

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/>



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1 Lecture 1

1.1 Describe the arrangement of grey/white matter in the spinal cord/brain

White matter is axons. Grey matter is somas & dendrites.

- **Spinal cord:** Grey matter is on the **inside**. White matter is on the **outside** so that axons can enter/exit without disrupting grey matter.
- **Brain:** White matter is on the **inside**. Grey matter is on the **outside**. There is no "wiring" in the skull and hence no need for grey matter to be on the inside.

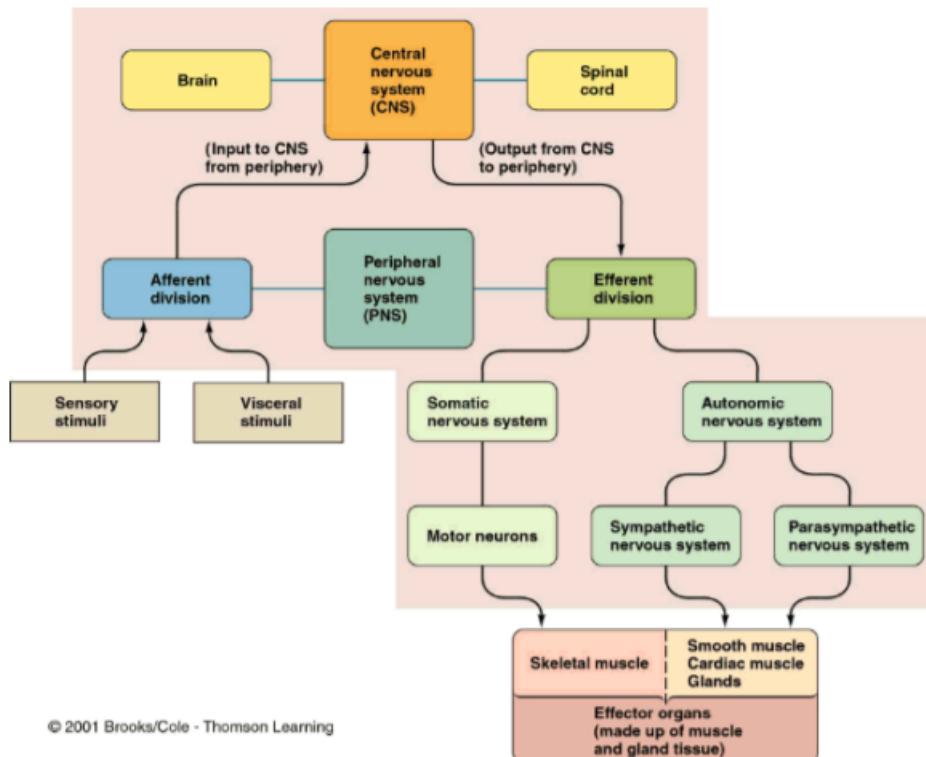
As well as facilitating the transport of inputs up the spinal cord, white matter or myelinated axon tracts also facilitate communication/integration/synchronisation between cortical regions in the brain.

- **Between hemispheres:** Corpus callosum, anterior commissure
- **Long-range intra-hemispherical connections**
- **Local connections:** Arcuate fibres.

Note: The organisation of the nervous system is **crossed**. Sensory inputs from the **right side** of the body are processed by the **left cerebral hemisphere** and vice versa.

1.2 Describe the major divisions and functional organisation of the brain

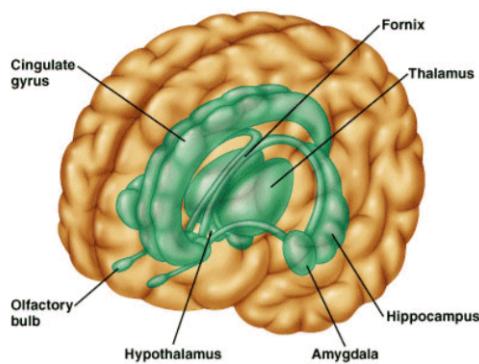
Divisions of the nervous system



You learn all the rest of this stuff in ANAT2511.

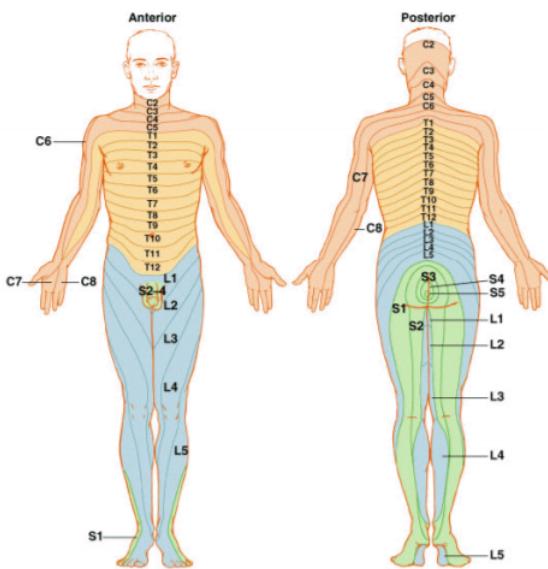
Limbic system (Emotions)

