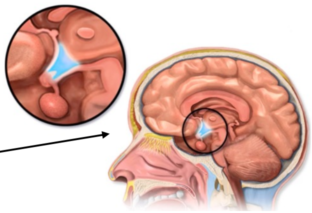
Autonomic system (vegetative)

Sympathetic, parasympathetic, and metasympathetic efferent pathways

IT IS VEGETATIVE
It regulates basic bodily functions essential for survival.
It does not involve conscious control.
It does not involve the cerebral cortex.

CONTROL POINT: Hypothalamus

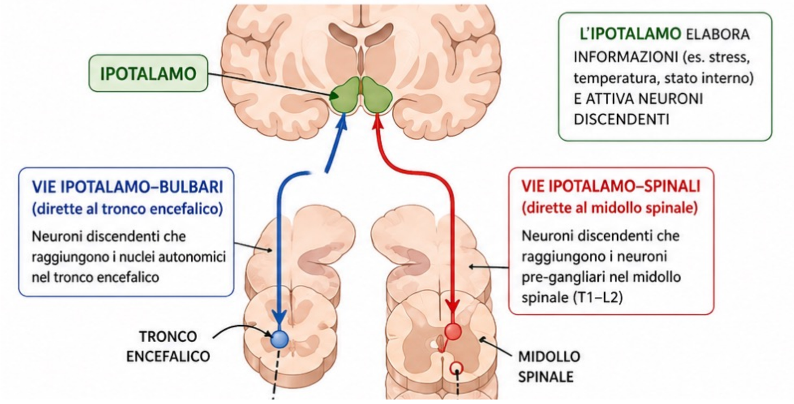


FUNZIONE: To maintain the homeostasis of the entire organism.
It plays a regulatory role in controlling the vital functions of the body.

Somatic motor system
the circuit runs directly from the cortex to the target organ

The autonomic system

Works at different levels
It is composed of peripheral nerves and ganglia.

