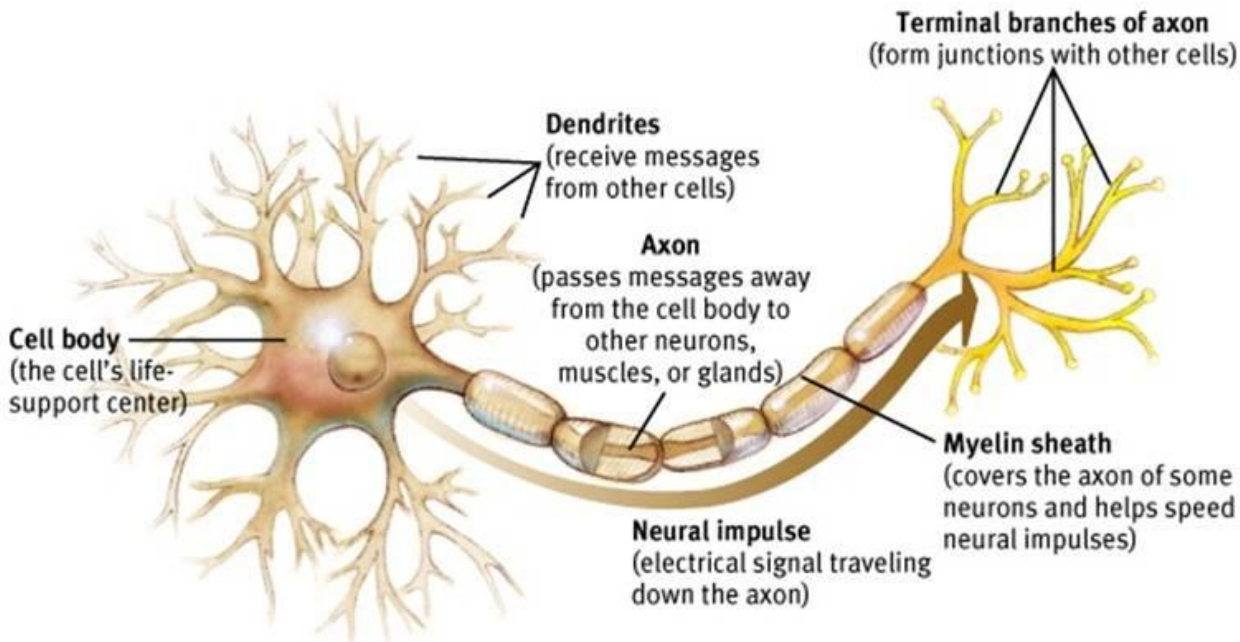
NERVOUS SYSTEM

The human nervous system is truly remarkable in its complexity and function. It is responsible for regulating and coordinating the functions of the trillions of cells in the body and for the most part does so automatically without our conscious awareness. The nervous system does its job of detecting, interpreting and reacting to internal and external signals with the goal of maintaining healthy functioning of the human body. The nervous system is made up of billions of cells called neurons.

Neurons are cells specialized in sending electrical signals (messages) throughout the body. There are several important features of this type of cell.

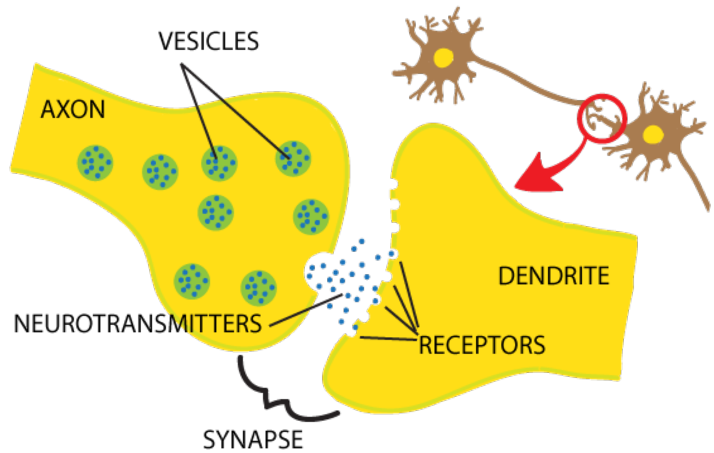
Source nerve cell: http://www.appsychology.com/Book/Biological/neuroscience.htm



Parts of a nerve cell (neuron):

- **Cell body**: contains the nucleus (brain) and other important structures of the nerve cell that keep the cell healthy and alive.
- **Dendrites**: usually these stretch out from the cell body and receive messages from the axons other neurons that connect with them. Think of them as the signal intake ports for the neuron.
- **Axon**: only one of these stretches out from the cell body and sends messages from a neuron to one or more cells in the body. The terminal branches of the axon connect with the dendrites of other neurons or with specialized receptors on other types of cells and transmit signals that result in specific events in those cells such as contraction of a muscle cell or release of a hormone (chemical message) from the cells in an endocrine gland.
- **Myelin sheath**: made up of specialized cells called Schwann cells that wrap around the nerve axon. Think of them as insulation for the axon that helps transmit the electrical signal more quickly.
- **Synapse**: a junction that mediates information transfer between neurons or between a neuron and another cell. The space where the electrical signal is translated into a chemical signal via neurotransmitters.

- **Neurotransmitters**: chemicals contained in the terminals of axons that allow passage of the electrical signal from a neuron to the next cell. In addition to facilitating transfer of signals from a nerve cell to another cell, neurotransmitters are also associated with a wide variety of things including fear, pleasure, joy, anger, memory, cognition, attention, concentration, alertness, energy, appetite, cravings, sleep and pain perception.



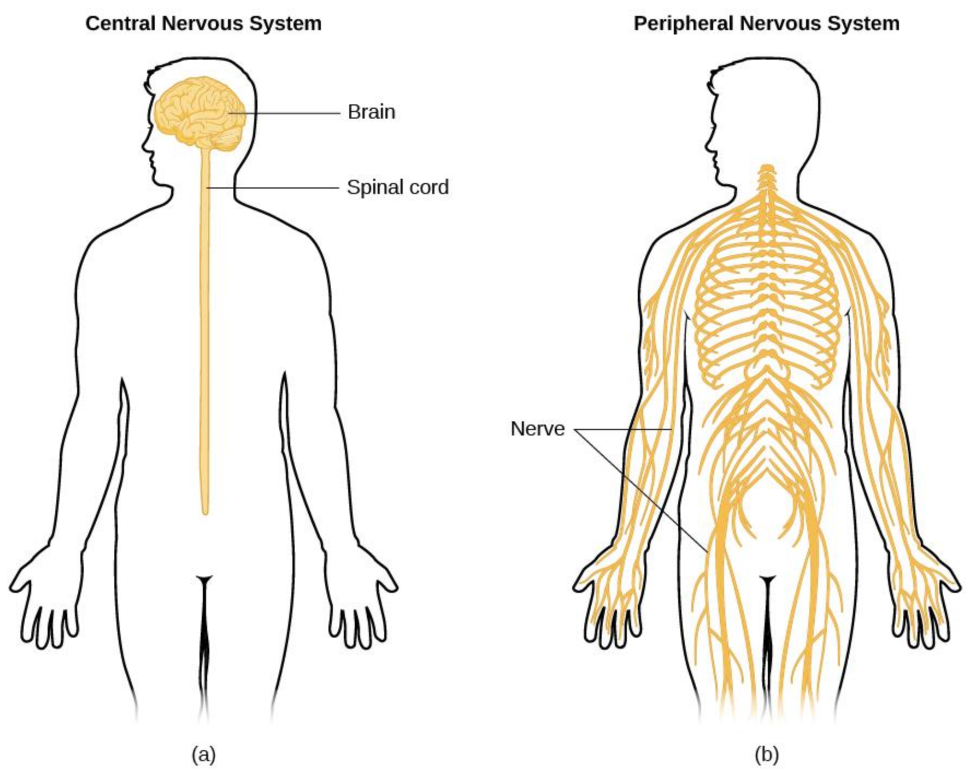
The functions of some major neurotransmitters are listed below:

- **Serotonin** – regulates the sleep cycle, appetite, and moods
- **Dopamine** – the feel good chemical, plays an important role in mood, energy, attitude, and motivation
- **Norepinephrine** – stimulates the "fight or flight" response; increases energy metabolism
- **Epinephrine** – stimulates the "fight or flight" response; increases energy metabolism
- **Acetylcholine** – involved in skeletal muscle contraction

The nervous system is subdivided into the central nervous system (CNS) and peripheral nervous system (PNS). The brain and spinal cord make up the CNS. The PNS is all the other neurons in the body. Source table of nervous system: https://courses.lumenlearning.com/wsu-sandbox/chapter/parts-of-the-nervous-system/

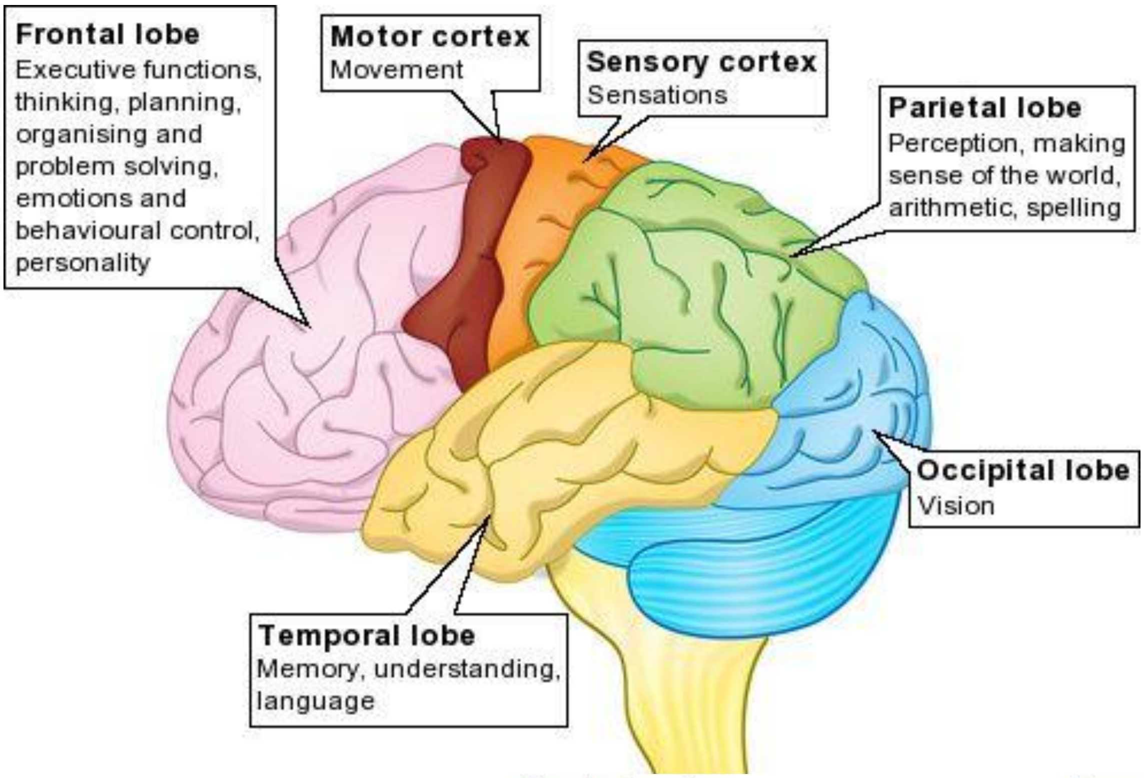
Nervous System (CNS)

The CNS receives, processes, interprets, and stores information, and issues "orders" to all parts of the body. The **brain** is the major part of the CNS. Several areas (lobes) of the brain have been identified along with many of their functions (see image). Most higher order functions of the brain are controlled from the cortical areas also known as the cerebral cortex.



The left and right cerebral hemispheres communicate through a structure called the corpus callosum and work together to perform a variety of tasks. While certain functions do appear to be localized in one hemisphere or the other, the concept of left or right brain dominance is a long-standing myth that never had a strong scientific foundation and has been totally debunked.

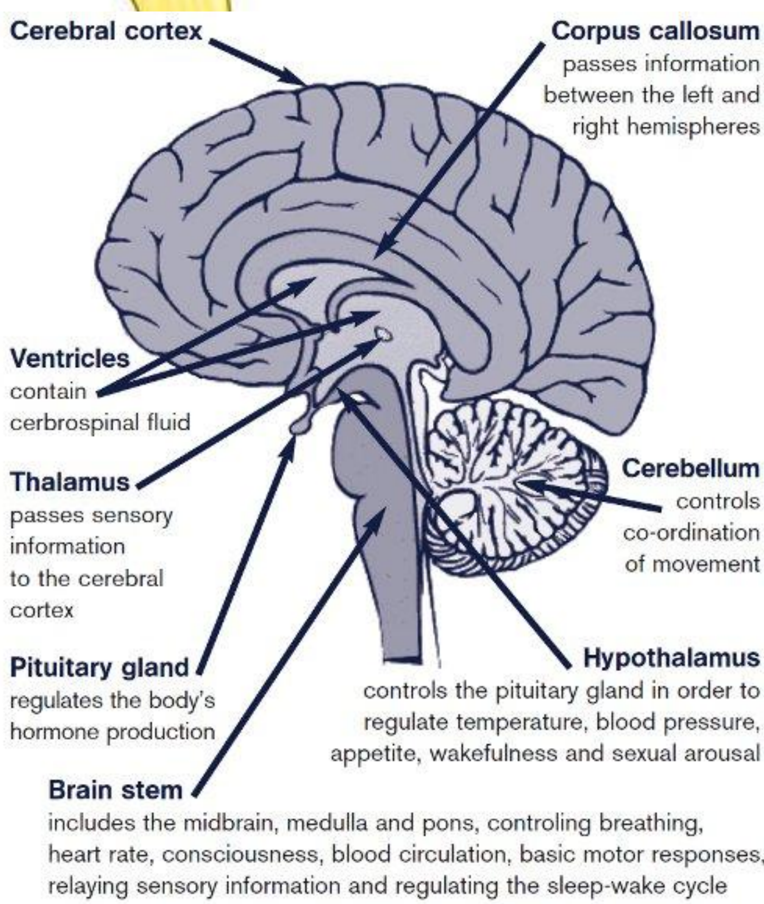
Source brain lobes: https://s-media-cache-ak0.pinimg.com/736x/25/a5/28/25a5282965b352a91bfff7a594303f80.jpg