- **Thalamus:** Deep brain structure functioning as **relay centre** between lower brain structures and subdivided into nuclei with connections to particular cortical regions. It is postulated that consciousness is the result of a loop. For instance in vision you have lots of information travelling through the thalamus and then the cortex. Hence it is expected that all the axons should be travelling from the thalamus to the cortical regions. However there are 10-20 times as many axons going back from the cortex to the thalamus than there are going up to the cortex. This implicates the thalamus in **consciousness**.
- **Hypothalamus:** Links autonomic and somatic nervous systems. Controls endocrine system via pituitary gland.
- **Cingulum:** Cortical interface
- **Amygdala:** Fear
- **Hippocampus:** Memory



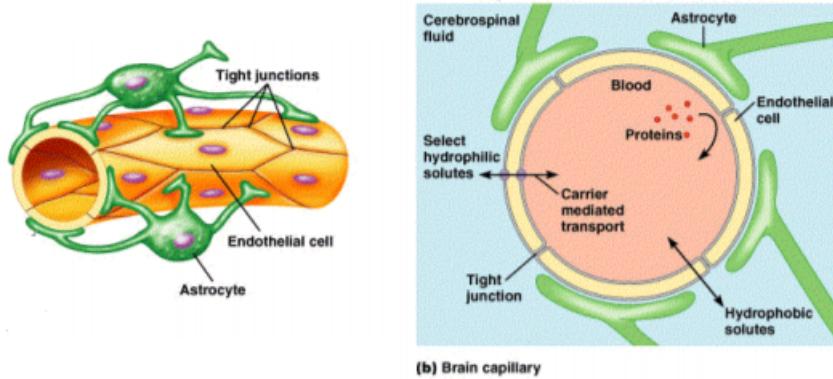
1.3 Describe the dermatomal organisation of spinal cord and differentiate between efferent and afferent fibres

- Each spinal nerve innervates particular regions of the body. Each region innervated by a spinal nerve is a **dermatome**. **Afferent** = axon going toward CNS (sensory), **efferent** = axon going away from CNS (motor).



1.4 Describe the blood-brain barrier and the role of cerebral spinal fluid (CSF)

- For **blood-brain barrier** refers to the **restricted permeability** of brain capillaries. **Astrocytes** work with capillary cells to make the tight junctions less leaky with the purpose of **protecting the brain from toxins**.



- CSF** supports the brain allowing it to float inside the skull. It provides an appropriate chemical environment for the brain by supplying nutrients and removing waste products. It is produced by the **choroid plexus** in the 3rd/4th ventricles. It has a low concentration of proteins, few cells but 50-75% concentration of blood glucose. The brain doesn't store glucose so (as well as the blood delivering O_2 /glucose) the CSF also provides it with glucose vital for function.

2 Lecture 2

2.1 Describe how afferent type, location and activity encodes the properties of skin stimulus

A **sensory system** has to be able to provide three main pieces of information about a stimulus obtained using the means listed below.

1. **Afferent type:** Modalities
2. **Afferent location:** Somatotopy/receptive fields.
3. **Afferent activity (intensity/duration):** Rate coding

Recall from Dr Moorhouse's lectures that a stimulus generates a change in the ionic permeability of a receptor cell or afferent nerve ending. This results in a change in the receptor potential generating action potentials to the CNS if threshold is reached.

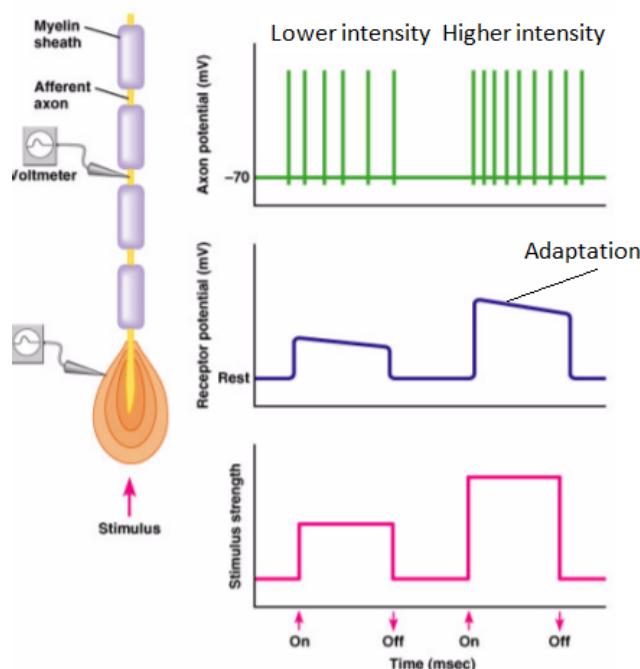
2.1.1 Rate coding: intensity

Imagine being **pushed**.