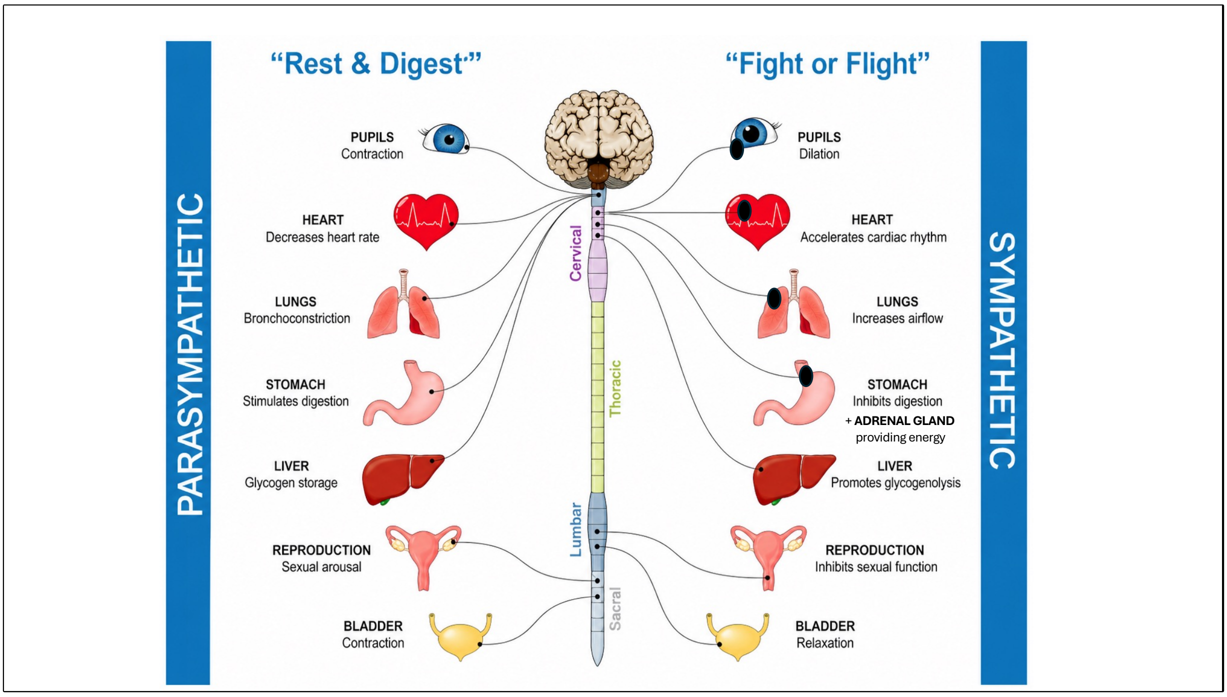


IPOTALAMO attiva **NEURONI DISCENDENTI** CHE CONTATTANO I **NEURONI PRE-GANGLIARI** utilizzando VIE DISCENDENTI

- **vie ipotalamo–bulbari** (dirette al tronco encefalico)
- **vie ipotalamo–spinali** (dirette al midollo spinale)

The hypothalamus is located in a central position that allows it to interact with multiple structures:
the brain, the brainstem, the limbic system, and down to the spinal cord.

The hypothalamus activates descending neurons that synapse with preganglionic neurons through descending pathways:
hypothalamic–bulbar pathways (directed to the brainstem)
hypothalamic–spinal pathways (directed to the spinal cord)



The autonomic nervous system is responsible for regulating involuntary visceral functions and is activated in response to both internal and external stimuli, including emotional states. A typical example is anxiety before an exam: in this situation, physiological changes such as increased heart rate, sweating, dry mouth, and a state of agitation can be observed. These responses are mediated by activation of the autonomic nervous system.
Subsequently, once the stressful stimulus has ended (for example, after the exam), there is a gradual normalization of physiological functions, associated with a feeling of relaxation. This process is also regulated by the autonomic nervous system.

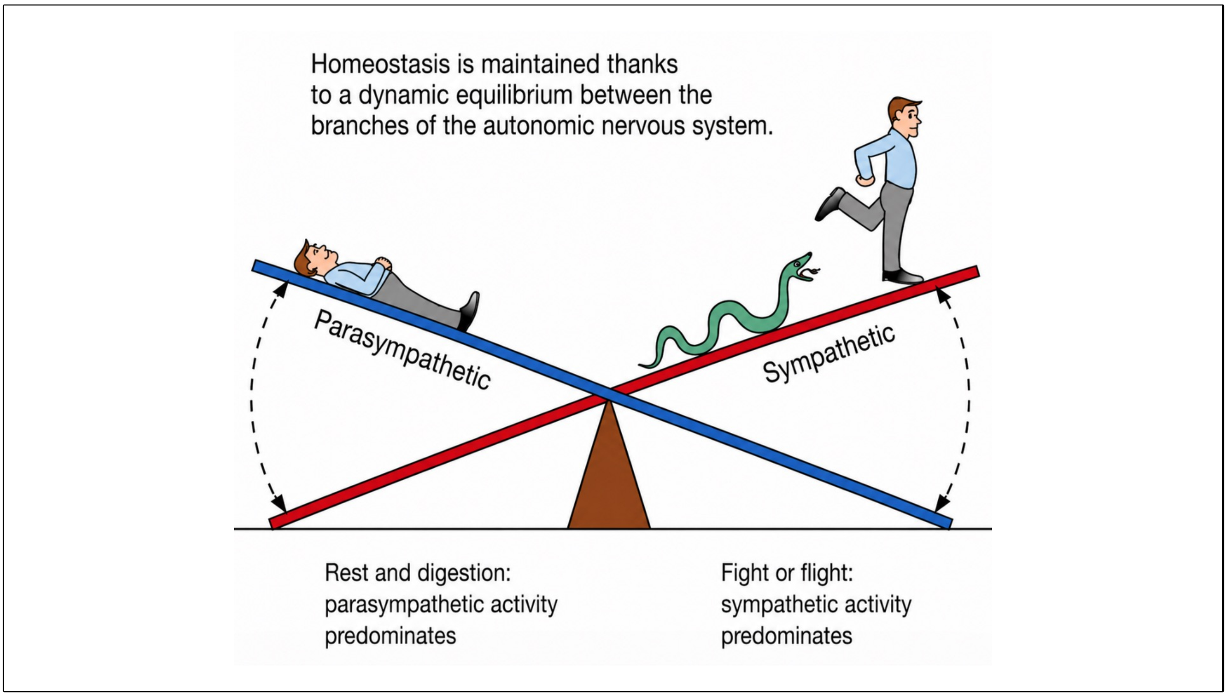
The autonomic nervous system operates in an involuntary and automatic manner, without conscious control, and is organized into two main components:
sympathetic nervous system
parasympathetic nervous system