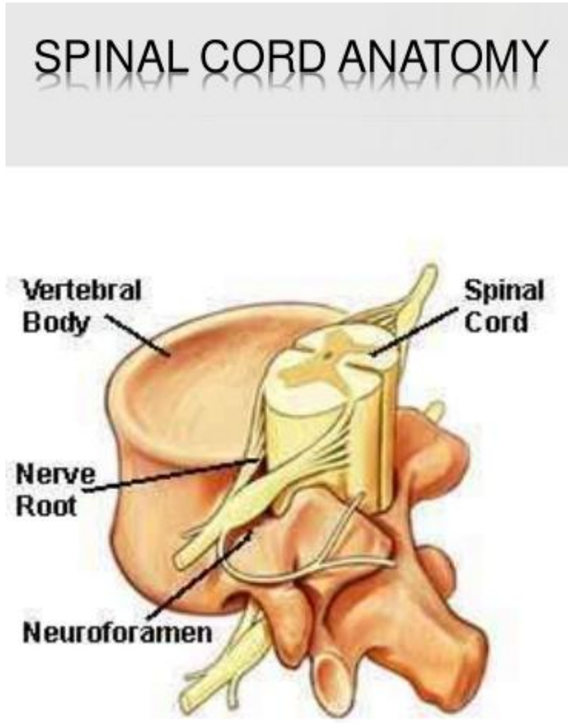
The brainstem is the part of the brain that connects the higher brain (cortical areas) with the spinal cord. It includes the midbrain, medulla oblongata, and the pons. It is a vital part of the CNS, because it controls vital functions in the body such as breathing, blood pressure, heart rate, sleep cycles, and many autonomic functions.

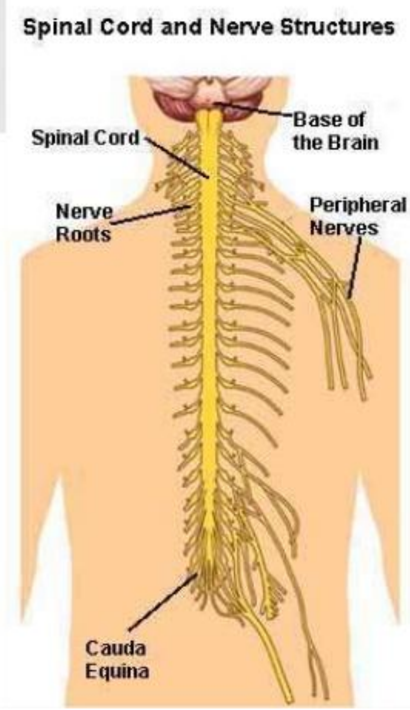
The cerebellum receives input from several sources and has multiple functions including:

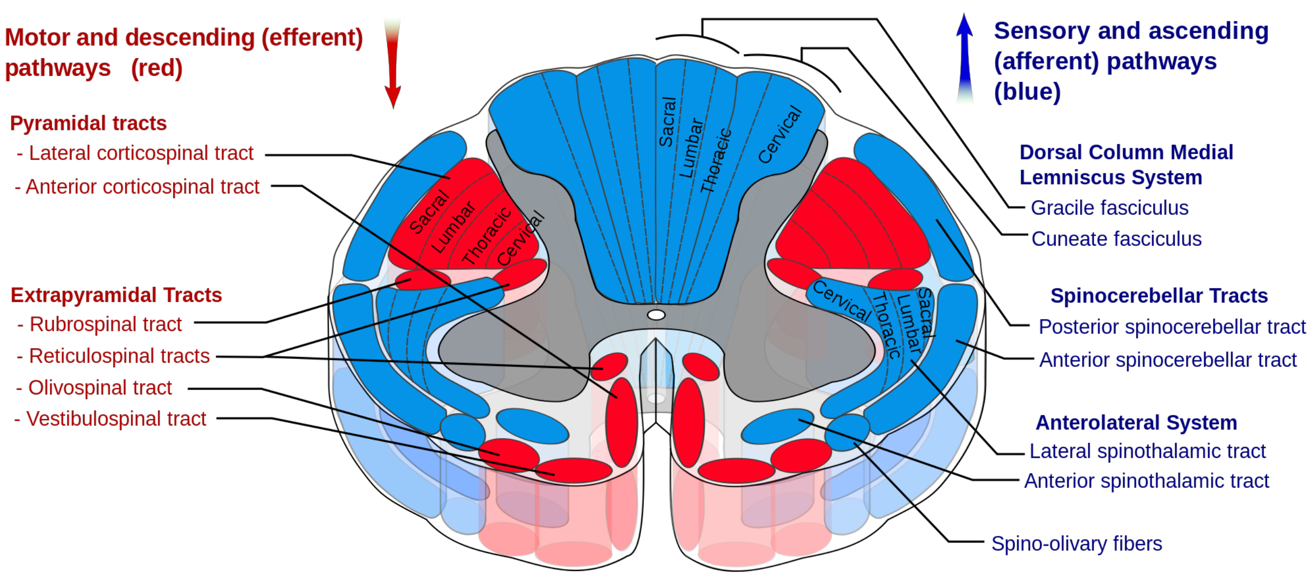
- Maintenance of balance and posture
- Coordination of voluntary movements resulting in smooth and balanced muscular activity.
- Motor learning – learning to play a musical instrument, throw a ball, or perform an asana with ease. This is sometimes called "muscle memory."



The **spinal cord** is a cylindrical bundle of nerves and support tissue that is enclosed in the vertebral column and connects virtually all parts of the body to the brain. It extends from the medulla in the brain stem to the lumbar vertebrae where it branches into the cauda equina, a bundle of spinal nerve roots that looks like a horse's tail.







The Peripheral Nervous System (PNS)

It's common for the axons of many neurons to be bundled together into groups much like individual wires in a telephone cable. The spinal cord is a good example of this. Such bundles of neuron axes are called tracts in the central nervous system and nerves or ganglia (in the case of the autonomic nervous system – see more below) in the peripheral nervous system.

