YO! Physiologer dudes

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Many of my friends have found these notes useful in their study for Physiology 1A.

But before you take a look at them and start cramming as if your life depends on it, take a moment to meet the God that created a universe that is so complex and worthy of study, yet knows you and I personally:

Psalm 139:13-14 - "For you created my inmost being; you knit me together in my mother's womb. I praise you because I am fearfully and wonderfully made; your works are wonderful, I know that full well."

Check it out sonnnnnn!: http://www.matthiasmedia.com.au/2wtl/

1 Lecture 1

1.1 Outline the operation of reflex control in the autonomic nervous system

1.1.1 Divisions of the nervous system and roles of the parasympathetic and sympathetic systems

- The human nervous system is divided into the **central nervous system** containing the brain and spinal cord ($\approx 10^{11}$ neurons), and the **peripheral nervous system** ($\approx 10^{8}$ neurons).
- The peripheral nervous system is further divided into the **somatic** and the **autonomic nervous system** consisting of the:
    1. **Parasympathetic system**: Dominant at rest, for example after a meal where blood is directed toward the gut for digestion.
    2. **Sympathetic system**: Dominant for "fight or flight", for example increased blood flow to the muscles, brain, increase in breathing rate during an escape situation.
    3. **Enteric system**: The gut has its own ANS consisting of 100 million neurons which allows it to autonomously control gut motility and secretion.
- The ANS controls **fighting** and **fleeing** (**sympathetic**), and **feeding** and **sex** (**parasympathetic**).
- The parasympathetic and sympathetic systems tend to work in **opposition**. However, if one system is active, the other system is less active but not completely stopped; it is simply making different parts of the body active.

1.1.2 Levels of control

- A **reflex** is essentially sensory input which leads to an autonomic effect.
- This can occur at **local** or **higher, more integrated levels**. Below are different levels in ascending order.

1. **Enteric nervous system or effector organ**: **Local levels of integration** allow the intestines/colon to contract in an organised manner with no other nervous input in response to distension.
2. **Ganglion (collection of neuronal cell bodies)**: The sensory information then travels to the ganglion. In Figure 1, as well as the sensory input from the ENS, there is also input from higher levels via preganglionic neurons, interneurons and then an output back to an effector organ. The ganglion integrates **sensory, preganglionic and interneurons**.
3. **Spinal cord**: The sensory information can be sent even higher to the spinal cord where there could be integration across the whole body (**between spinal levels**). This is important for global reflexes such as hairs on the body standing up in response to cold, rather than only standing up in a specific region.
4. **Brain stem**: Integrates sensory across different organs. Coordinates cardiovascular and respiratory function.
5. **Hypothalamus**: Integrates motivations and desires.

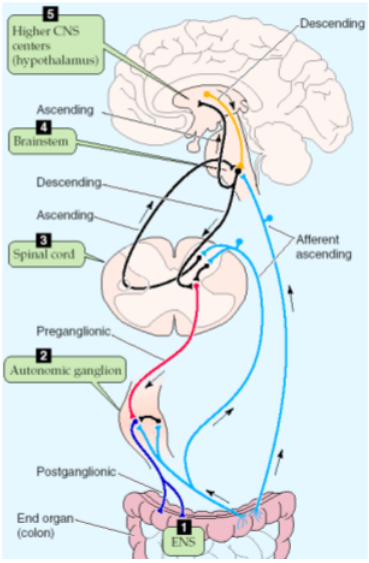


Figure 1: Levels of integration

1.1.3 Reflex loops depend on sensory input

- **Sensory information** is **required** for the **operation** of these systems; mostly **pain** for the **sympathetic** system and visceral senses such as **distension** or **blood chemistry** for the **parasympathetic** system. Most of the sensory input comes from the **autonomic/visceral afferents**.
- As addressed before, these afferents are mainly located in the innervated tissue and travel in the same nerve as the efferents. The higher centres then integrate inputs from these diverse sources to produce a coordinated output. **Somatic** inputs are also integrated to provide fast or predictive responses like posture readjustment.
- A simple example autonomic homeostasis is the reflex that stabilises the blood pressure when transitioning between lying down and standing up. Baroreceptors are specialised neurons that alter their activity based on vessel stretch providing sensory input. They synapse onto the brainstem cardiovascular centres. Increased sympathetic activity restores blood pressure by increasing peripheral vasoconstriction. Reduced parasympathetic activity increases heart rate. These principles apply throughout the ANS.

