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The Autonomic Nervous System

Acknowledgments: This article is based principally on: ANS Balance Assessment. Bioscan Medeia Inc.. https://www.bioscan.com/dtr_ans_overview.htm

“The Autonomic Nervous System (ANS) is the involuntary division of the nervous system. It consists of autonomic neurons that conduct impulses from the central nervous system (brain and/or spinal cord) to glands, smooth muscle and cardiac muscle. ANS neurons are responsible for regulating the secretions of certain glands (i.e., salivary glands) and the regulation of heart rate and peristalsis (contraction of smooth muscle in the digestive tract), among other functions.”[(5)]

“The organs of our body (viscera), such as the heart, intestines and stomach, are regulated by a branch of the nervous system known as the autonomic nervous system. The autonomic nervous system is part of the peripheral nervous system and controls the function of many muscles, glands and organs within the body. We are usually quite unaware of the functioning of our autonomic system because it functions in a reflexive and involuntary manner. For example, we are not aware when our blood vessels change size, and we are (usually) unaware when our hearts speed up or slows down.”[(5)]

“The role of the ANS is to constantly fine-tune the functioning of organs and organ systems according to both internal and external stimuli. The ANS helps to maintain homeostasis (internal stability and balance) through the coordination of various activities such as hormone secretion, circulation, respiration, digestion and excretion. The ANS is always "on" and functioning unconsciously, so we are unaware of the important tasks it is performing every waking (and sleeping) minute of every day.”[(5)]

“The ANS is divided into two subsystems, the SNS (the sympathetic nervous system) and the PNS (parasympathetic nervous system).”[(5)]

Autonomic nervous system function

“The ANS, through its two branches (sympathetic and parasympathetic), controls energy expenditure. The sympathetic branch mediates this expenditure while the parasympathetic branch serves a restorative function. In general:

- The sympathetic nervous system causes a speeding up of bodily functions (i.e. heart and respiratory rates) and protect the core by shunting blood from the extremities to the core
- The parasympathetic nervous system causes a slowing of bodily functions (i.e. heart and respiratory rates) and favours healing, rest and restoration, as well as coordinating immune responses”[(5)]

“Health can be adversely affected when the effects on one of these systems is unchecked by the other, resulting in a disturbance of homeostasis. The ANS affects changes in the body that are meant to be temporary; in other words, the body should return to its baseline state. It is natural that there should be brief excursions from the homeostatic baseline, but the return to baseline should occur in a timely manner. When one system is persistently activated (increased tone), health may be adversely affected.

The branches of the autonomic system are designed to oppose (and thus balance) each other.

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For example, as the sympathetic nervous system begins to work, the parasympathetic nervous system goes into action to return the sympathetic nervous system back to its baseline. Therefore, it is not difficult to understand that persistent action by one branch may cause a persistently decreased tone in the other, which can lead to ill health. A balance between the two is both necessary and healthy.

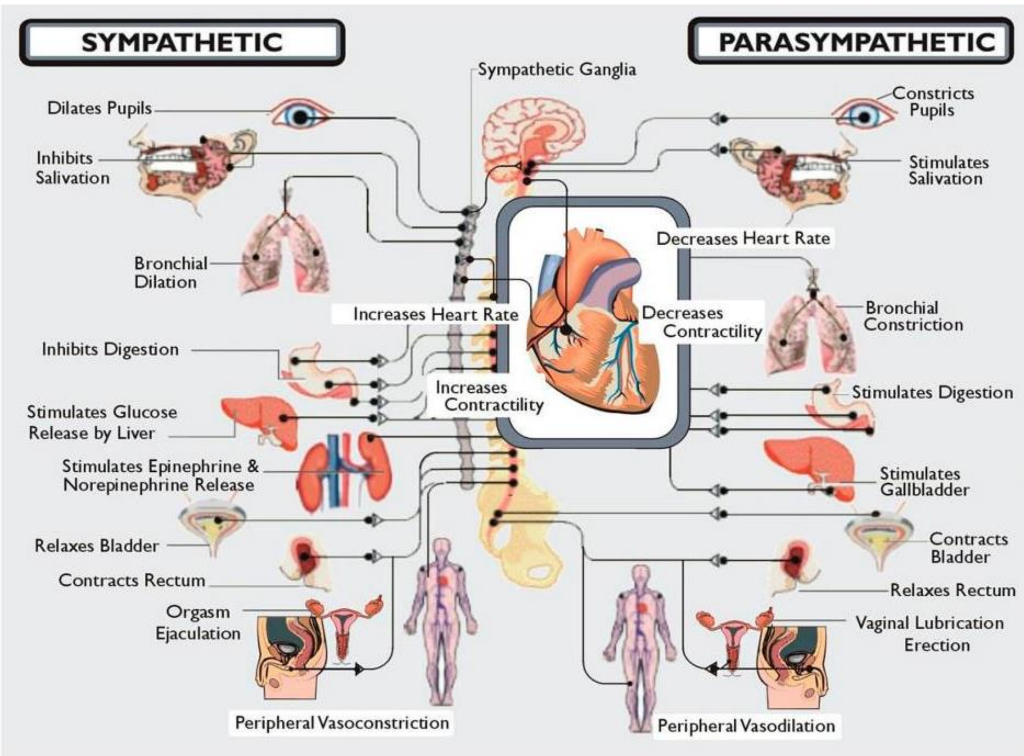
The parasympathetic nervous system has a quicker ability to respond to change than the sympathetic nervous system.

Why are we designed this way? Imagine if we weren't: exposure to a stressor causes tachycardia; if the parasympathetic system did not immediately begin to counter the increased heart rate, the heart rate could continue to increase until a dangerous rhythm, such as ventricular fibrillation, developed. Because the parasympathetics are able to respond so quickly, dangerous situations like the one described cannot occur.