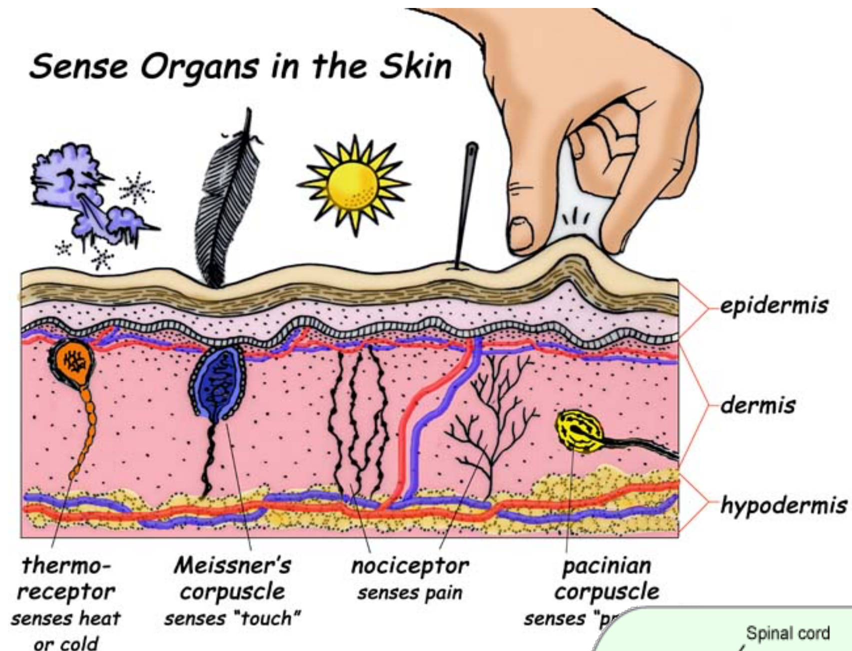
The sensory (input to the CNS) and motor (output from the CNS) aspects of the somatic nervous system transmit the conscious sensations of touch, pressure, pain, hearing, and vision, and control skeletal muscle.

Breathing is controlled by both the somatic and autonomic nervous systems (more on this later).

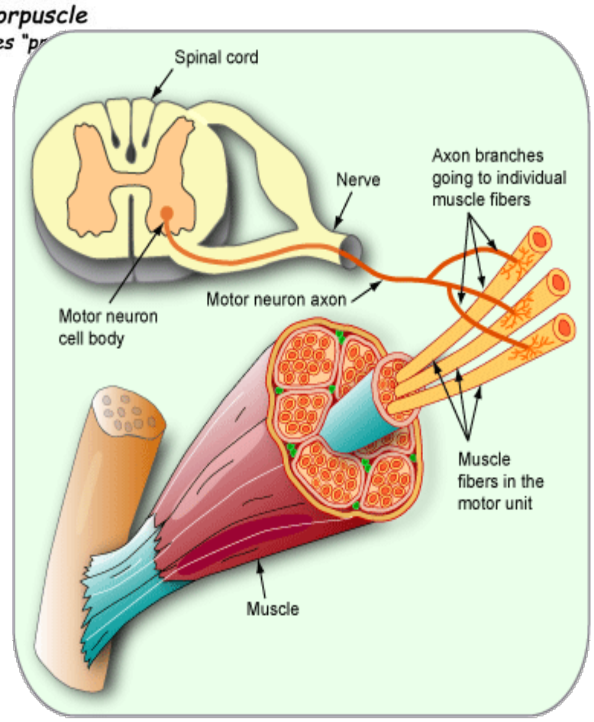
The autonomic nervous system, explained in more detail below, is responsible for control of smooth and cardiac muscle and most internal functions of the body that go on *without* conscious awareness.
The twelve cranial nerves are also part of the PNS.

https://image.slidesharecdn.com/orthopedics-spine3926/95/orthopedics-spine-26-638.jpg?cb=1422433923

Sensory (afferent) neurons
All five senses (smell, sight, hearing, taste, and touch) send input to the CNS. Each sense has specialized sense organs or receptors that transmit information to the CNS for processing and interpretation. In the skin, for example, there are several types of touch receptors, which help differentiate senses such as pain from pressure and hot from cold. To learn more about how pain receptors function, see information on the pain withdrawal reflex below.



Motor (Efferent) Neurons and Motor Units
Skeletal muscle fibers must be stimulated by a motor neuron before they can contract. Smooth muscle is innervated by the autonomic nervous system (see below). Motor neurons originate from the spinal cord. The basic neuromuscular unit is called a <u>motor unit</u>. It consists of a single motor neuron and all the skeletal muscle fibers it innervates. Some motor units contain as few as 20 muscles fibers (e.g. eye muscles) while others may have over a thousand muscle fibers (e.g. the gastrocnemius). When stimulated by a motor neuron, all the muscle fibers in a motor unit contract. The neurotransmitter associated with skeletal muscle contraction is acetylcholine.



Source motor unit: http://www.gatlineducation.com/demo/PTA_Demo/html/L14/L14CH02P01.htm

