Divisions of the Autonomic Nervous System

• The main function of the ANS is to maintain homeostasis of the internal environment of the body/
• This involuntary system regulates blood pressure, heart rate, respiration, body temperature, glandular secretion, digestion and reproduction. It does this with both efferent and afferent components.
• The ANS has as subsystem known as the enteric nervous system.

The main two divisions of the ANS:
• **Sympathetic nervous system** – “fight or flight”
• **Parasympathetic nervous system** – “rest and digest”
Receptors and Neurotransmitters

• Main receptor types of the ANS
  – Alpha and beta adrenergic receptors – Noradrenaline and adrenalin
  – Nicotinic and muscarinic cholinergic receptors – acetylcholine

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Adrenergic Receptors - Sympathetic

- $\alpha_1$ – Stimulates smooth muscle in arteries, urethra, gastrointestinal tract, iris (pupillary dilation), uterine contractions during pregnancy, ejaculation, glycogenolysis (glycogen breakdown) in liver; glandular secretions (salivation and lacrimation)
- $\alpha_2$ – Presynaptic inhibition of transmitter release from sympathetic and parasympathetic nerve terminals, stimulates contraction of some arterial smooth muscle
- $\beta_1$ – Increases heart rate and strength of contraction
- $\beta_2$ – Relaxes smooth muscle in airways and GIT, glycogenolysis (glycogen breakdown) in liver
- $\beta_3$ – Stimulates lipolysis in adipocytes, inhibits bladder contraction

(Lundy-Ekman, 2013; Purves et al, 2012; Beck, 2008; Kandel et al, 2013)
Acetylcholine Receptors

- **Nicotinic** – Fast EPSP in autonomic ganglion cells
- **Muscarinic**
  - Glandular secretions
  - Pupillary constriction
  - Stimulates endothelial cell production of Nitric oxide thus inducing vasodilation
  - Slow acting EPSP in sympathetic neurons
  - Slows heart rate
  - Presynaptic inhibition at cholinergic nerve terminals
  - Bladder contraction
  - Salivation

(Lundy-Ekman, 2013; Purves et al, 2012; Beck, 2008; Kandel et al, 2013)
The Sympathetic Nervous System
Structure (Macro scale)

- Sympathetic outflow originates in the intermediolateral cell column of T1-L2.
- These preganglionic neurons synapse with paravertebral or prevertebral ganglia.
- Postganglionic neurons synapse with various bodily tissues shown here.
Sympathetic Nervous System

Preganglionic Circuitry

Intermediolateral nucleus – ventral horn – ventral root – white ramus

At this point the neuron may synapse at paravertebral or prevertebral ganglia. It may also ascend or descend to synapse at paravertebral ganglia.
### Sympathetic NS

<table>
<thead>
<tr>
<th>Target organ</th>
<th>Location of preganglionic neuron</th>
<th>Location of ganglionic neuron</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye</td>
<td>Upper thoracic spinal cord (C8-T7)</td>
<td>Superior cervical ganglion</td>
<td>Pupillary dilation</td>
</tr>
<tr>
<td>Lacrimal gland</td>
<td>Upper thoracic spinal cord (C8-T7)</td>
<td></td>
<td>Tearing</td>
</tr>
<tr>
<td>Salivary glands</td>
<td>Upper thoracic spinal cord (C8-T7)</td>
<td></td>
<td>Vasoconstriction</td>
</tr>
<tr>
<td>Head and neck (blood vessels, sweat glands and piloerector muscles)</td>
<td></td>
<td></td>
<td>Sweat secretion, vasoconstriction and piloerection</td>
</tr>
<tr>
<td>Upper extremity</td>
<td>T3-T6</td>
<td>Stellate and upper thoracic ganglia</td>
<td>Sweat secretion, vasoconstriction and piloerection</td>
</tr>
<tr>
<td>Heart</td>
<td>T1-T5</td>
<td>Superior cervical and upper thoracic ganglia</td>
<td>Increase heart rate and stroke volume, dilation of coronary arteries</td>
</tr>
<tr>
<td>Bronchi, lungs</td>
<td></td>
<td>Upper thoracic ganglia</td>
<td>Vasodilation and bronchial dilation</td>
</tr>
</tbody>
</table>
### Sympathetic NS