- A **harder push** results in a **larger depolarisation** and **action potentials which fire closer together**. This is because harder pushes result in **more membrane channels being opened**. Furthermore, **larger** depolarisations can't overcome the absolute refractory period but they can overcome the **relative refractory period** of firing.
- Conversely, **softer pushes** result in the opening of **less channels** resulting in **lower depolarisations** that cause action potentials to **fire further apart**.

Adaptation

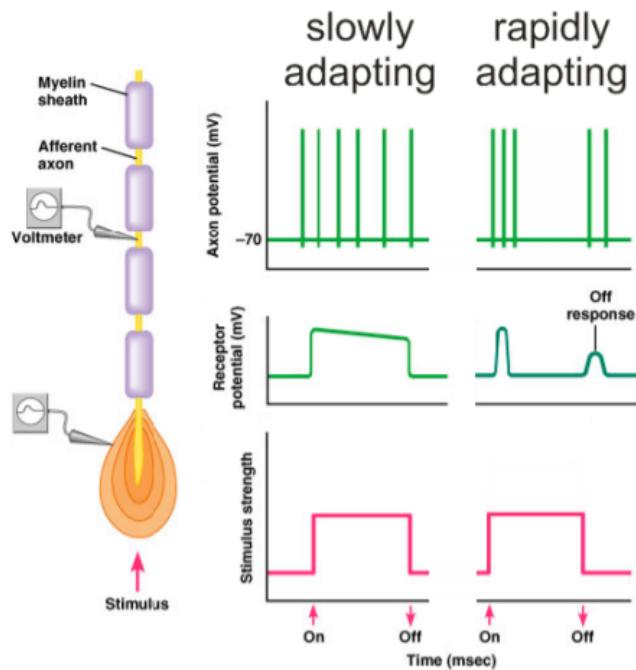
- **Adaptation** is the **gradual reduction** in the response of a neuron due to a **sustained stimulus**. As seen in the rate coding, adaptation results in a decrease in the depolarisation magnitude and thus rate of action potential firing.
- An example is **photoreceptor bleaching**.



2.1.2 Rate coding: duration

Duration can be coded in two ways depending on the **adaptation rate** of the receptors involved.

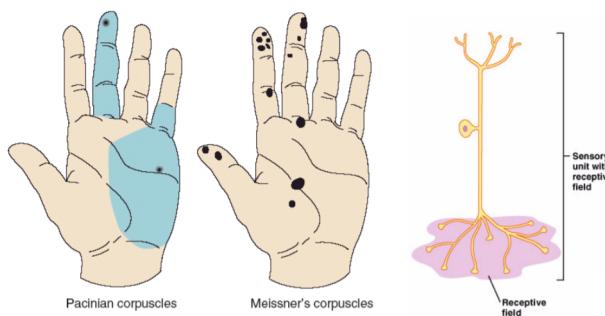
- Slowly adapting receptors are good for signalling **intensity**. Duration can be determined by taking the **difference of the times at which the depolarisation jumps from resting magnitude and returns to resting magnitude**.
- Rapidly adapting receptors are good for signalling changes in **movement**. Duration is determined by taking the **difference between the times at which the initial depolarisation occurs and the off depolarisation occurs**.



2.1.3 Receptive fields: Location

A **receptive field** is the region of space where a stimulus must be applied to activate a sensory neuron.

- Pacinian corpuscles detect **pressure** and **vibration**. Despite having a physical location, their receptive field is so large because they are sensitive enough to be activated by touch in a remote location.
- Meissner's corpuscles detect **fine discriminative touch**. Their receptive region is only a few mm across.



2.2 Provide an example of each of the receptors and afferents used to signal touch, pain and temperature

The four somatosensory modalities use distributed receptors rather than specialised sense organs.

2.2.1 $A\beta$ fibres: large myelinated; 30-70 m/s

Tactile

receptor type	fibre name	adaptation	receptive field	fibre class
Merkel disk	SA1	slowly adapting	superficial, small	$A\beta$
Ruffini ending	SA2	slowly adapting	deep, large	$A\beta$
Meissner corpuscle	FA1 / RA	rapidly adapting	superficial, small	$A\beta$
Pacinian corpuscle	FA2 / PC	rapidly adapting	deep, large	$A\beta$
hair follicle	HF	rapidly adapting	one or more hairs	$A\beta$

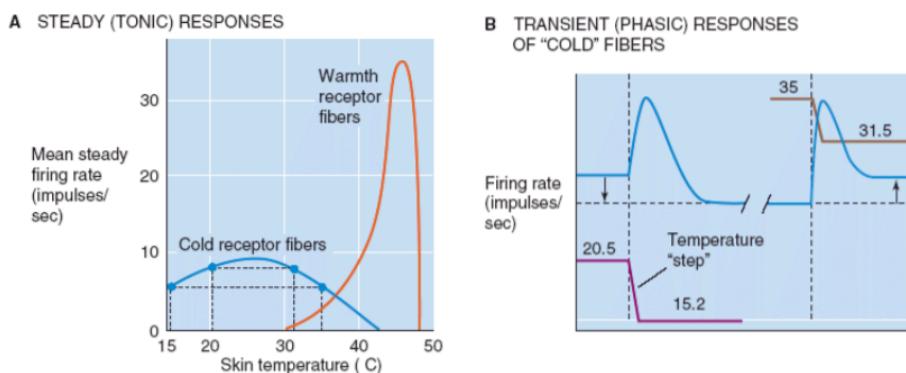
Proprioception: limb/joint position

- Spindle afferents
- Golgi tendon organs
- Joint receptors

2.2.2 $A\delta$ fibres: small myelinated; 5-30 m/s, C fibres: unmyelinated; 0.5-2 m/s

