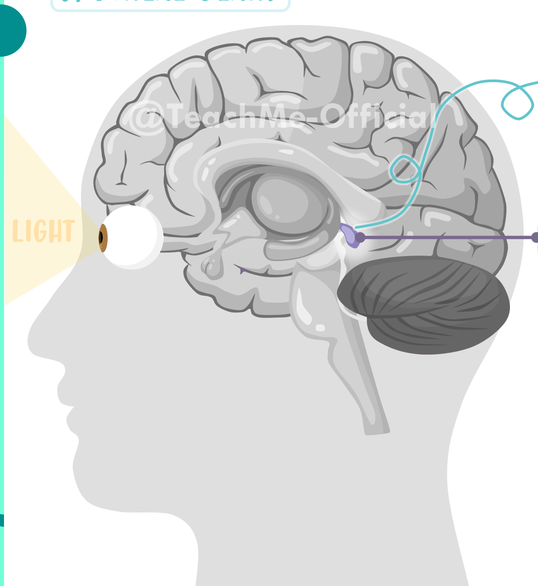
Big Brain Tip!

"Renal" & "Nephro" refers to the kidney
"epi" & "ad" means "on top"

ad**RENAL** gland: on top of kidney gland
ad**RENAL**ine: hormone made by the adrenal gland
epi**NEPHR**ine: hormone made by the adrenal gland

Brain & Integration

B. Pineal Gland

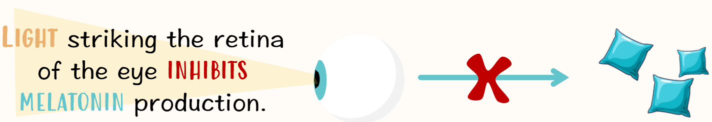


The PINEAL GLAND produces a hormone called MELATONIN; it allows to control the CIRCADIAN RHYTHM.

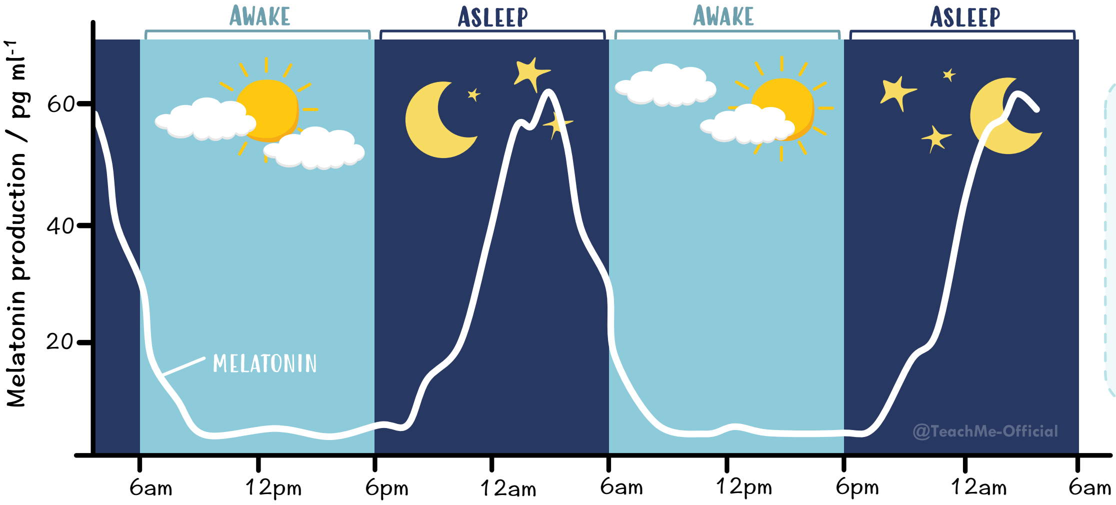
A circadian rhythm is any pattern of behavior (eat, sleep) or physiology that is based on a 24-hour cycle.