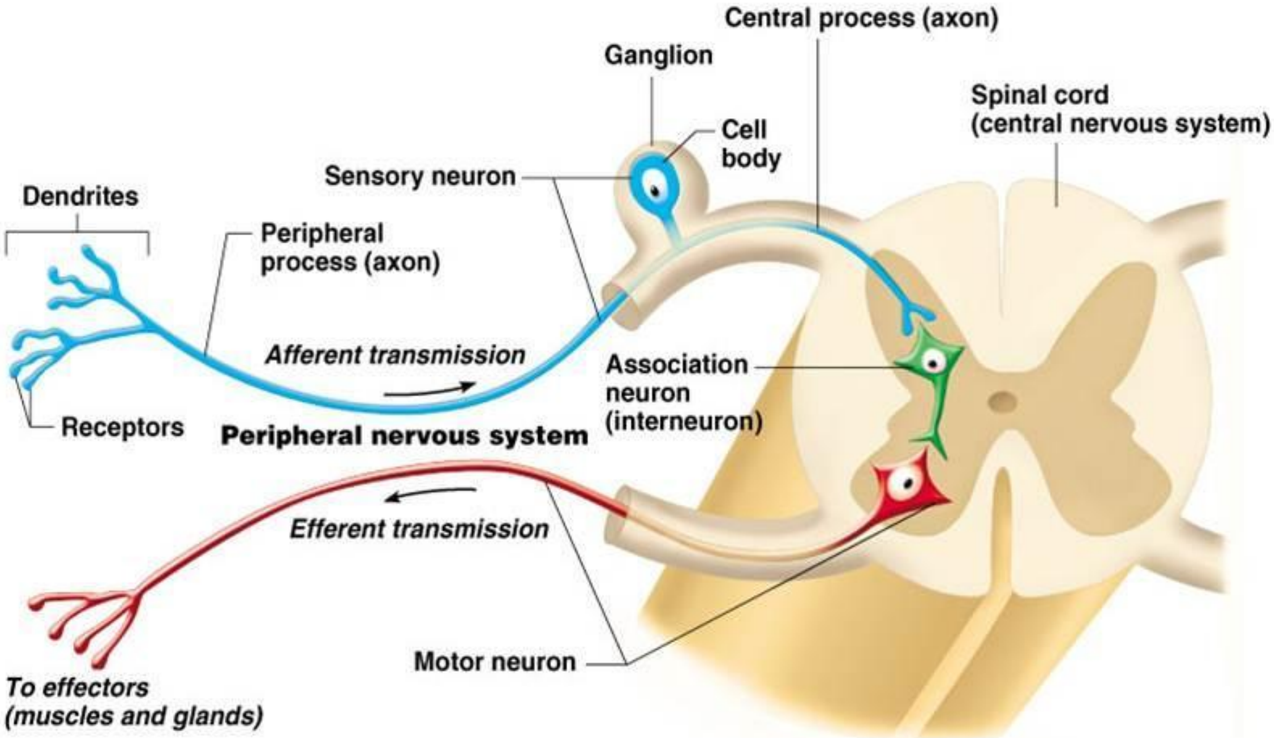
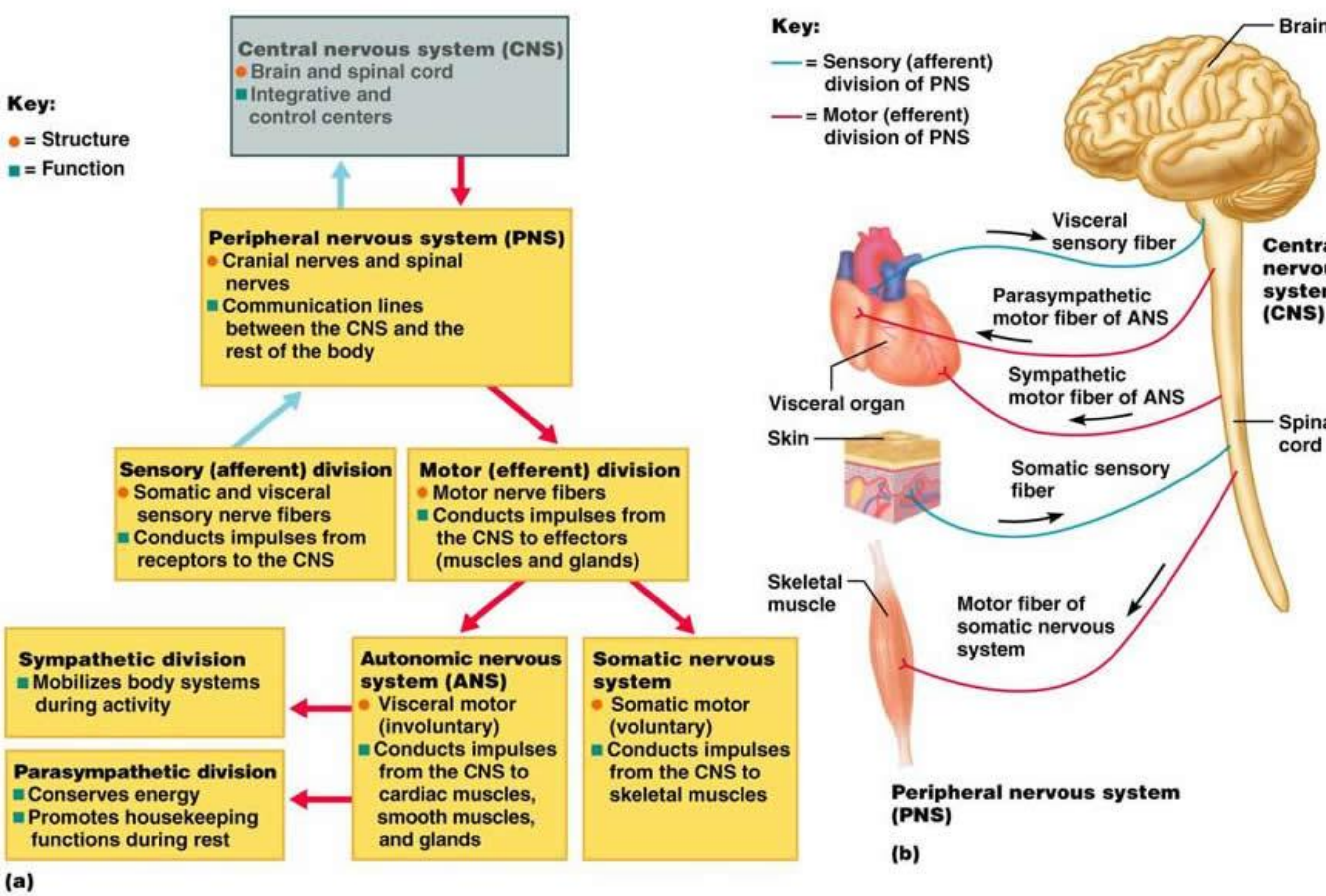


Image source: http://classes.midlandstech.edu/carterp/Courses/bio210/chap11/lecture1.html