Temperature

- Why do we need cold and hot receptors?
- Temperature is encoded in a rate code by thermoceptive afferents. The temperature response rate curves shown below are roughly parabolic, peaking in the centre. If only one receptor was used to detect temperature, then because of the parabolic nature of the response curves, two different temperatures can result in the same firing rate. **Hot receptors** are $A\delta$ fibres whilst **cold receptors** are C fibres.
- Using two different afferent fibres removes this ambiguity because the stimulation of different firing rates in these different receptors results in a unique combination that allows us to specify one temperature.
- Note the transients or **phasics** that occur at each temperature change before the firing rate approaches steady state.

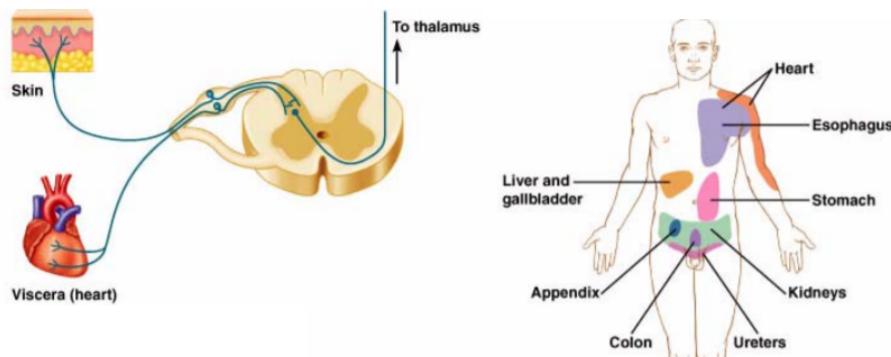


Pain

- **Nociceptors** are free nerve endings. They are classified by stimulus sensitivity: **mechano/thermo/ chemosensitive or polymodal**.
- **Somatic/skin pain** is detected by *A_δ* fibres (picking/well localised) and *C* fibres (burning pain/itch/poorly localised).
- **Deep/visceral pain** that is dull/diffuse is detected by *C* fibres.

2.2.3 Projected and referred pain

- **Projected pain** the site at which the noxious stimulus acts is not that at which the pain is sensed (phantom limbs).
- **Referred pain** is when the nociceptive stimulation of the viscera produces the sensation of pain in distant superficial structures rather than the affected organ.
 - Both the skin and viscera have nociceptors however most pain arises in the skin, and pain in the viscera is less common.
 - Having a neurons at the spinal cord, thalamus and cortex waiting for a very rare event is inefficient. Hence the visceral skin nociceptors converge onto the same neuron going into the spinal cord.
 - The cortex has learned that the skin is the usual source of pain and hence visceral pain results in pain at the skin site.
 - Hence **gate theory** says that innocuous stimuli e.g. rubbing the skin can actually reduce visceral pain.