The parasympathetic nervous system is the first to indicate a change in health condition in the body. The parasympathetics are the main influencing factor on respiratory activity. As for the heart, parasympathetic nerve fibres synapse deep within the heart muscle, while sympathetic nerve fibres synapse on the surface of the heart. Thus, parasympathetics are more sensitive to heart damage."[5]

The Physiology of the ANS

Neurotransmitters and receptors are integral to the automatic functioning of the ANS. Receptors mediate actions of the neurotransmitters involved in the ANS by activation of a second messenger, or by a change in ion channel permeability.[1]



Source: ANS Balance Assessment. https://www.bioscan.com/dtr_ans_overview.htm

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Effects of the Parasympathetic and Sympathetic Divisions on Various Organs

Target organ or system	Parasympathetic effects	Sympathetic effects
Eye (iris)	Stimulates sphincter pupillary muscles, constricts pupil	Stimulates dilator pupillae muscles; dilates pupils
Eye (ciliary muscle)	Stimulates muscle, resulting bulging of lens for close vision	Weakly inhibits muscle, flattening lens for far vision
Glands (nasal, lacrimal, gastric, pancreas)	Stimulates secretory activity	Inhibits secretory activity, causes vasoconstriction of blood vessels to glands
Salivary glands	Stimulates watery saliva	Stimulates thick, viscous saliva
Sweat glands	No effect (no innervation)	Stimulates copious sweating (cholinergic fibres)
Adrenal medulla	No effect (no innervation)	Stimulates medulla cells to secrete adrenalin and noradrenalin
Arrector pili muscles attached top hair follicles	No effect (no innervation)	Stimulates contraction which erects hairs and produces goosebumps
Heart (muscle)	Decreases heart rate	Increases heart rate and force of contraction
Heart (coronary blood vessels)	No effect (no innervation)	Causes vasodilation *
Urinary bladder/urethra	Contraction of smooth muscle of bladder wall, relaxes urethral sphincter, promotes voiding	Relaxation of smooth muscle of bladder wall, constricts urethral sphincter, inhibits voiding
Lungs	Constricts bronchioles	Dilates bronchioles *
Digestive tract organs	Increases motility (peristalsis) and amount of secretion by digestive organs, relaxes sphincters to allow movement of food along tract	Decreases activity of glands and muscles and constricts sphincters (eg anal sphincter)
Liver	Increases glucose uptake from blood	Stimulates secretion of glucose to blood *
Gallbladder	Excites (gallbladder contracts to expel bile)	Inhibits function, gallbladder is relaxed
Kidney	No effect (no innervation)	Promotes renin release, causes vasoconstriction, decreases urine output
Penis	Causes erection (vasodilation)	Causes ejaculation
Vagina/clitoris	Causes erection (vasodilation of clitoris), increases vaginal lubrication	Causes contraction of vagina

Blood vessels	Little or no effect	Constricts most vessels and increases blood pressure, constricts vessels of abdominal viscera and skin to divert blood to muscles, brain, and heart when necessary: Noradrenalin constricts most vessels, Adrenalin dilates vessels of the skeletal muscles during exercise *
Blood coagulation	No effect (no innervation)	Increases coagulation *
Cellular metabolism	No effect (no innervation)	Increases metabolic rate *
Adipose tissue	No effect (no innervation)	Stimulates lipolysis (fat breakdown)

- Effects mediated by adrenalin release into bloodstream from adrenal medulla

Source: Marieb,H.,Hoehn,K. Human Anatomy & Physiology, 8th Ed, Pearson International, 2010, p 538