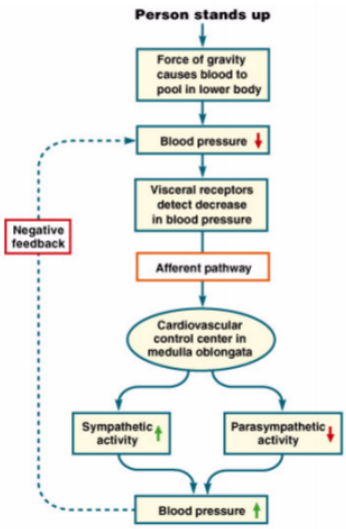
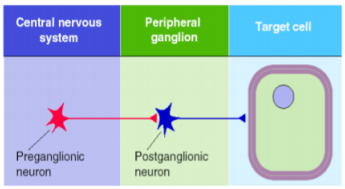


Figure 2: An example of a homeostatic reflex

1.2 Describe the anatomical organization of the sympathetic and parasympathetic systems

- Below is the basic plan of the efferent autonomic nervous system.
- An efferent travels from the **preganglionic neuron** in the **central nervous system** to the **postganglionic neuron** in the **peripheral nervous system** to a **target cell** to effect a response.



- The actual anatomical organisation of the ANS is much more complex.

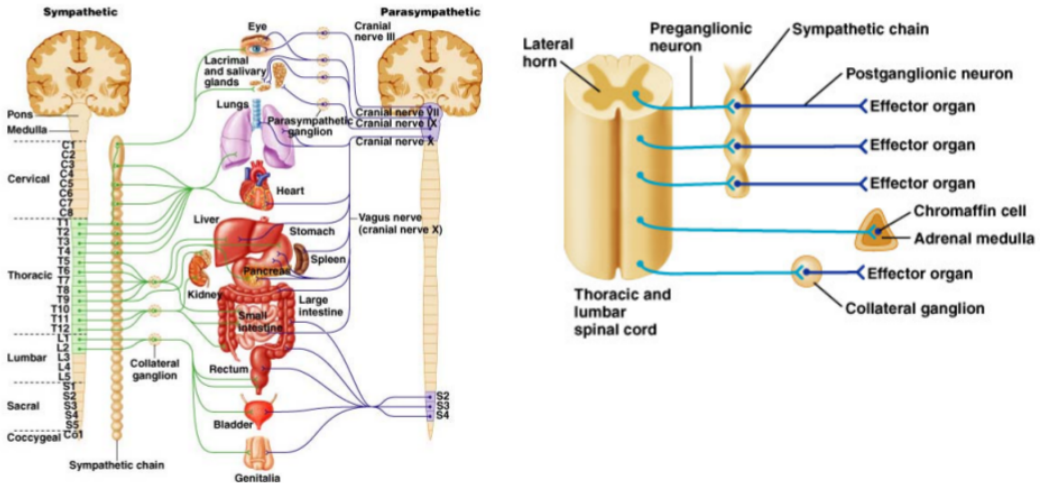


Figure 3: Anatomical organisation of the ANS

- On the left is the **sympathetic system**, in the middle is the **sympathetic chain ganglia** and the on the right is the **parasympathetic system**.
- The green dots on each vertebrae are the **preganglionic neurons** of the sympathetic system, most of which synapse at individual chain ganglia. Most sympathetic activity goes via this chain, but more specific effects can be via **collateral ganglia**. More general effects can be produced by adrenaline released from the adrenal medulla. Adrenal medullary cells are actually modified postganglionic neurons whose preganglionic fibres lead them directly from the CNS. These cells do not synapse, and contain chromaffin cells that secrete neurotransmitter when stimulated via the preganglionic fibres. The **postganglionic fibers** innervate a range of organs.
- In the parasympathetic system, postganglionic fibres aren't really visible because the collateral ganglia are on the organs themselves; the preganglionic fibres extend all the way down to the organ which synapses onto the postganglionic fibre effecting the response. It doesn't have a chain nor does it release circulating hormones.
- Both systems lack a cervical and lumbar component. This is because in the sympathetic system, the chain ganglia allow the spread of sympathetic activity to the cervical and lumbar regions. The parasympathetic components only exist in the brain stem and sacral regions suggesting the possibility that at one point in time they were a unified system before they split to serve specialised roles.
- Many organs are innervated by both systems. Some tissue such as skin is only innervated by one, meaning that only one system is required to achieve reflexes such as sweating or hair raising.