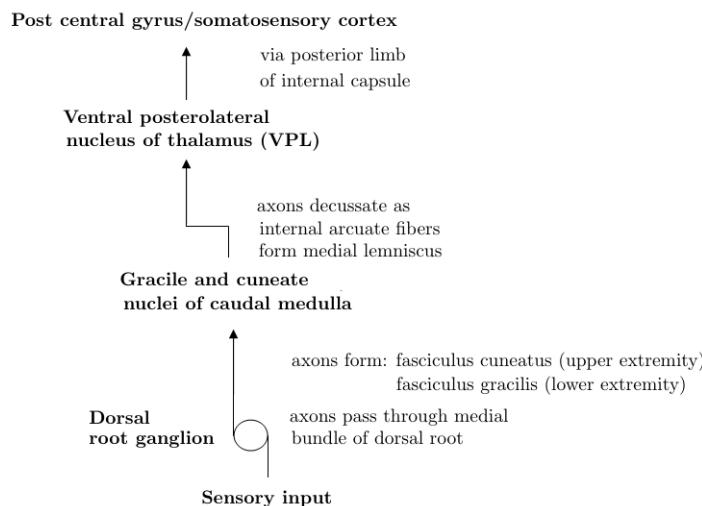


2.3 Outline the dorsal column/medial-lemniscal and spinothalamic pathways to somatosensory cortex

Will be addressed in more detail in later lectures (maybe) - Doc Vickery

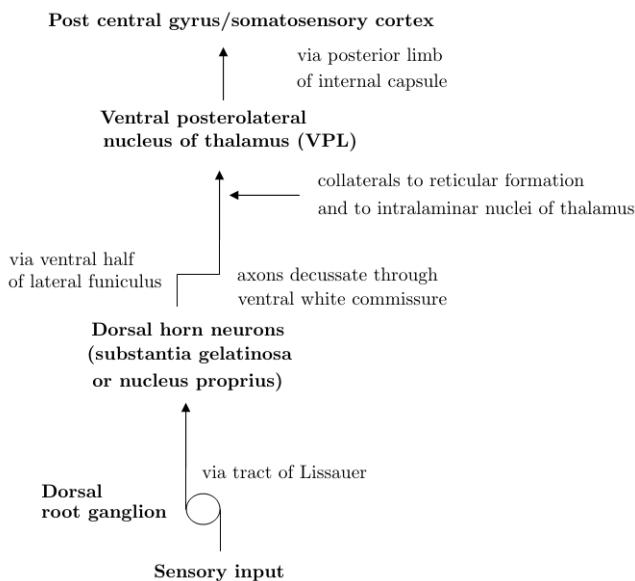
2.3.1 Dorsal column/medial-lemniscal pathway

- Tactile & proprioceptive afferents travel in the **ipsilateral dorsal column**.
- Stimulus comes into the spinal cord, travels upwards until it reaches the **medulla** where it **decussates (crosses over)** to form the medial lemniscus. Recall that this crossing over is necessary because right controls left and vice versa.



2.3.2 Contralateral spinothalamic tract

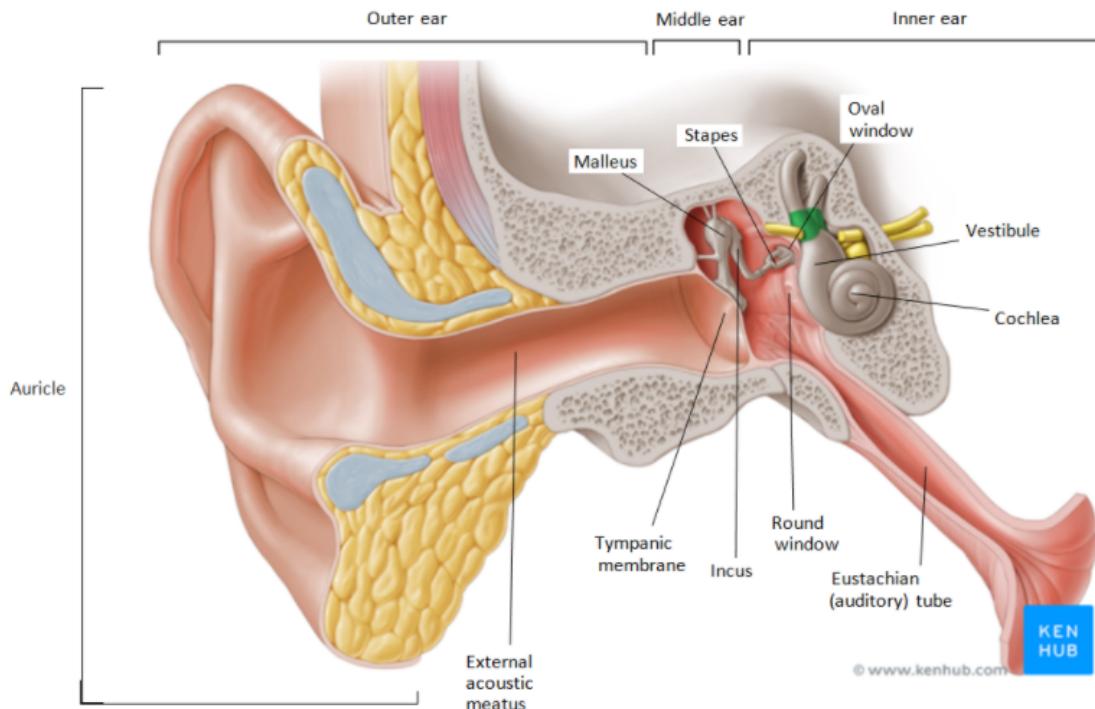
- Pain, temperature and crude touch follow a different route. They actually **decussate** in the **spinal cord** as opposed to the medulla.



- For touch, the axons don't cross over until the medulla. For pain, the axons cross over whilst in the spinal cord. Hence pain and touch travel on opposite sides for most of the spinal cord.
- It is thus possible to have spinal cord damage where a patient may only be able to feel touch in one leg, but can't feel pain in that leg (and opposite signs in the other leg).
- A **spinal hemi-lesion** affecting the left half of the spinal cord at T9 for instance results in:
 - No change in upper limb sensation because the spinal cord is undamaged above T9.
 - Loss of touch from left leg, but loss of pain from right leg.

3 Lecture 3

3.1 Describe the structure and function of the outer, middle and inner ear



Outer ear: Captures and amplifies sound

- **Pinna/auricle:** The intensity of sound waves decrease as they spread out according to the inverse square law. Because of its large size, the **pinna** captures more sound increasing **sensitivity**. Because of its shape, it **partially shields sound** approaching posteriorly and has small features which modify the timbre of the sound, facilitating the **localisation of sound**.
- **External acoustic meatus:** Passage for sound to travel. **Resonator**.