The production of melatonin is both AUTOMATIC and LIGHT-DEPENDENT. The body's internal clock (circadian rhythm), controls melatonin production in a roughly 24-hour cycle, even without external light cues. BUT light plays a significant role in FINE-TUNING this rhythm and melatonin production with the DAY-NIGHT cycle.

LIGHT striking the retina of the eye INHIBITS MELATONIN production.



Graph of melatonin production over the period of two days in a DIURNAL ORGANISM:



NOCTURNAL – organisms more active at night. Melatonin high in day-time.

DIURNAL – organisms more active in the daytime. Melatonin high in night-time.

What affects circadian rhythms: JET LAG, mobile-phone, computer screen...

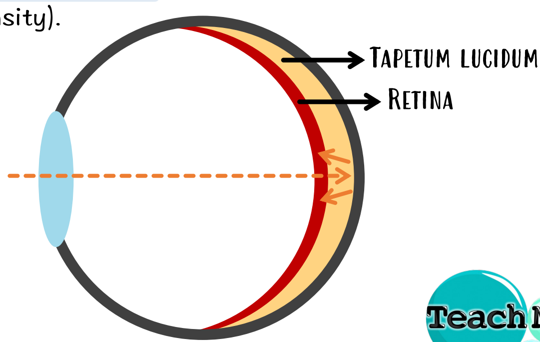
Automatic system is still on the old time zone. The effect of light takes time to influence the automatic production cycle of melatonin.

BIG BRAIN TIP! Melatonin = Midnight

Special adaptations

NOCTURNAL ANIMALS have a layer located behind their RETINA called TAPETUM LUCIDUM. This layer allows for light to be reflected off from it and sent back through the retina. This DOUBLES THE LIGHT INTENSITY striking the sensory cells of the retina: allowing such animals to see in the night (at very low light intensity).

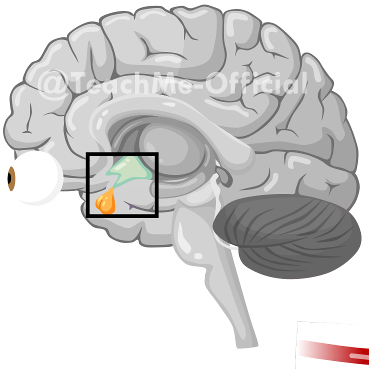
You may observe the effect of the **Tapetum Lucidum** layer on your own pet!