<table>
<thead>
<tr>
<th>Target organ</th>
<th>Location of preganglionic neuron</th>
<th>Location of ganglionic neuron</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stomach</td>
<td>Lower thoracic spinal cord (T6- T10)</td>
<td>Celiac ganglia</td>
<td>Increase ghrelin release (increase hunger)</td>
</tr>
<tr>
<td>Pancreas</td>
<td></td>
<td>Celiac, mesenteric ganglia</td>
<td>Release glucagon; inhibit insulin secretion</td>
</tr>
<tr>
<td>Small intestine and ascending/transverse colon</td>
<td></td>
<td>Inferior mesenteric, hypogastric and pelvic plexus</td>
<td>Inhibit peristalsis and secretions</td>
</tr>
<tr>
<td>Descending and sigmoid colon, rectum</td>
<td>T9-L2</td>
<td>Adrenal cells</td>
<td>Catecholamine release</td>
</tr>
<tr>
<td>Adrenal gland</td>
<td></td>
<td>hypogastric and pelvic plexus</td>
<td>Relaxation of bladder wall muscle and contraction of internal sphincter</td>
</tr>
<tr>
<td>Ureter, bladder</td>
<td>T11-T12</td>
<td>Lower lumbar and upper sacral ganglia</td>
<td>Sweat secretion, vasoconstriction and piloerection</td>
</tr>
<tr>
<td>Lower extremity</td>
<td>T10-L2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sympathetic Efferents to Face

- Cervical paravertebral ganglia are supplied by preganglionic fibers that ascend from the upper thoracic cord.
  - Cervical ganglia consist of the superior, middle, and cervicothoracic ganglia.
  - Cervicothoracic ganglion are formed by the fusion of the inferior cervical and first thoracic ganglion.
  - Effects: pupil dilation, vasoconstriction of the face, face sweating, elevation of eyelid and vasoconstriction of arteries to the salivary and lacrimal glands.
Sympathetic Innervation of the Heart

- Innervations come bilaterally from the cervical and upper 4 thoracic ganglia
Celiac Ganglia

- Sympathetic outflow via the celiac ganglia to the following organs

- **Stomach/small intestines/transverse colon** – inhibits peristalsis and secretion, causes vasoconstriction (stomach).

- **Pancreas** – inhibits insulin secretion

Image: (Felten & Shetty, 2009)

(Kandel et al, 2013)

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Superior and Inferior Mesenteric Ganglia

- Innervates **small intestines** and **large intestine**
- Inferior also innervates the rectum
- Inhibits peristalsis and secretions
## Parasympathetic Nervous System

<table>
<thead>
<tr>
<th>Target organ</th>
<th>Location of preganglionic neuron</th>
<th>Location of ganglionic neuron</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye</td>
<td>Edinger-Westphal nucleus</td>
<td>Ciliary ganglion</td>
<td>Pupillary constriction</td>
</tr>
<tr>
<td>Lacrimal gland</td>
<td>Superior salivatory nucleus</td>
<td>Pterygopalatine ganglion</td>
<td>Secretion of tears</td>
</tr>
<tr>
<td>Submandibular and sublingual glands</td>
<td>Superior salivatory nucleus</td>
<td>Submandibular ganglion</td>
<td>Secretion of saliva, vasodilation</td>
</tr>
<tr>
<td>Parotid gland</td>
<td>Inferior salivatory nucleus</td>
<td>Otic ganglion</td>
<td>Secretion of saliva, vasodilation</td>
</tr>
<tr>
<td>Heart</td>
<td>Nucleus ambiguous and dorsal motor nucleus of CNX</td>
<td>Cardiac plexus</td>
<td>Reduce heart rate</td>
</tr>
<tr>
<td>Bronchi, lungs</td>
<td>Dorsal motor nucleus of CNX</td>
<td>Pulmonary plexus</td>
<td>Bronchial constriction</td>
</tr>
<tr>
<td>Stomach</td>
<td>Dorsal motor nucleus of CNX</td>
<td>Myenteric and submucosal plexus</td>
<td>Peristalsis and secretion</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Dorsal motor nucleus of CNX</td>
<td>Pancreatic plexus</td>
<td>Secretion of insulin and digestive enzymes</td>
</tr>
<tr>
<td>Ascending/transverse colon and small intestine</td>
<td>Dorsal motor nucleus of CNX</td>
<td>Ganglia in the myenteric and submucosal plexus</td>
<td>Peristalsis and secretion</td>
</tr>
<tr>
<td>Descending/sigmoid colon, rectum</td>
<td>S3-S4</td>
<td>Ganglia in the myenteric and submucosal plexus</td>
<td>Peristalsis and secretion</td>
</tr>
<tr>
<td>Ureter, bladder</td>
<td>S2-S4</td>
<td>Pelvic plexus</td>
<td>Contraction of bladder wall and inhibition of internal sphincter</td>
</tr>
</tbody>
</table>
Parasympathetic Nervous System of the Brainstem

Image: (Felten & Shetty, 2009)
ANS Receptors and afferent pathways

Receptors of the autonomic system include the following:

- **Mechanoreceptors/baroreceptors**: Respond to pressure and to stretch.
- **Chemoreceptors**: Sensitive to chemical concentrations in the blood – oxygen and carbon dioxide.
- **Nociceptors**: Respond to stretch and ischemia.
- **Thermoreceptors**: Respond to very small changes in the temperature of circulating blood (hypothalamus) and the external environment.
ANS Afferent Pathways

- Visceral afferent information from the tongue and soft palate enters the brainstem through the Facial and Glossopharyngeal nerves.
- Information from the larynx and thoracic and abdominal viscera reaches the brainstem via the vagus nerve.
ANS Afferent Pathways

Stretch of blood vessels in the periphery is registered by free nerve endings in the vessel walls. This information is conveyed via fibres in peripheral nerves into the spinal cord.