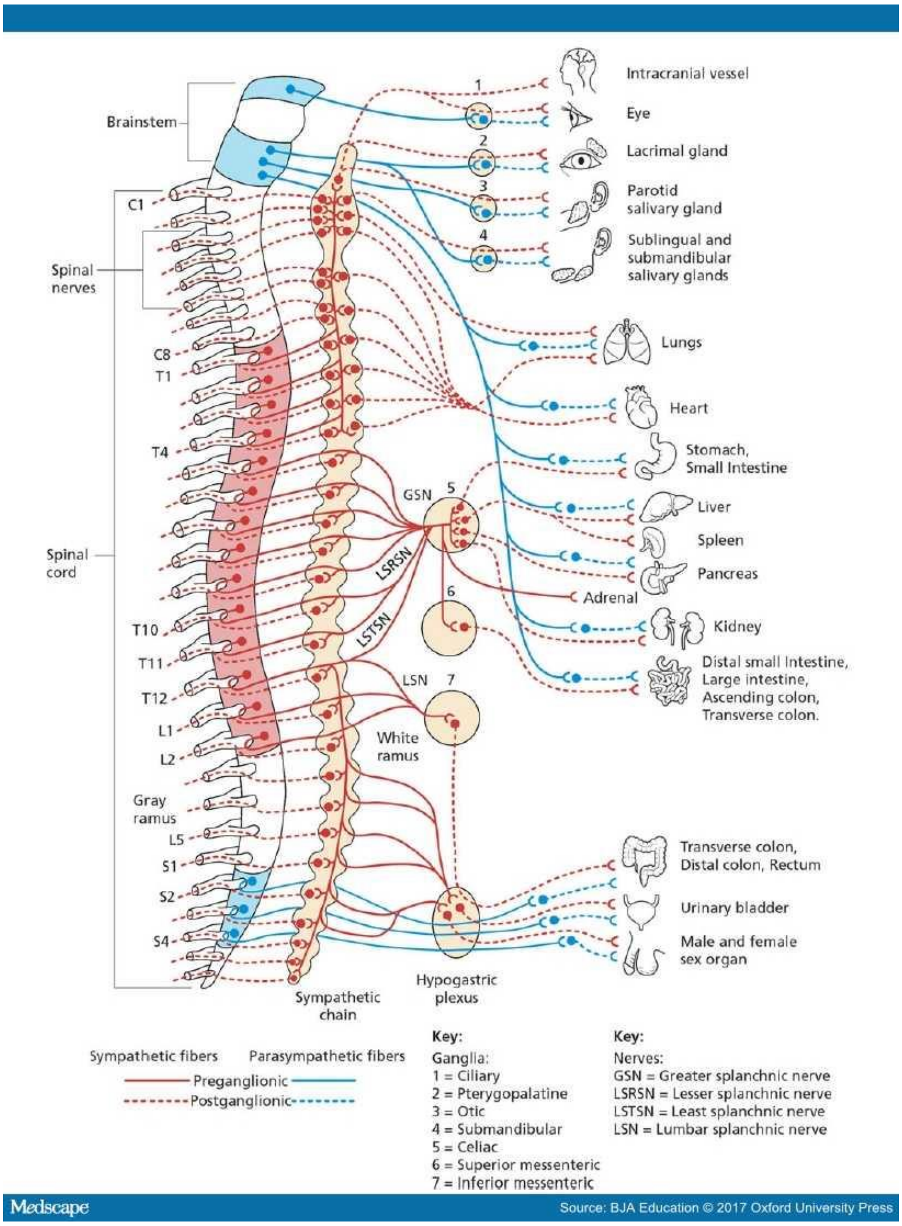

Figure 2 ANS overall anatomy. Parasympathetic pathways represented by blue and the sympathetic pathways in red. The interrupted red lines indicate post-ganglionic rami to the cranial and spinal nerves. This image is from the 20th US edition of *Gray's Anatomy of the Human Body* and is in the public domain.

The Sympathetic System- "Fight or Flight" response:

“Adrenalin and noradrenalin (epinephrine and norepinephrine) are two neurotransmitters that also serve as hormones, and they belong to a class of compounds known as catecholamines.”[(6)] Catecholamines are hormones made by the adrenal glands including dopamine as well as epinephrine and norepinephrine. “Chemically, epinephrine and norepinephrine are very similar. However, epinephrine works on both alpha and beta receptors, while norepinephrine only works on alpha receptors.

Alpha receptors are only found in the arteries. Beta receptors are in the heart, lungs, and arteries of skeletal muscles. It’s this distinction that causes epinephrine and norepinephrine to have slightly different functions. Both epinephrine and norepinephrine can affect your heart, blood sugar levels, and blood vessels. However, norepinephrine can also make your blood vessels become narrower, increasing blood pressure."[(6)]

The adrenal medulla produces norepinephrine in response to low blood pressure and stress. Norepinephrine promotes vasoconstriction, which is a narrowing of the blood vessels, and this increases blood pressure. Like epinephrine, norepinephrine also increases the heart rate and blood sugar levels.

Overproduction of adrenaline is very common. Most of us are familiar with the typical symptoms of adrenaline release, such as: rapid heartbeat, high blood pressure, anxiety, weight loss, excessive sweating and palpitations. However, this is a normal response of the body which is intended to help us respond to a stressful situation; once the acute stress is over, the symptoms quickly disappear as adrenaline secretion stops.

"Epinephrine is used to treat anaphylaxis, cardiac arrest, and severe asthma attacks. Norepinephrine, on the other hand, is used to treat dangerously low blood pressure. In addition, medications that increase norepinephrine can help with ADHD and depression.

Chronic stress, poor nutrition, and taking certain medications, such as methylphenidate (Ritalin), can make your less sensitive to epinephrine and norepinephrine. These factors can also cause your body to start producing less epinephrine and norepinephrine."[(6)]

Activation of adrenergic receptors

"The following effects are seen as a result of activation of adrenergic receptors:

- increased sweating
- decreased peristalsis
- increased heart rate (increased conduction speed, decreased refractory period)
- pupil dilation
- increased blood pressure (increased contractility, increased ability of the heart to relax and fill)

The following effects can occur:

- Constriction of peripheral blood vessels to shunt blood to the core, where it is needed
- Increased in supply of blood to skeletal muscles that may be needed for activity
- Dilation of the bronchioles under conditions of low oxygen in the blood
- Reduction in blood flow to the abdomen; decreased peristalsis and digestive activities
- Release of glucose stores from the liver to increase glucose in the bloodstream

As with the parasympathetic system, it is helpful to look at a real example to understand how the sympathetic nervous system functions:

Extreme heat is a stressor that many of us have experienced. When we are exposed to excessive heat, our bodies respond in the following manner: thermal receptors convey stimuli to sympathetic control centres located in the brain. Inhibitory messages are sent along the sympathetic nerves to the blood vessels in the skin, which dilate in response. This dilation of the blood vessels increases the flow of blood to the body's surface so that heat can be lost through radiation from the body surface. In addition to the dilation of blood vessels in the skin, the body also reacts to excessive heat by sweating. This occurs through the rise in body temperature, which is sensed by the hypothalamus, which sends a signal via the sympathetic nerves to the sweat glands, which increase the amount of sweat produced. Heat is lost by evaporation of the sweat produced.

- sympathetic neurons are generally considered to belong to the peripheral nervous system, although some of the sympathetic neurons are located in the CNS (central nervous system)
- sympathetic neurons of the CNS (spinal cord) interact with peripheral sympathetic neurons through a series of sympathetic nerve cells bodies known as ganglia
- via chemical synapses within the ganglia, sympathetic neurons join peripheral sympathetic neurons (for this reason, the terms 'presynaptic' and 'postsynaptic' are used to refer to spinal cord sympathetic neurons and peripheral sympathetic neurons, respectively)
- presynaptic sympathetic neurons release acetylcholine at synapses within the sympathetic ganglia. Acetylcholine (Ach) is a chemical messenger that binds nicotinic acetylcholine receptors to the postsynaptic neurons
- postsynaptic neurons release norepinephrine (NE) in response to this stimulus
- prolonged activation of this stimulus response can trigger the release of adrenaline from the adrenal glands (specifically the adrenal medulla)
- once released, NE and epinephrine (adrenaline) bind to adrenergic receptors on various tissues, resulting in the characteristic effects of "fight-or-flight".”[(5)]

The Parasympathetic System

Parasympathetic nervous system (PNS) - the PNS is sometimes referred to as the "rest and digest" system. In general, the PNS acts in the opposite way to the SNS, reversing the effects of the fight-or-flight response. However, it may be more correct to say that the SNS and the PNS have a complementary relationship, rather than one of opposition.