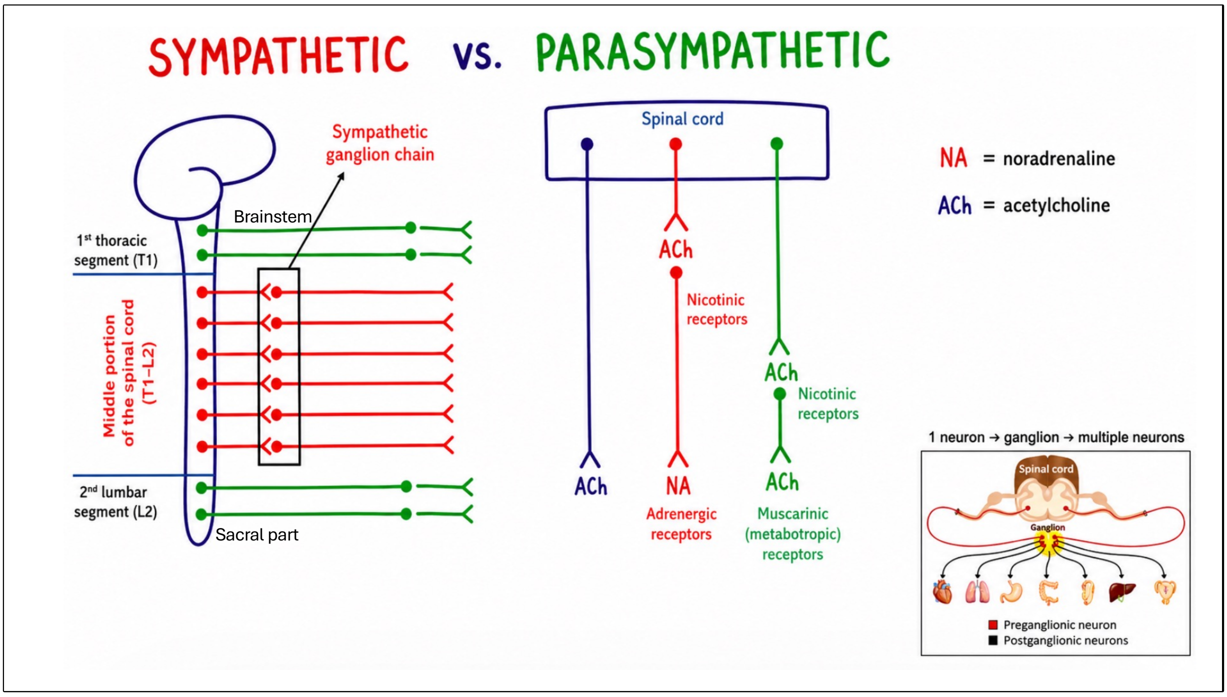
Both systems innervate the same target organs (smooth muscle, cardiac muscle, and glands), but they generally exert **opposing and complementary effects**.
The sympathetic nervous system is associated with conditions of **alertness and stress** and mediates the so-called **"fight or flight" response**, which has important evolutionary significance. In the presence of a real or perceived threat, sympathetic activation produces a series of physiological adaptations:
mydriasis (pupil dilation) to increase light entry
inhibition of salivation
increased heart rate and cardiac output
bronchodilation and increased ventilation
inhibition of gastrointestinal motility and secretions
mobilization of energy reserves (glycogen, lipids)
secretion of adrenaline from the adrenal medulla
These changes prepare the organism for a rapid and effective response to emergency situations.