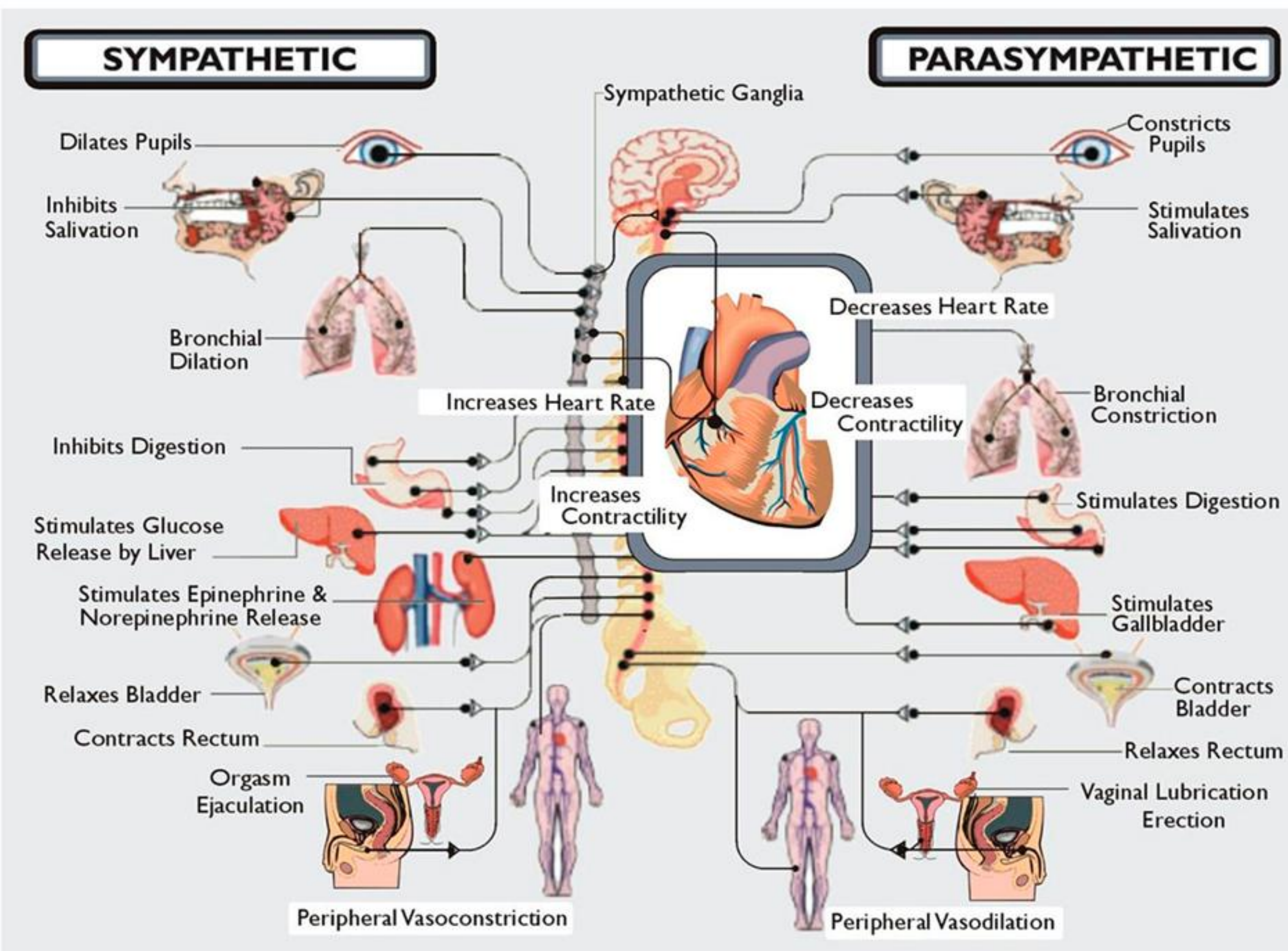


The Autonomic Nervous System (ANS)

As stated above, the ANS is responsible for regulating most of the "unconscious" activities that go on in the body, everything from the function of visceral organs in the gut to hormone secretion from glands to control of smooth muscle lining blood vessels. For the most part the ANS functions autonomously, hence the name autonomic, of the somatic nervous system. Within the brain, the ANS is regulated by the hypothalamus with input from the limbic system, a part of the brain involved with emotion, behavior, motivation, and formation of memories. The importance of this connection will become evident as you read on.

The ANS is traditionally viewed as having two divisions, the sympathetic nervous system (SNS) and the parasympathetic nervous system, which will be abbreviated PSNS to differentiate it from the peripheral nervous system or PNS. Both branches innervate most organs and glands in the body.

The SNS activates the "fight, flight" or stress response (more on this later when discussing stress). The PSNS activates the "stay and play" or "rest and digest" response as well as most essential background operations such as digestion, heart rate and breathing. The vagus nerve, the tenth cranial nerve, is the primary nerve for PSNS activity. The actions of the SNS and PSNS are often compared to the gas pedal and brakes of an automobile. In this analogy the SNS and PSNS function in a reciprocal fashion. Actions of the SNS and PSNS on various tissues and organs in the body are shown in the accompanying figure.



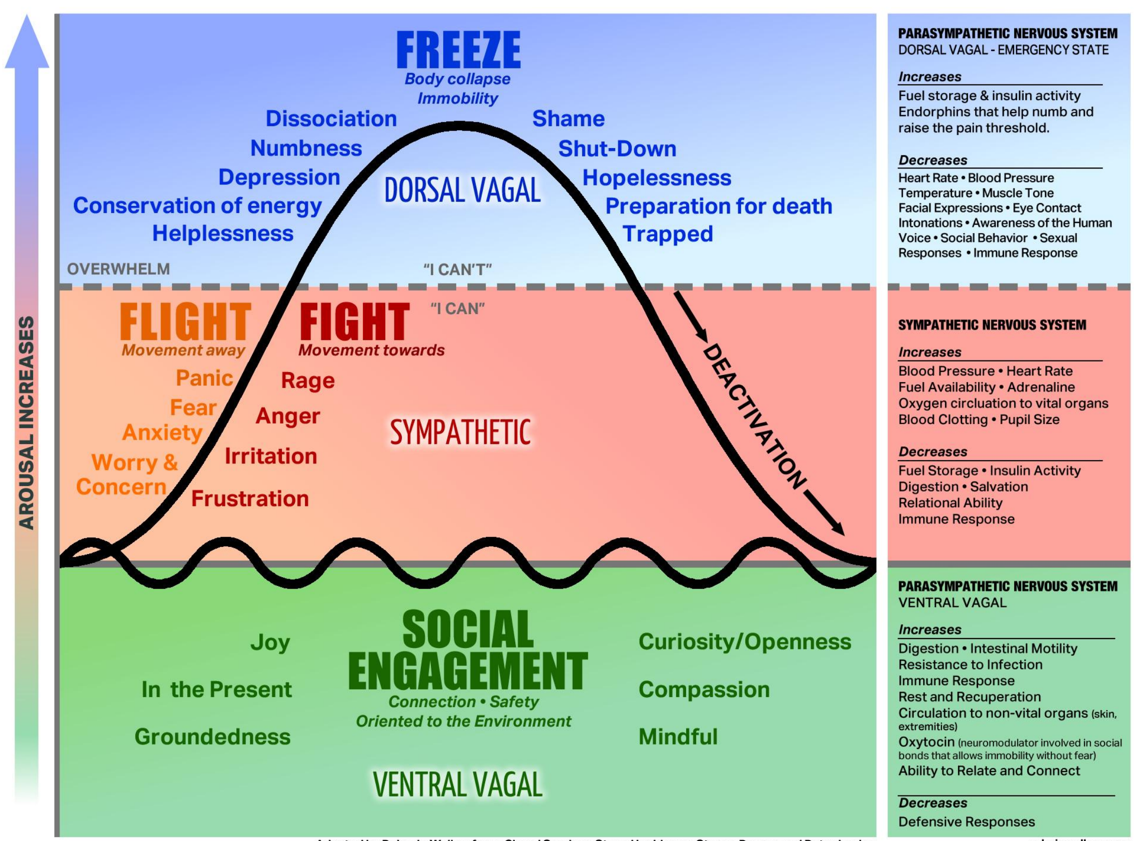
A Newer Understanding of the ANS: Polyvagal Theory

Over forty years of research in the field of psychophysiology led Dr. Stephen Porges to develop a newer description of ANS function he calls the polyvagal theory (Porges, S. (2007). The Polyvagal Perspective. *Biol Psychol*, 74(2): 116-143). According to this theory the ANS has three branches rather than two. Porges calls the third branch of the ANS the "social nervous system."

The three parts of the ANS and their functions are described below. Note that in this model the vagus nerve has two branches with very different functions.