Information from stretch receptors in the gastrointestinal tract passes through an autonomic ganglion, without synapsing, before entering the spinal cord.
Afferents from the Heart

Visceral information converges in the solitary nucleus of the brainstem.

An example is the convergence of blood pressure and blood chemical composition information, monitored by pressure and chemoreceptors in the carotid artery and the aortic arch. The information is transmitted to the solitary nucleus in the medulla.
Regulation of Body Temperature

• Effects on the metabolism and the effectors in the skin regulate body temperature.
• Epinephrine released by the adrenal medulla increases the metabolic rate throughout the body.
• Sympathetic signals control the diameter of the blood vessels, secretion of the sweat glands, and the erection of hairs in the skin.
Cardiovascular Regulation

• The cardiovascular system works to precise reflex regulation – the checks and balances are made by the monitoring of blood pressure by baroreceptors and gas concentrations in the blood by chemoreceptors in the carotid bodies and aorta.

• The aortic arch is innervated by the vagus nerve

• The carotid bodies are innervated by the glossopharyngeal nerve

• Both nerves are updating the solitary tract which will relay to the hypothalamus and other relevant autonomic centres in the reticular formation.
Cardiovascular Regulation

- The afferent information (chemoreceptors and baroreceptors) from the aortic arch and carotid body signals the nucleus ambiguus/vagus nerve to inhibit the SA node (via the cardiac plexus) and lower the heart rate.

- Afferents also go down to inhibit the related sympathetic preganglionic neurons stopping tonic activation of the heart and allowing for peripheral arteriole dilation resulting in lowering blood pressure.

(Lundy-Ekman, 2013; Siegel & Sapru, 2015)

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Cardiovascular Regulation

• The reverse can also occur, when there is a sharp drop in blood pressure if the person is bleeding from a wound or due to standing up quickly.
• The low blood pressure elicits a sympathetic response to increase the heart rate, enhance cardiac contractility and increases the tone of smooth muscles in arterioles in order to shunt blood to the most relevant areas mainly brain, heart and kidneys if blood is being lost.
• **Orthostatic hypotension** is when a person stands up quickly and the blood in their thorax/abdomen moves quickly to the legs, thus causing a sharp decrease in output of the heart – resulting in dizziness or fainting.
Role of the Hypothalamus, Thalamus, and Limbic System

- Hypothalamus, thalamus, and limbic system modulate brainstem autonomic control.
- Hypothalamus:
  - Uses visceral information to maintain equilibrium in the interior of the body.
  - Influences cardiorespiratory, metabolic, water reabsorption, and digestive activity by acting on the pituitary gland, control centers in the brainstem, and spinal cord.

(Lundy-Ekman, 2013; Siegel & Sapru, 2015)

Image: (Felten & Shetty, 2009)
Role of the Hypothalamus, Thalamus, and Limbic System

• Thalamus:
  – Visceral information is projected mainly to the limbic system, which is a collection of cerebral areas involved in emotion, mood, and motivation.

• Limbic system:
  – Activated limbic areas can produce autonomic responses (e.g., increased heart rate as a result of anxiety, blushing with embarrassment, crying).
Somatic Motor System, Autonomic Efferent System

• Three major differences:
  – Unlike the somatic nervous system, the regulation of the autonomic functions is typically nonconscious and can be exerted by hormones.
  – Unlike skeletal muscles, many internal organs can function independently of CNS input.
  – Somatic efferent pathways use one neuron; autonomic efferent pathways usually use two neurons, with a synapse outside the CNS.
Step 1 - HPA Axis

In response to stress, the paraventricular nuclei of the hypothalamus releases corticotropin-releasing factor (CRF) and vasopressin (AVP) to stimulate the anterior pituitary gland.

(Kvetnansky et al, 2009)
Step 2 - HPA Axis

**CRF** binds to **CRFr1**’s which activates **cAMP pathways** thus inducing the release of **adrenocorticotropic hormone (ACTH)** into systemic circulation.