1.2.1 Myenteric plexus

- Below is an EM of the myenteric plexus. The highly interconnected meshwork innervating the intestine provides an abundance of processing power to detect radial or longitudinal stretch in the wall, chemical changes and then communicate these to other neurons which produce an integrated response.

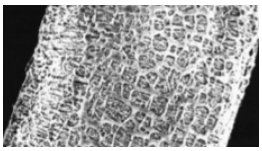


Figure 4: Dense meshwork of myenteric plexus

1.2.2 Autonomic synapses

- The autonomic system is similar to the skeletal system in that it has postganglionic neurons that that form synapses on the target tissue. These synapses are characterised as varicosities on the surface of the effector organ.
- Like at the neuromuscular junction, when the pre-synaptic terminal is depolarised, it also triggers Ca^{2+} channels to open causing Ca^{2+} influx. This triggers the exocytosis of neurotransmitter from vesicles docked at the axon terminal that is eventually decomposed by acetylcholinesterase.
- The autonomic synaptic cleft may however be wider than at somatic synapses, forcing the neurotransmitter to diffuse a greater distance but allowing more spill-over effects.

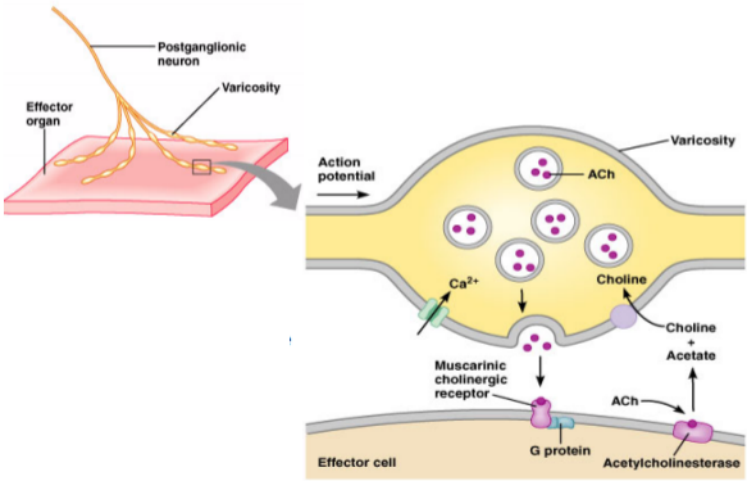


Figure 5: Autonomic synapse

1.3 List the neurotransmitters and receptor classes used by the sympathetic & parasympathetic systems at pre-ganglionic & post-ganglionic synapses

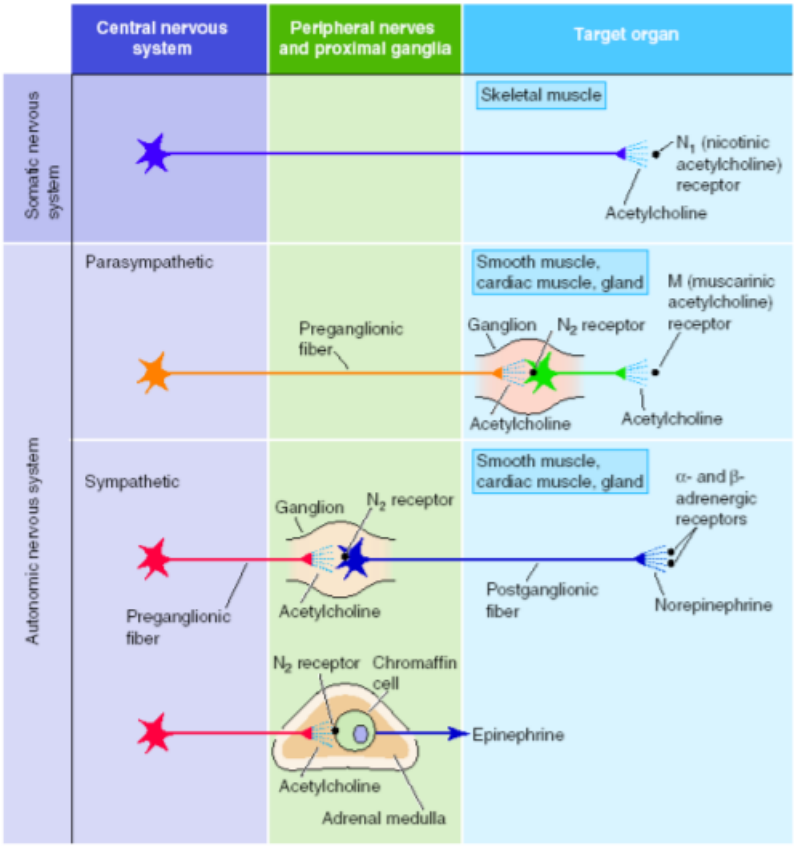
1.3.1 ANS uses specific neurotransmitters and receptors