In contrast, the parasympathetic nervous system is associated with conditions of **rest and recovery**, and is often

described as the **“rest and digest”** system. It promotes:
reduction of heart rate
increased salivation
stimulation of digestion and intestinal motility
conditions favorable for energy restoration

In addition, the parasympathetic system contributes to the maintenance of **homeostasis** and, indirectly, supports immune system activity, whereas prolonged activation of the sympathetic system may have inhibitory effects on it.


Homeostasis is maintained thanks
to a dynamic equilibrium between the
branches of the autonomic nervous system.
Parasympathetic
Sympathetic
Rest and digestion:
parasympathetic activity
predominates
Fight or flight:
sympathetic activity
predominates



The autonomic nervous system consists of two main components, the **sympathetic nervous system** and the **parasympathetic nervous system**, which differ in anatomical origin, organization of neural pathways, and mechanisms of signal transmission.

The fibers of the sympathetic nervous system originate from the **thoracolumbar region** of the spinal cord, specifically between segments T1 and L2. In contrast, the fibers of the parasympathetic nervous system originate from the **brainstem** and the **sacral spinal cord**, in segments S2–S4. This organization is referred to as thoracolumbar for the sympathetic system and craniosacral for the parasympathetic system.
Among the components of the parasympathetic system, the **vagus nerve** plays a fundamental role, as it innervates numerous visceral organs, including the heart, lungs, and gastrointestinal tract. At the cardiac level, it exerts a **bradycardic effect**, contributing to the maintenance of a low resting heart rate. Alterations in its function may lead to tachycardia and gastrointestinal disturbances such as nausea and vomiting.

A fundamental difference between the somatic motor system and the autonomic nervous system lies in the organization of efferent pathways. In the somatic motor system, a single motor neuron originates from the central nervous system and directly innervates skeletal muscle.
In contrast, in the autonomic nervous system, the efferent pathway consists of a **two-neuron chain**: a **preganglionic neuron**, whose cell body is located in the central nervous system, and a **postganglionic neuron**, whose cell body is located in a peripheral ganglion. The preganglionic neuron forms a synapse within the ganglion with one or more postganglionic neurons, resulting in a phenomenon of **divergence** that allows signal amplification and distribution of the response to multiple target organs.

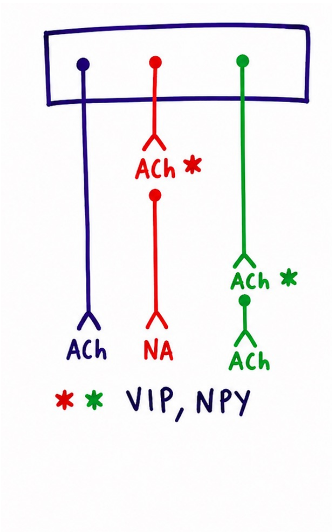
The two components of the autonomic system also differ in fiber length and ganglion location. In the sympathetic system, preganglionic neurons are relatively short and synapse in ganglia located near the spinal cord, organized in the **paravertebral chain**. In the parasympathetic system, preganglionic neurons are longer and reach ganglia located close to or within the target organs.

From the perspective of chemical transmission, in both the sympathetic and parasympathetic systems, the preganglionic neuron releases **acetylcholine**, which acts on **nicotinic receptors** on the postganglionic neuron. At the level of the effector synapse, however, differences are observed: postganglionic neurons of the sympathetic system primarily release **norepinephrine**, which acts on **adrenergic receptors** of target organs, whereas postganglionic neurons of the parasympathetic system release **acetylcholine**, which binds to **muscarinic (metabotropic) receptors**.