- the PNS uses acetylcholine (Ach) as its primary neurotransmitter
- when stimulated, the presynaptic nerve releases acetylcholine (Ach) at the ganglion
- Ach in turn acts on nicotinic receptors of postsynaptic neurons
- postsynaptic nerves then releases acetylcholine to stimulate the muscarinic receptors of the target organ

The following effects are seen as a result of activation of the PNS:

- Increase in blood flow to the gastrointestinal tract, which helps to meet the greater metabolic demands placed on the body by the GI tract
- Constriction of the bronchioles when oxygen levels are normalized
- Control of the heart via the Vagus nerve cardiac branches and spinal accessory nerves of the thoracic spinal cord
- Constriction of the pupil allowing for near vision control
- Stimulation of salivary gland production and speeds up peristalsis to aid digestion
- Relaxation/contraction of the uterus and erection/ejaculation in men

The following effects may be felt with PNS activation:

- decreased sweating
- increased peristalsis

- decreased heart rate (decreased conduction speed, increased refractory period)
- pupil constriction
- decreased blood pressure (decreased contractility, decreased ability of the heart to relax and fill)" [(5)]

The Messengers of the SNS and PNS

"The autonomic nervous system releases chemical messengers to influence its target organs. The most common are norepinephrine (NE, or noradrenalin) and acetylcholine (Ach). All presynaptic neurons use Ach as a neurotransmitter. Ach is also released by some sympathetic postsynaptic neurons and all parasympathetic postsynaptic neurons. The SNS uses NE as its principle postsynaptic chemical messenger. NE and Ach are the best-known neurotransmitters of the ANS. In addition to neurotransmitters, certain vasoactive substances are released by postsynaptic automatic neurons, which bind to receptors on target cells and influence the target organ."[(5)]

How does the SNS mediate its action?

"In the sympathetic nervous system, catecholamines (norepinephrine, epinephrine [or adrenalin]) act on specific receptors located on the cell surface of the target organs. These receptors are called adrenergic receptors.

- Alpha 1 receptors exert their effect on smooth muscle, mainly by constriction. Effects may include constriction of arteries and veins, decreased motility within the GI (gastrointestinal) tract, and constriction of the pupil. Alpa1 receptors are usually located postsynaptically.
- Alpha 2 receptors bind both epinephrine and norepinephrine, thus reducing the effect of alpha 1 receptors to a certain extent. However, alpha 2 receptors have several specific effects of their own, including vasoconstriction. Effects may include coronary artery constriction, constriction of smooth muscle, constriction of veins, decreased intestinal motility and inhibition of insulin release.
- Beta 1 receptors exert their effect mostly on the heart, causing an increase in cardiac output, increased contractility and increased cardiac conduction, leading to an increase in heart rate. There is also stimulation of the salivary glands.
- Beta 2 receptors exert their effect mostly on the skeletal and cardiac muscles. Increased contraction speed and mass of muscles, as well as dilation of blood vessels occurs. Receptors are stimulated by circulating neurotransmitters (catecholamines)."[(5)]

How does the PNS mediate its action?

"Acetylcholine is the primary neurotransmitter of the PNS. Acetylcholine acts on cholinergic receptors known as muscarinic and nicotinic receptors. Muscarinic receptors exert their effect on the heart. There are two main muscarinic receptors:

M2 receptors- acted on by acetylcholine, M2 receptors are located in the heart; stimulation of these receptors causes the heart to slow (decreased heart rate and contractility and an increase in refractoriness).

M3 receptors- located throughout the body; activation causes increased synthesis of nitric oxide, which results in relaxation of cardiac smooth muscle cells."[(5)]

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How is the autonomic nervous system organized?

"As previously discussed, the autonomic nervous system is subdivided into two separate divisions: the sympathetic nervous system and the parasympathetic nervous system. It is important to understand how these two systems function in order to determine how they each affect the body, keeping in mind that both systems work in synergy to maintain homeostasis within the body.

Both the sympathetic and parasympathetic nerves release neurotransmitters, primarily norepinephrine and epinephrine for the sympathetic nervous system, and acetylcholine for the parasympathetic nervous system. These neurotransmitters (also called catecholamines) relay the nerve signals across the gaps (synapses) created when the nerve connects to other nerves, cells or organs. The neurotransmitters then attach to either sympathetic receptor sites or parasympathetic receptor sites on the target organ to exert their effect."(5)

How is the autonomic nervous system controlled?

"The ANS is not under conscious control. There are several centres which play a role in control of the ANS:

- Cerebral cortex- the cerebral cortex areas control homeostasis by regulating the SNS, the PNS and the hypothalamus.
- Limbic system- the limbic system is composed of the hypothalamus, the amydala, the hippocampus, and other nearby areas. These structures lie on both sides of the thalamus, just under the cerebrum.
- Hypothalamus- the cells that drive the ANS are located in the lateral medulla. The hypothalamus projects to this area, which includes the parasympathetic vagal nuclei, and also to a group of cells which lead to the sympathetic system in the spinal cord. By interacting with these systems, the hypothalamus controls digestion, heart rate, sweating and other functions.
- Brain stem- the brainstem acts as the link between the spinal cord and the cerebrum. Sensory and motor neurons travel through the brainstem, conveying messages between the brain and spinal cord. The brainstem controls many autonomic functions of the PNS, including respiration, heart rate and blood pressure.
- Spinal cord- two chains of ganglia are located on either side of the spinal cord. The outer chains form the parasympathetic nervous system, while the chains closest to the spinal cord form the sympathetic element."(5)

What are some receptors of the autonomic nervous system?