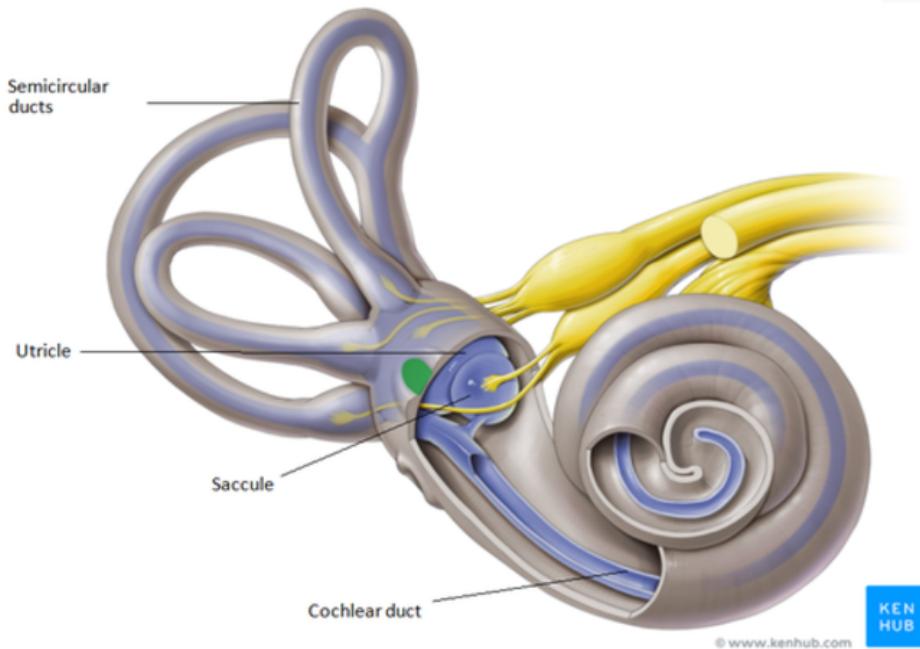
Middle ear: Impedance matching

- Contains the **ossicles**: the **malleus**, **incus** and **stapes**. The handle of the malleus rests medially against the tympanic membrane. The **oval window** is the boundary between the middle and internal ear. The foot plate of the stapes covers it. The **round window** is inferior to the oval window.
 - **Acoustic impedance** is the measure of the extent to which motion induced by pressure applied to a surface is impeded.
 - Because the fluid on the opposite side of the **oval window** has a much higher impedance than air, if it were not for the ossicles, 97% of energy would be lost at this interface.
 - This loss is reduced to 25% because of three mechanisms,
 1. As the **tympanic membrane** vibrates, it transmits a force to the malleus and incus. Because the surface area of the tympanic membrane is ~ 17 times larger than that of the oval window, the force applied to the oval window is amplified 17 fold.
 2. The length of the moment arm of the malleus is much longer than the moment arm of the incus, the force applied to the oval window is amplified 1.3 fold.
 3. The **buckling motion** of the tympanic membrane also result in an increased force of 4 fold and decreased velocity.
 - As force is applied to the oval window, the **round window** bulges slightly outwards due to pressure.

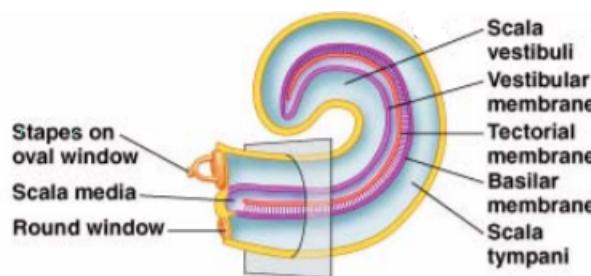
- The **Eustachian tube** extends from the middle ear. It is used to equalise the pressure and drain infection/debris that has accumulated in the middle ear.

Inner ear: Sound transduction

- Consists of the **cochlea**, **semi-circular canals** and the **vestibule**. This region consists of a network of **bony labyrinths** that support the **inner membranous labyrinth**.
- The **cochlea** and its ducts contribute to hearing, the **semicircular canals** are used to detect **rotational acceleration** and the **utricule** and **saccule** in the vestibule **detect linear acceleration**.