From a morphological perspective, the neurons involved in descending pathways, as well as preganglionic and postganglionic neurons, are **multipolar neurons**. Descending and preganglionic neurons have **myelinated axons**, allowing faster conduction, whereas postganglionic neurons are generally **unmyelinated** and conduct more slowly.

Overall, this organization enables the autonomic nervous system to exert a **fine, modulated, and widespread control** over visceral functions, contributing to the maintenance of **homeostasis** of the organism.

Co-transmitter peptides and signal amplifiers



VIP (vasoactive intestinal peptide)
It helps to:
relax (smooth muscles, blood vessels)
increase secretions (glands)

In simple terms:
it makes the response more "smooth" and stronger

Typical of the **parasympathetic system**

NPY (neuropeptide Y)
It helps to:
strengthen the sympathetic response
help save energy
often cause vasoconstriction

In simple terms:
it makes the response stronger and longer-lasting

Typical of the **sympathetic system**

To enhance the effects of acetylcholine, the pre-ganglionic neuron (in both the sympathetic and parasympathetic systems) also releases some peptides, such as:
Vasoactive intestinal peptide (VIP; typical of the parasympathetic system)
Neuropeptide Y (NPY; typical of the sympathetic system)
We can define them as **co-transmitters** that modulate and strengthen the action of the main neurotransmitters in the autonomic nervous system.

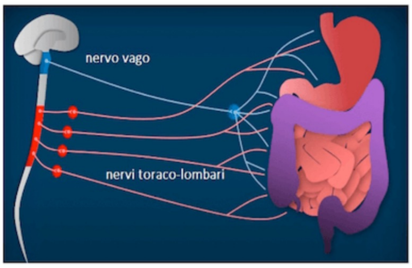
Enteric autonomic Nervous System

Metasympathetic

It is represented by **autonomic (enteric) ganglia** located within the digestive tract (oesophagus, stomac, and intestine).

It controls and regulates the main functions of the digestive system.

Characteristics:



Independent from the central nervous system (CNS)

Connected to the CNS indirectly through:

- the **parasympathetic system**, via the **vagus nerve**
- the **sympathetic system**, via the **thoracolumbar nerves**

Besides the sympathetic and parasympathetic systems, there is also the **enteric system**, also called the **metasympathetic system**.
It is made of autonomic ganglia located withi the digestive tract.
It controls the main functions of the digestive system.
This system is partly independent from the **central nervous system (CNS)**.
Some scientists think this is because these ganglia develop **before** the fibers of the CNS reach them.
In other words, they are already formed before being connected to the CNS.

This idea comes from observations that, after animals die, **intestinal peristalsis** can continue for several hours.
However, the enteric (metasympathetic) system is still connected to the CNS, even if not directly:
through the **parasympathetic system**, especially via the **vagus nerve**
through the **sympathetic system**, via the **thoracolumbar nerves**, which control blood vessel activity

Organization into plexuses

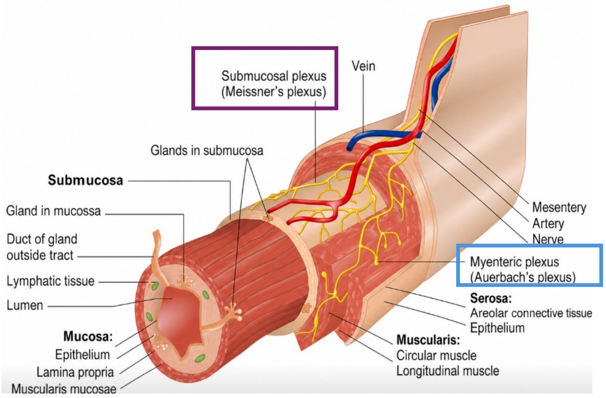
Two plexuses:

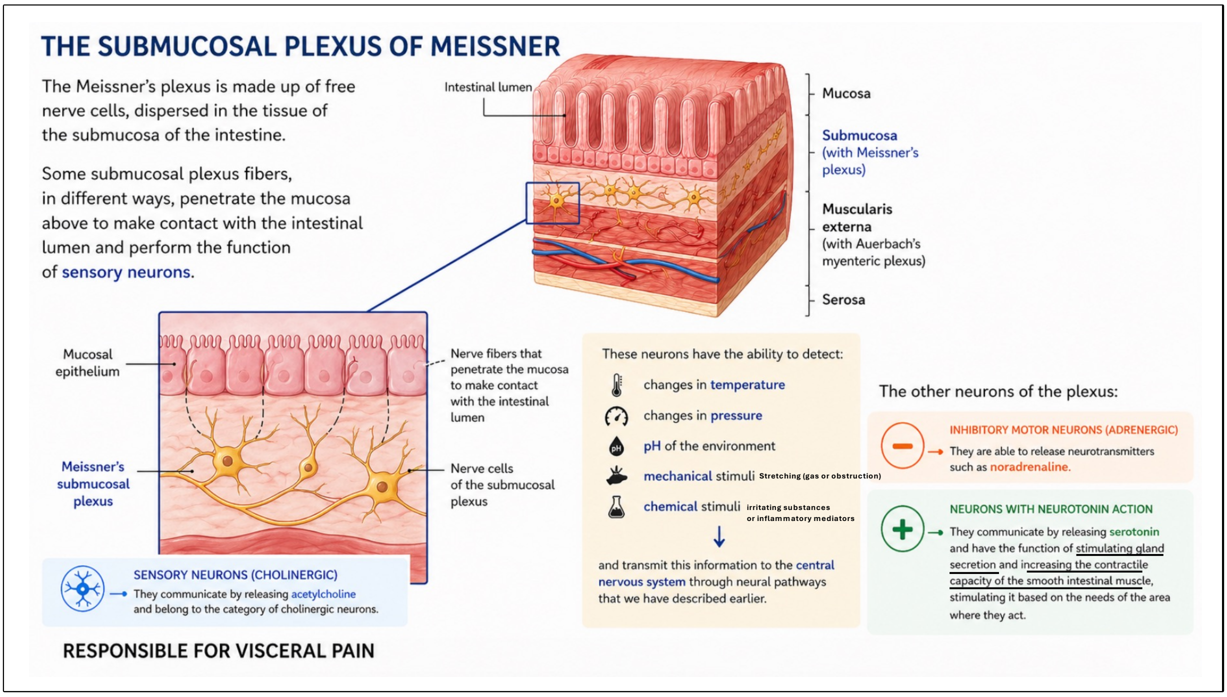
Submucosal plexus (Meissner) → controls secretory functions of the intestinal glands
Myenteric plexus (Auerbach) → controls intestinal motor functions

These plexuses control different functions that interact with each other to ensure proper **peristalsis** and overall **intestinal function**.

They form a complex network made of different types of neurons with different functions:

Motor neurons
Vasomotor neurons
Secretory neurons
Sensory neurons





Curiosity:

What kind of signals activate sensory neurons in the intestine?
*- The most important is **stretching**: when the intestine is too full, when there is gas, or in case of obstruction. This is the main cause of **visceral pain**.*
*- Another stimulus is **pressure**, for example when internal pressure increases or when contractions are too strong.*
*- There are also **chemical stimuli**, such as those caused by inflammation, irritating substances, or inflammatory mediators.*
*- Finally, **ischemia** (reduced blood and oxygen supply to the intestine) can activate these neurons and often causes intense pain.*

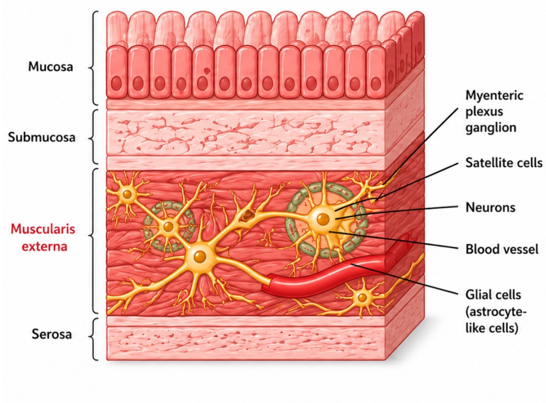
THE AUERBACH PLEXUS (MYENTERIC PLEXUS)

Neurons are grouped into **microganglia**, surrounded by a layer of cells called **satellite cells**.