"Sensory neuron dendrites are sensory receptors that are highly specialized, receiving specific types of stimuli. We do not consciously sense impulses from these receptors (except perhaps pain). There are numerous sensory receptors:

- Photoreceptors- respond to light
- Thermoreceptors- respond to alterations in temperature
- Mechanoreceptors- respond to stretch and pressure (blood pressure or touch) including baro (pressure) receptors
- Chemoreceptors- respond to changes in internal body chemistry (i.e., O2, CO2) and dissolved chemicals during sensations of taste and smell

- Nociceptors- respond to various stimuli associated with damage to tissues (brain interprets the pain)

Autonomic (visceral) motor neurons synapse onto neurons located in the ganglia of the sympathetic and parasympathetic nervous system, which in turn directly innervate muscles and some glands. In this way, visceral motor neurons can be said to indirectly innervate smooth muscles of arteries and cardiac muscle. Autonomic motor neurons work by increasing (in the SNS) or decreasing (in the PNS) activities of their target tissues. In addition, autonomic motor neurons can continue to function even if their nerve supply is damaged, albeit to a lesser extent."(5)

Transmission of Autonomic Stimuli

"Neurons generate and propagate action potentials along their axons. They then transmit signals across a synapse through the release of chemicals called neurotransmitters, which stimulate a reaction in another effector cell or neuron. This process may cause either stimulation or inhibition of the receiving cell, depending which neurotransmitters and receptors are involved.

Propagation- along the axon, axon potential propagation is electrical and occurs through the exchange of N+ and K+ ions across the membrane of the axon. Individual neurons generate the same potential after receiving each stimulus and conduct the axon potential at a fixed rate of velocity along the axon. Velocity is dependent upon the diameter of the axon and how heavily it is myelinated- speed is faster in myelinated fibres because the axon is exposed at regular intervals (nodes of Ranvier). The impulse "jumps" from one node to the next, skipping myelinated sections.

Transmission- transmission is chemical, resulting from the release of specific neurotransmitters from the terminal (nerve ending). These neurotransmitters diffuse across the cleft of the synapse and bind to specific receptors attached to the effector cell or adjoining neuron. Response may be excitatory or inhibitory depending on the receptor. Neurotransmitter-receptor interaction must occur and terminate quickly. This allows for repeated and rapid activation of the receptors. Neurotransmitters can be "reused" in one of three ways:

- Reuptake- neurotransmitters are quickly pumped back into presynaptic nerve terminals
- Destruction- neurotransmitters are destroyed by enzymes located near the receptors
- Diffusion- neurotransmitters may diffuse into the surrounding area and eventually be removed

Receptors- receptors are protein complexes that cover the membrane of the cell. Most interact primarily with postsynaptic receptors; some are located on presynaptic neurons, which allows for finer control of the release of the neurotransmitter. There are two major neurotransmitters in the autonomic nervous system:

- Acetylcholine- the major neurotransmitter of autonomic presynaptic fibres, postsynaptic parasympathetic fibres.
- Norepinephrine- the neurotransmitter of most postsynaptic sympathetic fibres"(5)

Autonomic Neurons

"Neurons that conduct impulses away from the central nervous system are known as efferent (motor) neurons. They differ from somatic motor neurons in that Efferent neurons are not under conscious control. Somatic neurons send axons to skeletal muscle, which is usually under conscious control.

- Visceral efferent neurons- motor neurons whose job it is to conduct impulses to cardiac muscle, smooth muscles and glands. They may originate in the brain or spinal cord (CNS). Two visceral efferent neurons are required to conduct an impulse from the brain or spinal cord to the target tissue.
- Preganglionic (presynaptic) neurons- the cell body of the neuron is located in the grey matter of the spinal cord or brain. It ends in a sympathetic or parasympathetic ganglion.
- Preganglionic autonomic fibres- may begin in the hindbrain, midbrain, upper thoracic spinal cord, or fourth sacral level of the spinal cord. Autonomic ganglia may be found in the head, neck or abdomen. Chains of autonomic ganglia also run parallel to each side of the spinal cord.
- Postganglionic (postsynaptic) neurons- cell body is located in the autonomic ganglion (sympathetic or parasympathetic). The neuron ends in a visceral structure (the target tissue)

Where preganglionic fibres originate and autonomic ganglia are found helps in differentiating between the sympathetic nervous system and the parasympathetic nervous system."(5)

Divisions of the Autonomic Nervous System

"A summary of the ANS divisions:

- Consists of visceral (motor) efferent fibers
- Divided into the sympathetic and parasympathetic divisions
- Sympathetic neurons exit the CNS through the spinal nerves located in the lumbar/thoracic regions of the spinal cord
- Parasympathetic neurons exit the CNS via cranial nerves and also spinal nerves located in the sacral spinal cord
- There are always two neurons involved in nerve transmission: presynaptic (preganglionic) and postsynaptic (postganglionic)
- Sympathetic preganglionic neurons are relatively short; postganglionic sympathetic neurons are relatively long
- Parasympathetic preganglionic neurons are relatively long; postganglionic parasympathetic neurons are relatively short
- All neurons of the ANS are either adrenergic or cholinergic
- Cholinergic neurons use acetylcholine (Ach) as their neurotransmitter (including: preganglionic neurons of the SNS and PNS divisions, all postganglionic neurons of the PNS division and postganglionic neurons of the SNS division that act on the sweat glands)
- Adrenergic neurons use norepinephrine (NE) as their neurotransmitter (including all postganglionic SNS neurons except those that act on the sweat glands)"(5)

Adrenal Glands

"The adrenal glands are located above each kidney (also referred to as the suprarenal glands). They are located at approximately the level of the 12th thoracic vertebrae. The adrenal gland has two parts, an outer cortex and an inner medulla. Both parts produce hormones: the outer cortex produces aldosterone, androgens and cortisol, while the medulla mainly produces epinephrine and norepinephrine. The medulla releases epinephrine and norepinephrine when the body responds to a stressor (i.e., the SNS is activated) directly into the bloodstream.