**AVP** induces a **CRF** dependant release of **ACTH**.

(Kvetnansky et al, 2009)
Circulating **ACTH** binds to the melanocortin type 2 receptor (MC2-R) in the **adrenal cortex** where it stimulates **glucocorticoid** synthesis and secretion into the systemic circulation. **Glucocorticoids** (cortisol) regulate physiological events and inhibit further HPA axis activation via the hippocampus-PVN or directly on PVN.
Limbic structures of the forebrain contribute to the regulation of the HPA axis. Neuronal populations in the hippocampus, prefrontal cortex, and amygdala are the anatomical substrates for memory formation and emotional responses.
Chemical signalling between the nervous system and the immune system in response to stress.

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Effects of prolonged psychological stress on immune and blood-vascular system function.

Chronic psychological stress

- Pituitary hormonal activation of adrenal glands
  - Release cortisol
    - Increase plasma triglyceride levels
  - Release epinephrine
    - Inhibit lymphocyte and cytokine production

- Sympathetic nerve endings in the adrenal glands
  - Release norepinephrine and peptides
    - Suppress natural killer cells and proliferation of lymphocytes; increased number of white blood cells
    - Blood vessel changes
      - May lead to heart attacks and strokes

- Sympathetic nerve endings in thymus, lymph nodes, spleen, bone marrow

Image: (Lundy-Ekman, 2013)
Emotions Drive the Sympathetic Response

- Our brain perceives stimuli around us in many ways
  - Ignore stimuli that is deemed not relevant – ambient noises etc
  - Some stimuli will startle you based on you not having all the required information, like hearing a loud sound and when you find out that it was nothing serious you don’t worry anymore.
  - Some stimuli you recognise straight away and this can activate your sympathetic nervous system to the point where you are sweating and your pupils are dilated. This also happens when you are angry or fearful.
  - Other stimuli may make you feel happy and others sad.
  - The reason there is different responses is based on your perception of the stimuli which is based on previous experience.
Brain Regions Involved in Emotions

**Orange** indicates structures that recognize emotional stimuli, generate and perceive emotions, and regulate autonomic aspects of emotions.

**Light green structures** automatically regulate emotions.

**Yellow structures** are involved in both automatic and voluntary regulation of emotions, and dark green structures voluntarily regulate emotions.
Areas of the brain involved in emotions.

<table>
<thead>
<tr>
<th>Function</th>
<th>Structure</th>
<th>Specific function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify emotional significance of stimuli, generate and perceive</td>
<td>Amygdala</td>
<td>Detects emotional and social cues; generates feelings of fear and disgust</td>
</tr>
<tr>
<td>emotions, regulate autonomic aspects of emotions</td>
<td>Area 25 and Mediodorsal nucleus thalamus</td>
<td>Generate sad mood and depression</td>
</tr>
<tr>
<td></td>
<td>Ventral striatum</td>
<td>Reward oriented behavior and responses to conditioned stimuli</td>
</tr>
<tr>
<td></td>
<td>Anterior insula</td>
<td>Awareness of emotions and of stimuli inside the body</td>
</tr>
<tr>
<td>Automatic emotional regulation (cortical regions are part of the</td>
<td>Rostral anterior cingulate cortex</td>
<td>Direct attention away from emotion; motivated behavior</td>
</tr>
<tr>
<td>behavioral flexibility and control basal ganglia loop)</td>
<td>Orbital cortex</td>
<td>Use of rewards to guide behavior; inhibits undesirable behavior</td>
</tr>
<tr>
<td></td>
<td>Hippocampus</td>
<td>Resolve goal conflicts</td>
</tr>
<tr>
<td></td>
<td>Parahippocampal gyrus</td>
<td>Detect novel stimuli</td>
</tr>
<tr>
<td>Automatic and voluntary emotional regulation (part of the limbic basal</td>
<td>Medial dorsal prefrontal cortex</td>
<td>Perception of other’s emotions and infer other’s beliefs and intentions</td>
</tr>
<tr>
<td>ganglia loop, connects with the ventral striatum and pallidum)</td>
<td>Ventromedial prefrontal cortex</td>
<td>Sad mood, value assessment of objects, reward associations, elicits visceral</td>
</tr>
<tr>
<td></td>
<td>Ventrolateral prefrontal cortex</td>
<td>response</td>
</tr>
<tr>
<td></td>
<td>Dorsal anterior cingulate cortex</td>
<td>Guilt, recall of personal memories</td>
</tr>
<tr>
<td>Voluntary emotional regulation (part of the executive basal ganglia</td>
<td>Dorsolateral prefrontal cortex</td>
<td>Goal-directed behavior, expressing emotions, error monitoring</td>
</tr>
<tr>
<td>loop)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Lundy-Ekman, 2013)
References

  
Image References

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