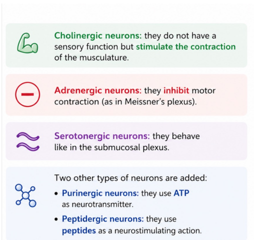
Inside these microganglia, we find **neurons** associated
with **blood vessels**
and with cells that are similar, in structure and function, to **astrocytes of the CNS**.

Functions of astrocytes:

- filter nutrients directed to neurons
- make the transmission of nerve impulses easier
- they also form a protective structure called the **blood–myenteric barrier**



Neuron types



Note:
Similarly to the blood–brain barrier, which protects neurons of the central nervous system by selecting which substances from the bloodstream can come into contact with nerve cells, these astrocyte-like elements form a protective structure known as the blood–myenteric barrier.

Overview of the Limbic System

Our body has an automatic system that continuously maintains vital functions (such as heart rate and respiration).

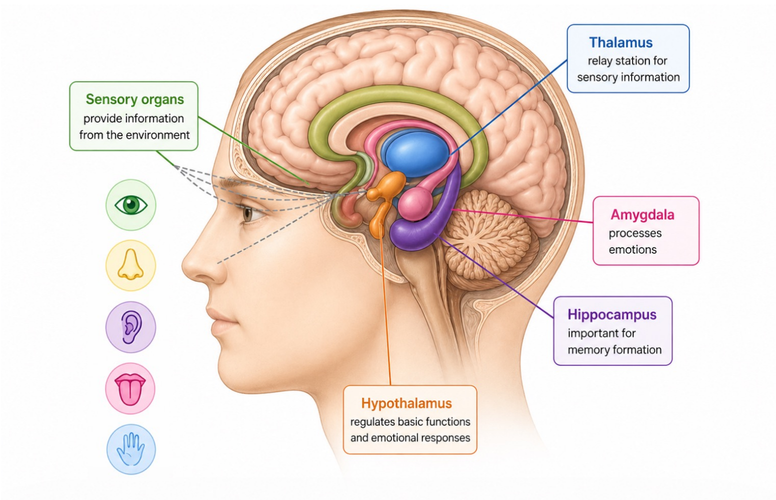
*this is the **autonomic nervous system***
(regulated by the hypothalamus)

*In addition, there is the **limbic system**, which is the system involved in emotions.*
When we experience emotions such as fear or stress, the limbic system activates the hypothalamus, which in turn modulates the activity of the autonomic nervous system.

THE AUTONOMIC NERVOUS SYSTEM MAINTAINS BASELINE HOMEOSTATIC BALANCE.

THE LIMBIC SYSTEM MODULATES THIS BALANCE ACCORDING TO EMOTIONAL STATES.

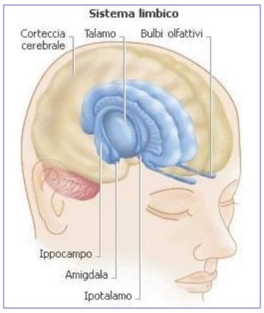
Overview of the Limbic System



The **limbic system** is the system involved when we feel emotions, and it becomes active in our emotional life.
The word *limbic* refers to all the brain structures involved in emotions. For this reason, it is also called the **emotional brain**. It includes both cortical and subcortical structures such as:

sensory organs
thalamus
amygdala
hippocampus
hypothalamus

Overview of the Limbic System



Stimulus to the thalamus
↓
Amygdala → emotion
↓
Hippocampus → associated memory
↓
Hypothalamus → bodily response (hormones + body)

A stimulus is perceived by the senses (through sensory receptors) and sent to the brain, to the **thalamus**. From there, the information reaches the **amygdala**, which quickly **evaluates the emotional meaning** of the stimulus.