The cells of the adrenal medulla are derived from the same embryonic tissue as sympathetic postganglionic neurons; therefore the medulla is akin to a modified sympathetic ganglion. The cells of the medulla are innervated by sympathetic preganglionic fibres. In response to neural stimulation, the medulla secretes epinephrine into the bloodstream. Epinephrine effects are similar to norepinephrine.

The hormones produced by the adrenal glands are crucial to normal healthy functioning of the body. Cortisol released as a response to chronic stress (or increased sympathetic tone) can be damaging to the body (i.e., hypertension, altered immune function). If the body is stressed for a prolonged period of time, cortisol levels may be insufficient (adrenal fatigue), causing low blood sugar, excessive tiredness and muscle pain."[5]

Parasympathetic (Craniosacral) Division

"The parasympathetic division of the autonomic nervous system is often referred to as the craniosacral division. This is due to the fact that cell bodies of preganglionic neurons are located in the brain stem nuclei, and also in the lateral grey horns of the 2nd through the 4th sacral segments of the spinal cord; hence, the term craniosacral is often used to refer to the parasympathetic division.

Parasympathetic cranial outflow:

- Consists of myelinated preganglionic axons that emerge from the brain stem in cranial nerves (III, VII, IX and X)
- Has five components
- Largest is the vagus nerves (X); carry preganglionic fibers comprising nearly 80% of the total outflow
- Axons end in terminal ganglia in the walls of target (effector) organs, where they synapse with ganglionic neurons

Parasympathetic sacral outflow:

- Consists of myelinated preganglionic axons that emerge in the anterior roots of the 2nd through the 4th sacral nerves
- Collectively, they form the pelvic splanchnic nerves, which synapse with ganglionic neurons in the walls of reproductive/elimination organs"[5]

Functions of the Autonomic Nervous System

"The "3F's" mnemonic (fear, fight, or flight) makes it easy to predict the workings of the sympathetic nervous system. When faced with situations of intense fear, anxiety or stress, the body reacts by speeding up the heart rate, increasing blood flow to vital organs and muscles, slowing digestion, making changes to our vision to allow us to see better and numerous other changes that allow us to react quickly in dangerous or stressful situations. These reactions have allowed us to survive as a species for thousands of years.

As is often the case with the human body, the sympathetic system is perfectly balanced by the parasympathetic division, which returns our system to normal following activation of the sympathetic division. The parasympathetic system not only restores balance, but also performs other important functions in reproduction, rest and sleep, and digestion. Each division uses different neurotransmitters to perform their actions- for the sympathetic nervous system, norepinephrine and epinephrine are the neurotransmitters of choice, while the parasympathetic division uses acetylcholine to perform its duties."[5]

Stress and ANS

"When a person is placed in a threatening situation, messages from the sensory nerves are carried to the cerebral cortex and limbic system (the "emotional" brain) and also to the hypothalamus. The anterior portion of the hypothalamus excites the sympathetic nervous system. The medulla oblongata contains centres that control many functions of the digestive, cardiovascular, pulmonary, reproductive and urinary systems.

The vagus nerve (which has both sensory and motor fibers) supplies sensory input to these centres through its afferent fibres. The medulla oblongata is itself regulated by the hypothalamus, the cerebral cortex and the limbic system. Thus there are several areas involved in the body's response to stress.

When a person is exposed to extreme stress (picture a terrifying situation that occurs without warning, such as a wild animal poised to attack you), the sympathetic nervous system may become completely paralyzed so that its functions cease completely. The person may be frozen in place, unable to move. They may lose control of their bladder. This is due to an overwhelming number of signals that the brain must "sort" and a corresponding tremendous surge of adrenalin. Thankfully, most of the time we are not exposed to stress of this magnitude and our autonomic nervous system functions as it should!"[5]

Disturbances Clearly Related to Autonomic Involvement

"There are numerous diseases/conditions which result from automatic nervous system dysfunction:

- Orthostatic hypotension- symptoms include dizziness/lightheadedness with position change (i.e., going from sitting to standing), fainting, blurred vision, and sometimes nausea. It is sometimes caused by failure of baroreceptors to sense and respond to low blood pressure caused by blood pooling in the legs.
- Horner syndrome- symptoms include decreased sweating, drooping eyelid and pupil constriction affecting one side of the face. It is caused by damage to the sympathetic nerves that supply the eyes and face.
- Hirschsprung's disease- also referred to as congenital megacolon, this disorder features dilation of the colon and severe constipation. It is caused by a lack of parasympathetic ganglia in the wall of the colon.
- Vasovagal syncope- a common cause of fainting, vasovagal syncope occurs when the ANS abnormally responds to a trigger (disturbing sights, straining at stool, standing for prolonged periods) by slowing the heart rate and dilating the blood vessels in the legs, allowing blood to pool in the lower extremities, resulting in a rapid drop in blood pressure.
- Raynaud's phenomenon- this disorder frequently affects young women, causing discoloration of the fingers and toes, and occasionally the ears and other areas of the body. It is caused by extreme vasoconstriction of peripheral blood vessels resulting

from hyperactivation of the sympathetic nervous system. It is often precipitated by stress and cold.

- Spinal shock- caused by severe injury or damage to the spinal cord, spinal shock may cause autonomic dysreflexia, characterized by sweating, severe hypertension and loss of bowel or bladder control resulting from sympathetic stimulation below the level of the spinal cord injury that is unchecked by the parasympathetic nervous system.”[(5)]

Autonomic Neuropathy

“Autonomic neuropathies are a collection of conditions or diseases that affect sympathetic or parasympathetic neurons (or sometimes both). They may be hereditary (present from birth and passed down from an affected parent) or acquired later in life.