- Myelinated vagus nerve (ventral vagal complex)
  - Social engagement system: influences eye contact, facial expression and voice
  - Calming, self-soothing, grounding
  - Associated with positive emotions (joy, love, compassion, openness)
  - Inhibits SNS
- Sympathetic nervous system (SNS)
  - Aggressive defense system
  - System for "fight or flight" response
  - Mobilizes body systems for action
  - Associated with more negative emotions (frustration, fear, anger)
- Unmyelinated vagus nerve (dorsal vagal complex)
  - Passive defense system
  - System for conservation and withdrawal
  - "Freeze" response: immobilization (feigning death, passive avoidance)
  - Associated with negative emotions/moods (helplessness, depression, numbness)

Source for image: https://vivifychangecatalyst.wordpress.com/2016/10/06/polyvagal-theory-fight-freeze-or-engage/



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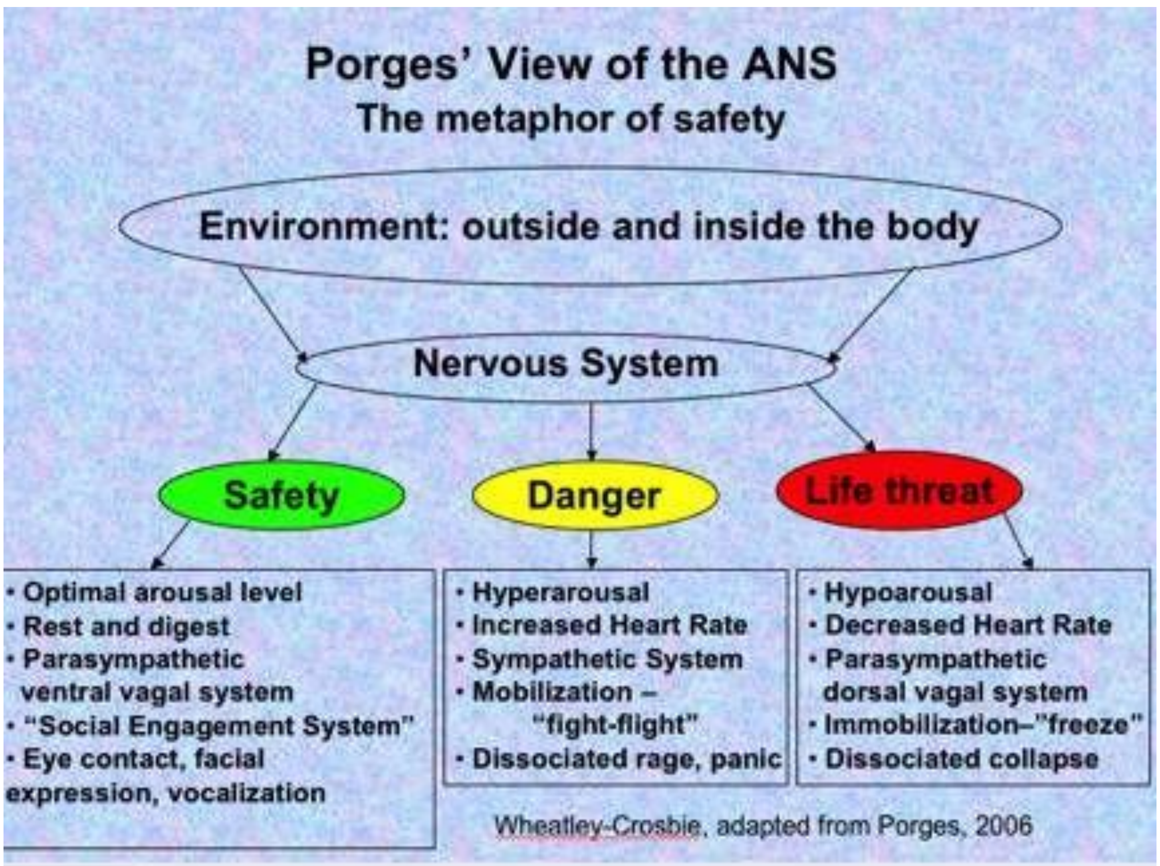
The perception of safety determines whether a person's reaction in a given situation will be prosocial (i.e. social engagement) or defensive (i.e. fight or flight or freeze). Porges uses the term neuroception to describe neural circuits in the brain, which serve as an unconscious safety-threat detection system capable of distinguishing among situations that are safe, dangerous or life threatening. These three systems are thought of as dynamic and providing adaptive responses to safe, dangerous, or life threatening events or situations.

The myelinated vagus nerve tract, the social engagement system, can act as a brake to inhibit the more primitive SNS and unmyelinated vagus nerve parts of the ANS. It is this system that allows people to self-regulate and choose to initiate pro-social behaviors rather than simply react to all stressful situations, even mild ones, with a fight or flight or freeze response. Porges theorizes that these three systems can be activated in sequence. Under stress a person can choose to activate the social engagement system, then the SNS fight or flight system, and lastly the freeze/shut down system as survival strategies as the perceived threat increases from minimal to life threatening. Exposure to daily stressors inhibits the myelinated vagus system (PSNS withdrawal). This in turn makes it more difficult to socially bond with others and engage in executive functions like self-regulation and planning.

Source for image: https://vivifychangecatalyst.wordpress.com/2016/10/06/polyvagal-theory-fight-freeze-or-engage/



Neural Control of Breathing

Given the importance of breathing or ventilation (movement of air into and out of the lungs) and respiration (exchange of oxygen and carbon dioxide in the body) to overall function in the body, it's not surprising that breathing is controlled by multiple neural systems. Here is a brief summary of these control systems.

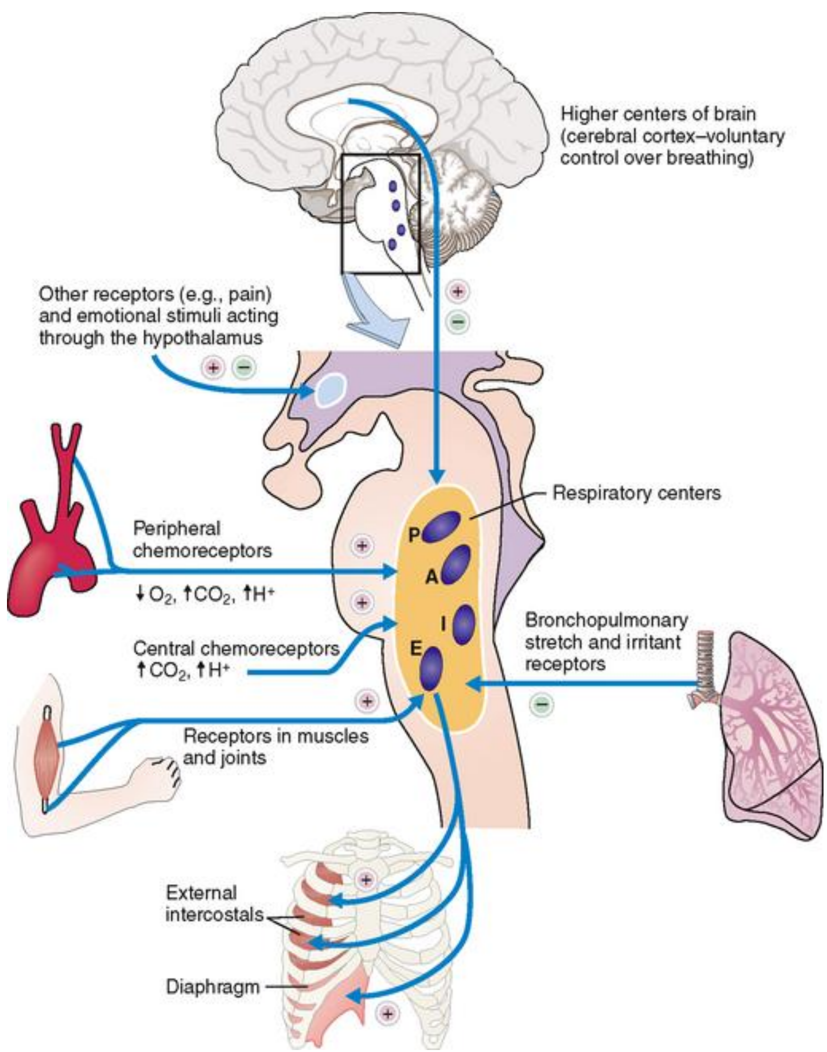
Control Center for Breathing: there are clusters of specialized neurons located in the brainstem (pons and medulla) that receive sensory or afferent input from several sources and send motor or efferent output to the diaphragm, external intercostal and other accessory muscles used in breathing (see section on respiratory system). Collectively these areas are commonly called the respiratory control center.