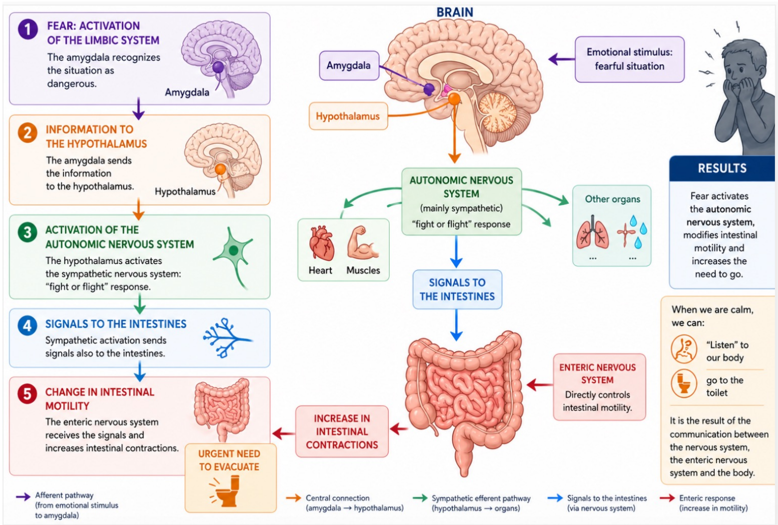
If the stimulus is relevant, the amygdala activates the **hypothalamus,** which produces a response through the autonomic nervous system and hormones.

At the same time, the **hippocampus** links the stimulus to memory, while the **prefrontal cortex** processes the experience in a more rational way.

Sensory receptors send information to the thalamus, and then the following happens:
The information reaches the **amygdala**, which quickly evaluates the emotional meaning of the stimulus.
If the stimulus is important, the amygdala activates the **hypothalamus**, which produces a body response through the autonomic nervous system and hormones.
At the same time, the **hippocampus** connects the stimulus to memory, while the **prefrontal cortex** processes the experience in a more rational way.

The only sense that is evolutionarily connected to the limbic system without passing through the thalamus is **smell (olfaction)**. In fact, the limbic system developed together with the olfactory system.
You may have noticed that a particular smell or perfume can trigger a specific memory and a positive or negative emotion. This happens because these two systems work closely together in all mammals, even in less evolved ones, where the sense of smell plays an important role in **fight-or-flight responses**.

Example of interaction between systems



So far, we have analyzed **afferent pathways**, **efferent pathways**, and the different components of the nervous system separately. However, in the organism these systems do not operate in isolation; rather, they are highly integrated and function in a continuous and coordinated manner.

To better understand this integration, it is useful to consider a common example: the physiological response associated with fear, such as the sudden urge to defecate.
When an individual perceives a situation as threatening, the information is initially processed at the cortical level, particularly in the **prefrontal cortex**, which is involved in cognitive and decision-making processes. Neuronal activity in these regions generates action potentials that, through cortico-limbic projections, reach the **amygdala**.
The amygdala plays a key role in recognizing emotionally relevant stimuli, especially those related to fear, and transmits this information to the **hypothalamus**.
The hypothalamus, in turn, activates the efferent pathways of the **autonomic nervous system**, predominantly engaging the sympathetic division, which is responsible for the **"fight or flight" response**.
This activation does not only involve the cardiovascular and muscular systems, but also affects the gastrointestinal tract.
The **enteric nervous system**, which locally regulates intestinal function, receives input from the autonomic nervous system and modulates **intestinal motility**.
Under conditions of stress or fear, these signals can lead to increased peristalsis and intestinal contractions, resulting in a sensation of urgency to evacuate.
Therefore, sensations such as an "upset stomach" or the sudden need to go to the bathroom represent the outcome of functional integration between the **limbic system**, the **autonomic nervous system**, and the **enteric nervous system**.