The autonomic nervous system controls many body functions, therefore autonomic neuropathies may cause any number of symptoms and signs that may be elicited through exam or laboratory studies. Sometimes only a single nerve of the ANS is affected; however, physicians must watch for development of symptoms stemming from involvement of other areas of the ANS. Autonomic neuropathies can cause a wide variety of clinical symptoms. These symptoms are dependent upon which nerves of the ANS are affected.

Symptoms may be widely variable and can affect almost all body systems:

- Integumentary system- pale colour, lack of ability to sweat affecting one side of the face, itching, hyperalgesia (hypersensitivity of the skin), dry skin, cold feet, brittle nails, worsening of symptoms at night, lack of hair growth on lower legs
- Cardiovascular system- palpitations (racing or skipping beats), tremors, blurring of vision, lightheadedness, presyncope, shortness of breath, chest pain, ringing in the ears, lower extremity discomfort, fainting
- Gastrointestinal system- diarrhea or constipation, feeling full after eating very little (early satiety), swallowing difficulties, incontinence, decreased salivation, gastroparesis, fainting during toileting activities, increased gastric motility, vomiting (associated with gastroparesis)
- Genitourinary system- erectile dysfunction, inability to ejaculate, inability to achieve orgasm (in women and men), retrograde ejaculation, urinary urgency and frequency, urinary retention (overflow incontinence), urinary incontinence (stress or urge incontinence), nocturia, enuresis, incomplete emptying of the bladder
- Respiratory system- decreased response to cholinergic stimuli (impaired bronchoconstriction), impaired response to low levels of oxygen in the blood (heart rate and ventilation response)
- Nervous system- burning sensation in the feet, inability to regulate body temperature
- Ocular system- blurring/graying of vision, photophobia, tunnel vision, reduced tearing, difficulty focusing, loss of papillary size over time

Causes of autonomic neuropathy may be related to numerous diseases/conditions, medications used to treat other diseases or procedures (such as surgery):

- Alcoholism- chronic ethanol (alcohol) exposure may lead to impaired axonal transport and damage to cytoskeletal properties. Alcohol has been shown to be toxic to both peripheral and autonomic nerves.
- Amyloidosis- in this condition, insoluble proteins are deposited within various tissues and organs; autonomic dysfunction is common in both primary and hereditary amyloidosis.

- Autoimmune diseases- acute intermittent and variegate porphyria, Holmes-Adie syndrome, Ross syndrome, multiple myeloma are all examples of diseases that have a known or speculated autoimmune component/cause of the disease. The immune system wrongfully identifies body tissues as foreign and attempts to destroy them, leading to widespread damage to nerves.
- Diabetes-neuropathy occurs commonly in diabetes, affecting both sensory and motor nerves; diabetes is the most common cause of AN.
- Multiple system atrophy-this is a neurological disorder causing degeneration of nerve cells, causing alterations in autonomic functions and problems with movement and balance.
- Nerve damage- nerves may be damaged as a result or trauma or surgery, resulting in autonomic dysfunction.
- Medications-medications used therapeutically to treat other disorders may affect the ANS.

Obviously, some individuals cannot control their risk factors for autonomic neuropathy (i.e., hereditary causes of AN). Diabetes is by far the largest contributing factor to AN and puts individuals with the disease at high risk for AN. Diabetics can reduce their risk of AN by controlling their blood sugars carefully to prevent damage to their nerves. Smoking, consuming alcohol regularly, hypertension, hypercholesteremia (high blood cholesterol) and obesity may also increase the risk of developing AN, so these factors should be controlled as much as possible to reduce the risk of developing AN.

Treatment of autonomic dysfunction is largely dependent on the cause of AN. When treatment of the underlying cause is not possible, physicians will attempt various therapies to mitigate symptoms of AN:

- Integumentary system- itching (pruritis) may be treated using medications or may be combated by moisturizing the skin, which may be the primary cause of pruritis; hyperalgesia of the skin may be treated with medications such as gabapentin, a medication used to treat neuropathy and nerve pain.
- Cardiovascular system-symptoms of orthostatic hypotension may be improved by wearing compression stockings, increasing fluid intake, increasing salt in the diet and medications that regulate blood pressure (i.e. fludrocortisones). Tachycardia may be treated with beta blockers. Patients should be counselled to avoid sudden position changes.
- Gastrointestinal system- patients may be counselled to eat small, frequent meals if they have gastroparesis. Medications may sometimes be helpful in increasing motility (i.e., Reglan). Increasing fiber in the diet may help with constipation. Bowel retraining is also sometimes helpful for the treatment of bowel issues. Diarrhea is sometimes helped by antidepressants. Eating a diet that is low in fat and high in fiber may improve digestion and constipation. Diabetic individuals should strive to normalize their blood sugars.
- Genitourinary system- bladder retraining, medications for overactive bladder, intermittent catheterization (used to completely empty the bladder when incomplete bladder emptying is an issue) and medications to treat erectile dysfunction (i.e., Viagra) may be used to treat sexual issues.
- Ocular issues- medications to reduce tearing are sometimes prescribed.”(5)

Basic Anatomy

The organization of the ANS is on the basis of the reflex arc and it has an afferent limb, efferent limb, and a central integrating system.[3]

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The Afferent Limb

The afferent limb transmits information from the periphery to the central nervous system (CNS). The receptors are present in the abdominal and thoracic viscera.[2] The transmissions from these receptors are conducted along neural pathways into the spinal cord via the dorsal root ganglion or to the brain stem via cranial nerves. Baroreceptors and chemoreceptors are examples of the afferent pathway. These are present in the aortic arch and carotid sinus. The sensory impulses from these receptors are transmitted via glossopharyngeal and vagus nerves to the brain stem.(1)