- Refer to **Table 1**.
- In **skeletal muscle** as previously mentioned, ACh is released from the axon terminal and binds to a nicotinic (N_1) ACh receptor.
- In both the **parasympathetic** and **sympathetic** systems, ACh is released from the preganglionic terminal and binds to a nicotonic (N_2) ACh receptor.

- However, in the **parasympathetic** system, this triggers the release of ACh which binds to an **M (muscarinic ACh receptor)** whilst in the **sympayhetic system**, this binds to nicotinic (N_2) ACh receptors triggering the **chromaffin cells** to secrete adrenaline into the circulation or, the **postganglionic fibres** to release **noadrenaline** which acts on **adrenergic receptors**.

Note: As seen in the In Figure 4 and Tables 1 and 2, the ANS uses ionotropic receptors in the ganglia then switches to metabotropic at the target organ. In a metabotropic receptor, the main advantage is depending on the coupled G protein, specific ion channels can open and close resulting in depolarisation (excitatory) or hyperpolarisation (inhibitory). An ionotropic nicotinic receptor can only result in the opening of Na^+/K^+ channels which cause depolarisation (excitatory).

Table 1: Neurotransmitters and receptors in the ANS



1.3.2 Receptor classes for ACh

Table 2: Receptor classes for ACh

Receptor type	Signal transduction mechanism	Target cell	Effect on target cell
Nicotinic	Opens channels for sodium and potassium ions	Postganglionic cell body, chromaffin cells, skeletal muscle cells	Excitatory
Muscarinic	G protein-coupled; opens or closes specific ion channel	Effector organs of parasympathetic nervous system	Excitatory or inhibitory

1.3.3 Receptor classes for noadrenaline

- Adrenergic receptors come in several subtypes which allows differential regulation of tissues by facilitating specificity in the effect.

Table 3: Receptor classes for noradrenaline

Receptor type	Effector organ with receptor type	Relative affinities*	Signal transduction mechanism	Effect on effector organ†
α_1	Most vascular smooth muscle, pupils	NE > Epi	Activates IP_3	Excitatory
α_2	CNS, platelets, adrenergic nerve terminals (autoreceptors), some vascular smooth muscle, adipose tissue	NE > Epi	Inhibits cAMP	Excitatory
β_1	CNS, cardiac muscle, kidney	NE = Epi	Activates cAMP	Excitatory
β_2	Some blood vessels, respiratory tract, uterus	Epi >> NE	Activates cAMP	Inhibitory
β_3	Adipose tissue	NE = Epi	Activates cAMP	Excitatory

*NE = norepinephrine; Epi = epinephrine; > = greater than; >> = much greater than
†Effects are generalizations and not absolute.

1.3.4 Multiple neurotransmitters are released

- Most neurons release a mix of different neurotransmitters; not just one, which bind to a number of different receptors leading to varying responses. When neurons are named, for example glutamate neurons, the naming usually refers to the fastest action that the neuron produces despite the fact that it also produces some slower responses.
- In Figure 6, ATP is binding to ionotropic receptors which produce a fast response. Noradrenaline is binding to adrenergic receptors which produce a moderately fast response. Peptides (small protein fragments) are also binding to Y1 receptors which produce an even slower response by affecting what is happening at the nuclear level.