Sensory (Efferent) Input to Control Center

- **Cerebral cortex** (higher brain centers) – voluntary control over breathing
- **Other receptors and emotional stimuli acting through the hypothalamus** – this is how breathing is affected by strong emotions, pain, and stress
- **Chemoreceptors –** sensitive to changes in blood chemistry
  - **Central:** monitor pH (a measure of acid-base balance) and carbon dioxide level in the CNS – a decrease in pH or increase in carbon dioxide level in the CNS stimulates breathing
  - **Peripheral:** located in the aortic arch and carotid artery in the neck (see section on the cardiovascular system for details on anatomy). Peripheral chemoreceptors monitor pH, carbon dioxide and oxygen levels in arterial blood. A drop in pH, increase in carbon dioxide or decrease in oxygen levels in the arterial blood signals for an increase in breathing.
- **Specialized receptors in muscles and joints**: sense muscle contraction and tension in tendons and send input to the control center to increase breathing. This is how breathing automatically increases with the onset of physical activity.
- **Specialized receptors in the lungs and airways:** sense stretch as the lungs fill with air and any irritants in the air and send input to the control center to prevent over inflation of the lungs and protective measures to clear irritants in the lungs.

Motor (Afferent) Output to Muscles

- **Phrenic nerve:** a motor nerve that stimulates diaphragm to contract
- **Intercostal nerves**: motor nerves that stimulate the external and internal intercostal muscles to contract



How does yoga practice (breathing, meditation) affect the nervous system?

Neuroscientists and neurologists used to believe that each of us was born with a finite number of neurons. When a neuron died for any reason, it was not replaced. Furthermore, it was believed that the ability to generate new neural pathways or connections, a process called neuroplasticity, dropped off sharply around the age of 20, and then became permanently fixed around the age of 40.

In the last decade, new research has shown through the use PET and MRI brain scanning technology, that neurogenesis (the creation of nerves) is possible . We now know that new neurons and new neural pathways are generated throughout life. Even the elderly are capable of creating measurable changes in brain organization.

According to Timothy McCall, M.D. (source: http://gracefulpathyoga.com/wp-content/uploads/2015/10/Scientific-Basis-of-Yoga-Therapy.pdf) repeated thoughts and actions can rewire your brain, and the more you do something, the stronger those new neural networks become. Almost 2,000 years ago, Patanjali, author of the Yoga Sutras, was onto this when he suggested that the key to success in yoga is dedicated, uninterrupted practice over a long period of time. The resulting neural networks (analogous to samskaras in yoga science) get stronger and stronger as you stay with the practice. Slowly but surely, these healthy grooves of thought and action help guide people out of the ruts in which they've been stuck.

Dr. Richard Davidson, a world-renowned neuroscientist at University of Wisconsin Center for Healthy Minds, highlights research in the field of yoga, largely mindfulness meditation, and neuroplasticity (source: http://www.mindful.org/how-the-brain-changes-when-you-meditate/). He emphasized three key points:

1. You can train your brain to change
2. The change is measurable
3. New ways of thinking can change it for the better

According to Davidson, research suggests that we can intentionally shape the direction of plasticity changes in our brains. By focusing on wholesome thoughts, for example, and directing our intentions in those ways, we can potentially influence the plasticity of our rains and shape them in ways that can be beneficial. Based on recent research, Davidson cites four ways the brain may change from the practice mindfulness:

1. Increased grey matter/cortical thickness in several areas of the brain associated with
    a. Enhanced self-regulation and cognitive flexibility (anterior cingulate cortex)
    b. Enhanced executive functioning such as planning, problem solving, and emotional regulation (prefrontal cortex)
    c. Enhanced learning and memory and less susceptible to stress and stress-related disorders (hippocampus)
2. Decreased amygdala size: less active “fight or flight” center; seat of fearful and anxious emotions
3. Diminished or enhanced functionality in certain neural connections:
    a. Less reactivity
    b. Strengthened higher order brain functions: attention, concentration, etc.
4. Reduced activity in areas of the brain normally responsible for the “monkey mind” most people experience.

Rebecca Gladding, M.D. explains how and why meditation works on the brain. Several areas of the brain are affected by meditation.

Lateral prefrontal cortex (the assessment center): in the yoga model of the brain, the buddhi

- allows you to look at things from a more rational, logical and balanced perspective
- modulates emotional responses (originating from the fear center) overriding automatic behaviors/habits and decreasing the brain's tendency to take things personally by modulating the "me center" (medial prefrontal cortex). Aka "self-referencing center."

Brains of people who don't meditate:

- Strong neural connections within the Me Center (the part of the brain that processes information related to you) and between the Me Center and the bodily sensation/fear centers in the brain. However, the connections between Me Center and Assessment Center are weak.
- Translation: whenever you feel anxious, scared or have a body sensation, you are far more likely to assume that there is a problem and your safety is threatened. The assessment center is like a brake for the unhelpful parts of the Me Center – and it's not working.

Brains of people who do meditate:

- **Why does anxiety decrease?** The strong connections between the Me Center and body sensation/fear centers begin to break down. So body sensations or momentary feelings of fear no longer are assumed to mean something is wrong with you or that you are the problem. The ability to ignore sensations of anxiety is enhanced as you begin to break those connections.
- Increased ability to look at body sensations/pain form a more rational perspective (rather than an automatic reaction) – this stems from enhanced connections between the Me Center and the Assessment Center (buddhi).
- **Enhanced empathy** is due to improved connections with the Assessment center – this enhances our capacity to understand where another person is coming from, to infer other people's states of mind, their motivations and desires.

Dr. Gadding emphasizes that regular practice is important, because the brain can easily revert back to its old ways if you are not vigilant (neuroplasticity works in both directions). It's important to keep reinforcing the new neural pathways to keep them strong.