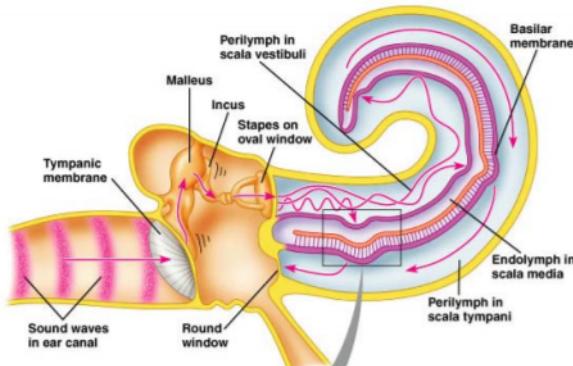


- A **transverse** slice from the cochlea reveals its different chambers.
 - Scala vestibuli, scala tympani:** filled with perilymph
 - Scala media:** filled with endolymph
 - Vestibular membrane**
 - Tectorial membrane**
 - Basilar membrane**

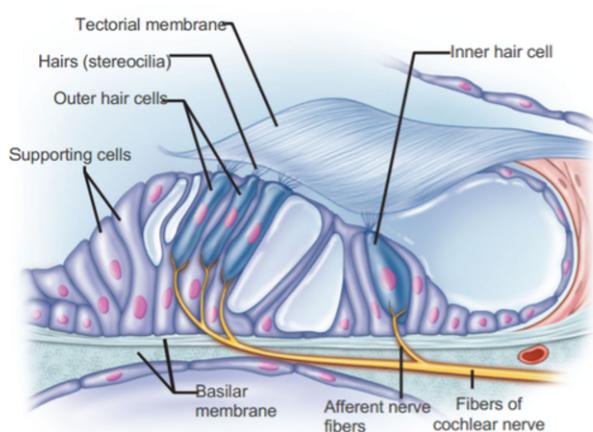
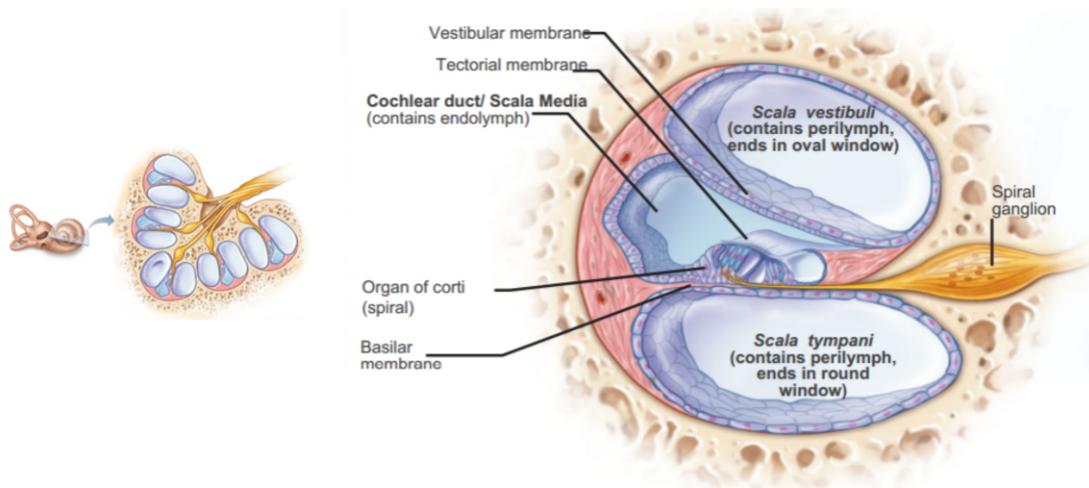


3.2 Explain how mechanical energy is transduced into a neural signal by the cochlear hair cells

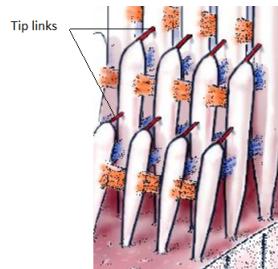
1. Pressure waves created by the stapes pushing on the oval window set the perilymph within the scala vestibuli in motion.
2. This sets up standing waves that propagate along the **basilar membrane**.



3. The **organ of Corti** attaches to the basilar membrane within the **scala media**. It contains **three sets of outer hair cells**, for every **one inner hair cell**. The gelatinous **tectorial membrane** sits above the hairs. On top of these cells are small hairs called **stereocilia**.