The Efferent Limb

The efferent limb is made up of preganglionic and post-ganglionic fibres and an autonomic ganglion. The efferent limb is further subdivided based on its anatomic and physiological differences into sympathetic and parasympathetic components. A useful generalization is that the sympathetic system responds for 'flight-or-fight' and prepares the body for such a response by increasing the heart rate, arterial pressure, blood flow to the skeletal muscles, heart, and brain.[2) The parasympathetic system prepares the body for 'rest and digest' by depressing the central venous system and increasing the activity of the abdominal viscera.[2)

Central Integration

Simple reflexes are completed within the organ system involved. More complex reflexes are regulated by higher autonomic centres present in the CNS, mainly the hypothalamus and the brain stem.[2)

Structure of the CNS

Preganglionic fibres of both the sympathetic and parasympathetic system are myelinated, whereas the post-ganglionic fibres are unmyelinated. Both the divisions of the ANS innervate most of the organs in the body, usually with opposing effects. The effects may also be parallel as seen in the salivary glands.(1)

The Sympathetic Nervous System

Preganglionic fibres originate from cell bodies in the grey matter of the lateral horn of the spinal cord between the first thoracic segment down to the second or third lumbar segment (T1 to L2/3). The so-called 'thoraco-lumbar' outflow.[3) These preganglionic fibres synapse with the post-ganglionic neurones in the ganglia of the sympathetic chain (Fig. 1). The ganglia form the sympathetic chain arranged as two paravertebral chains. The post-ganglionic fibres leave the ganglia and join the spinal nerves or visceral nerves to innervate the target organs.[2)

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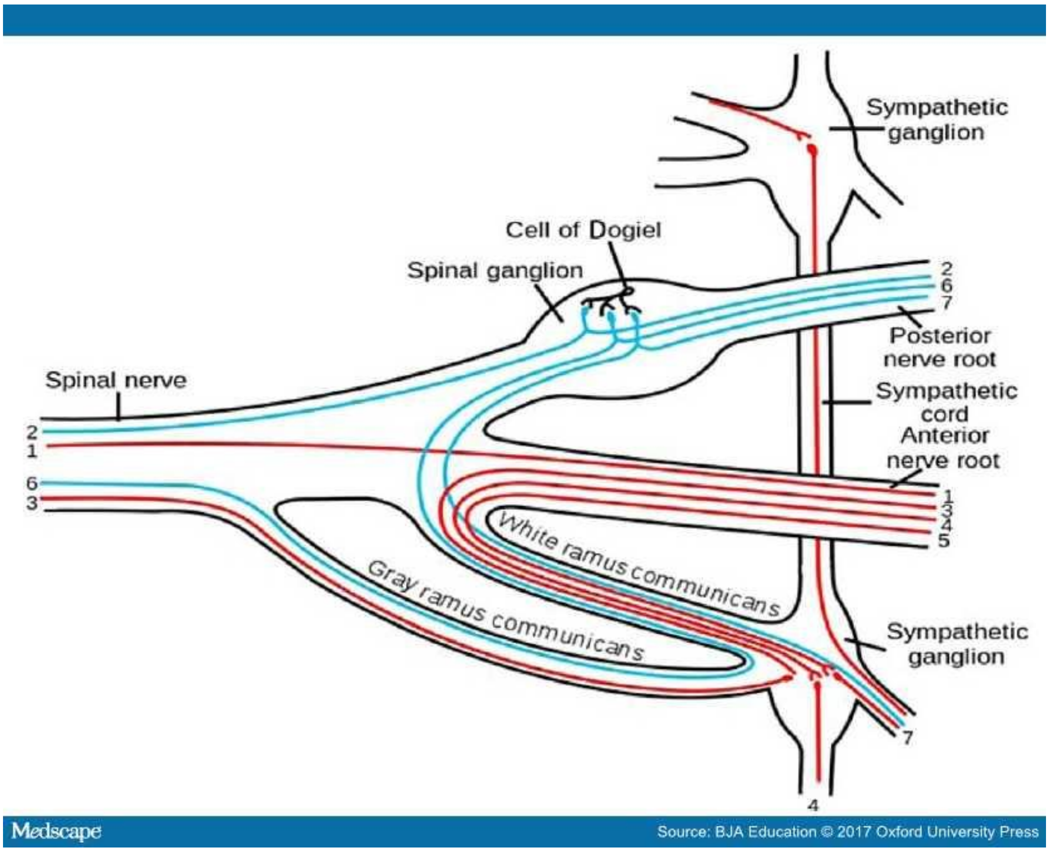

Figure 1.

Sympathetic nervous system anatomy at the spinal cord level. 1, Somatic efferent; 2, somatic afferent; 3–5, sympathetic efferent; 6 and 7, sympathetic afferent. This image is from the 20th US edition of *Gray's Anatomy of the Human Body* and is in the public domain.

The Paravertebral Sympathetic Chain

The paravertebral sympathetic chain is divided into four parts.

i. *A cervical part*: consists of three ganglia (superior, middle, and inferior) supplying the head, neck, and thorax. The inferior cervical ganglion fuses with the first thoracic ganglion to form the stellate ganglion.
ii. *A thoracic part*: consists of series of ganglia from each thoracic segment. T1–T5 branches supply the aortic, cardiac, and pulmonary plexus.
iii. *Lumbar part*: situated in front of the lumbar vertebral column as the prevertebral ganglia. Branches from the lumbar part form the coeliac plexus.
iv. *Pelvic part*: lies in front of the sacrum and consists of the sacral ganglia.(1)

The Parasympathetic Nervous System

Preganglionic fibres arise from the CNS from both the cranial (from brain stem) and sacral nerves called 'craniosacral' outflow. Cranial parasympathetic fibres arise from brainstem motor nuclei of the 3rd, 7th, 9th, and 10th cranial nerves. Sacral outflow arises from the second, third, and fourth sacral segments of the spinal cord. Fibres emerge from ventral rami of nerves S2–4 and form the pelvic splanchnic nerves.[1]

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