Schematic diagram of eye

Brain & Integration

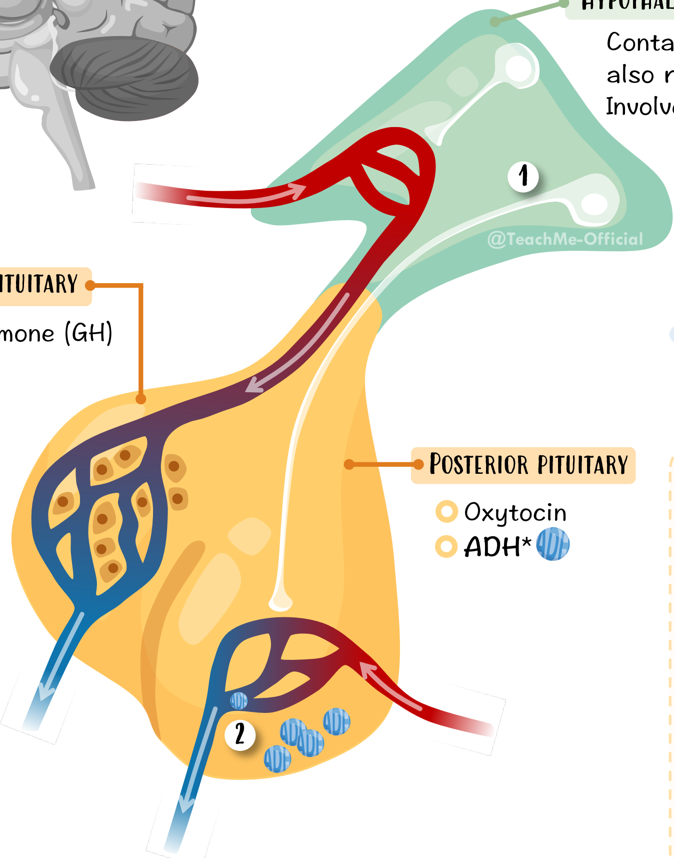
C. Hypothalamus & Pituitary



The **HYPOTHALAMUS** and **PITUITARY** are highly interlinked structures. The hypothalamus, sitting on top, acts as a link between the nervous system and the endocrine (hormone) system. It is directly connected to the pituitary gland: sitting just underneath.

Big Brain Tip!

Hypothalamus is the **BOSS**; it tells the pituitary what to do.



Hypothalamus

Contains receptors associated with ANS function. Can also receives signals from other areas of the body. Involved in temperature, glucose, water level etc.

Composed of both neurons and glandular cells (These produce hormones that either **stimulate** or **inhibit** hormone release by the pituitary).

Anterior Pituitary

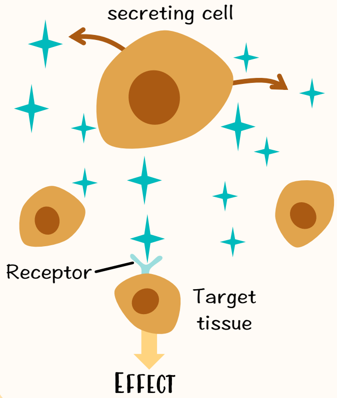
- Growth hormone (GH)
- FSH & LH
- TSH
- Prolactin

Posterior Pituitary

- Oxytocin
- ADH*

You need to know in this chapter about one important hormone: ADH

Key Concept!



Hormones can freely move around the body through the blood BUT they only have effect on targetted cells which have the specific receptor for this hormone!

AntiDiuretic Hormone (ADH)

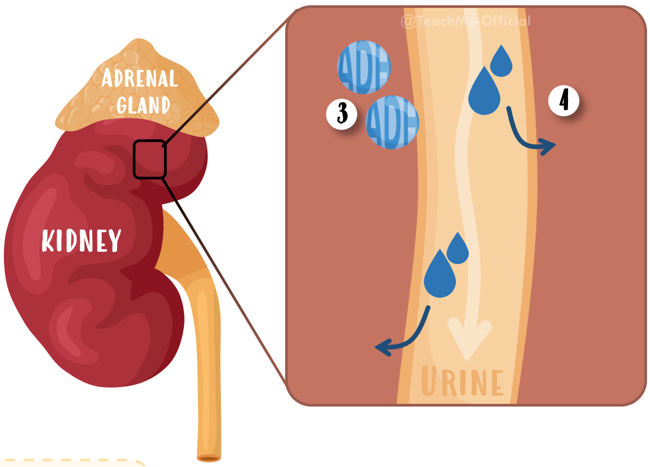
Hypothalamus makes **ADH**. Sent to the **POSTERIOR PITUITARY** to be stored (until needed). **OSMORECEPTORS** (in the hypothalamus) continuously senses the water content of blood.

1. If low water content, hypothalamus sends signal to posterior pituitary cells.
2. Posterior pituitary cells then secrete ADH into the bloodstream.
3. Triggers target tissue (collecting tubules of nephrons in the kidneys) to reabsorb water back into bloodstream from urine. (Negative feedback).
4. Leads to less urine (less water loss). Water level returned to normal.

Big Brain Tips!

ADH = Anti Dehydration Hormone

HL students learn more about ADH in D3.3



Vice versa

If too much water in blood:

If high water content, hypothalamus sends signal to posterior pituitary to inhibit ADH production. Lack of reabsorption from the kidney tubules leads to more urine (more water loss): water levels returns to normal.

notes