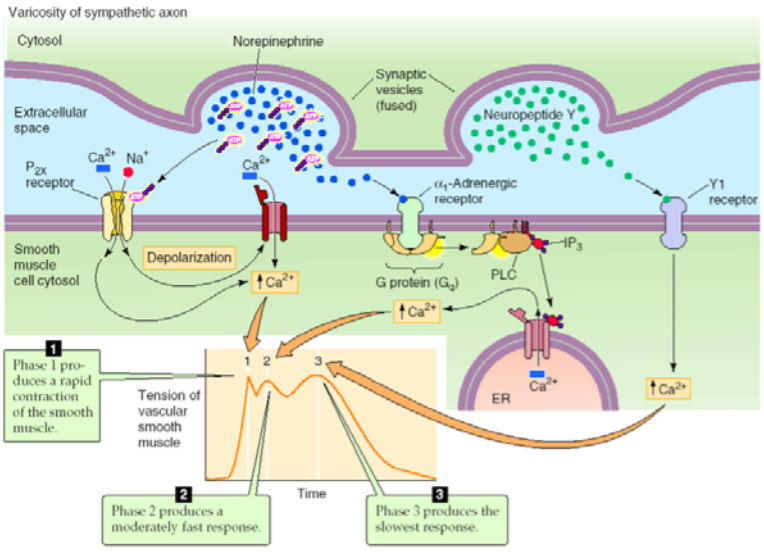


Figure 6: Varicosity of sympathetic axon

1.4 List the effects of the autonomic nervous system on three organs

- A table of the effects of the ANS on 9 different organs has been provided for completeness but you are only required to know 3.
- **Note:** The parasympathetic system does not have a column of different receptors classes like the sympathetic system. This is because the postganglionic fibres of the parasympathetic system **always release ACh** which always binds to **muscarinic** receptors.

Table 4: Effects of the ANS on different organ systems

	PARASYMPATHETIC NERVOUS SYSTEM*	SYMPATHETIC NERVOUS SYSTEM	
Organ system	***Effect***	***Effect***	***Adrenergic receptor class***
Urinary bladder			
Bladder wall	Contraction	Relaxation (small effect)	β_2
Sphincter	Relaxation	Contraction	α_1
Male reproductive tract			
Blood vessels (erection)	Vasodilation	None	
Vas deferens and seminal vesicles (ejaculation)	None	Ejaculation	α_1
Female reproductive tract			
Uterus, nonpregnant	Unknown	Relaxation	β_2
Uterus, pregnant	Unknown	Contraction	α_1
Skin			
Sweat glands	Stimulates secretion	Stimulates secretion	α_1, muscarinic†
Piloerector muscles	None	Contraction (hairs stand up)	α_1
Eye			
Iris muscles (pupil size)	Contraction of circular muscle (pupillary constriction)	Contraction of radial muscle (pupillary dilation)	α_1
Ciliary muscles (accommodation)	Contraction for near vision	Relaxation for far vision (small effect)	β_2
Digestive tract			
Motility	Increased	Decreased	α_1, α_2, β_2
Secretions	Stimulated	Inhibited	α_2
Sphincters	Relaxation	Contraction	α_1
Heart			
SA node	Decreases heart rate	Increases heart rate	β_1
AV node	Decreases conduction velocity	Increases conduction velocity	β_1
Force of contraction	Decreases (small effect)	Increases	β_1
Blood vessels			
Arterioles to most of body	None	Vasoconstriction	α_1
Arterioles to skeletal muscle	None	Vasoconstriction Vasodilation (epinephrine)	α_1 β_2
Arterioles to brain	None	None	
Veins	None	Vasoconstriction Vasodilation (epinephrine)	α_1 β_2
Lungs			
Bronchial muscle	Contraction	Relaxation	β_2
Bronchial glands	Stimulates secretion	Inhibits secretion	α
Digestive tract			
Motility	Increased	Decreased	α_1, α_2, β_2
Secretions	Stimulated	Inhibited	α_2
Sphincters	Relaxation	Contraction	α_1