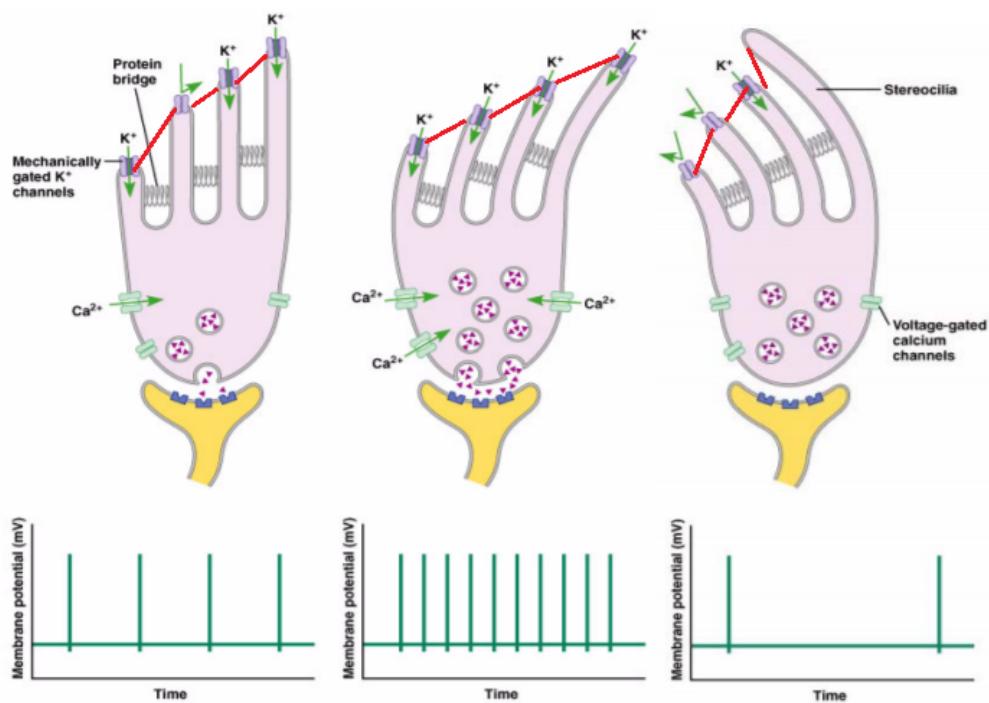


Stereocilia are generally arranged in organised bundles consisting of three rows of graded lengths connected by **tip links**.



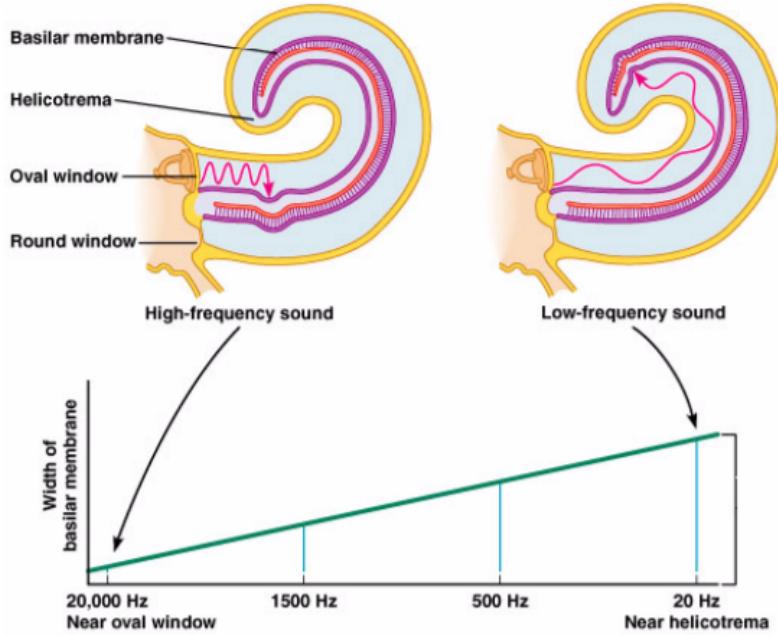
These tip links attach to **mechanically gated** ion channels at the tips of the stereocilia.

4. Recall that the **scala media** contains **endolymph** with a high positive potential of 80-120 mV relative to other fluids such as the perilymph due to its **high concentration of cations**. Because hair cells are at a negative potential of ~ -50 mV, the potential difference from the endolymph to hair cell is ~ 150 mV. Thus as vibrations of the basilar membrane cause the stereocilia to deform against the tectorial membrane.
5. During deformation, the tip links pull on the mechanically gated channels causing them to open. This results in a significant influx of K^+ which depolarises the cell, activating voltage activated Ca^{2+} channels.
6. The Ca^{2+} influx signals the exocytosis of neurotransmitter which binds to receptors in the post synaptic region. This triggers cation channels to open at the post synaptic region resulting in a depolarisation that reaches threshold and generates action potentials that are sent to the CNS.
7. If the stereocilia are deflected in the opposite direction, the system goes silent. **Note** that there is a tonic rate of firing; deflection increases or decreases this rate. In response to the action potential, the **outer hair cells contracts**, driving oscillations at the same frequency as the sound resulting in **amplification**.



3.3 Explain the cochlear place code for pitch

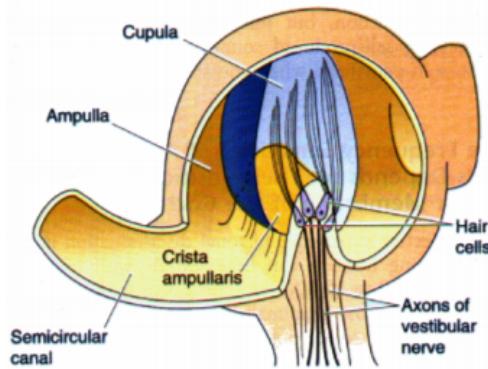
- The properties of the basilar membrane change along its length.
- At the **base** the membrane is **narrow** and **stiff** and becomes **wider** and **floppy** as it approaches the **apex**.
- Hence the natural frequency ω_n decreases along the membrane, meaning that high frequencies cause maximal vibration near the base whilst low frequencies cause maximal vibration near the apex, strongly activating the hair cells. This is the **cochlear place code for pitch**



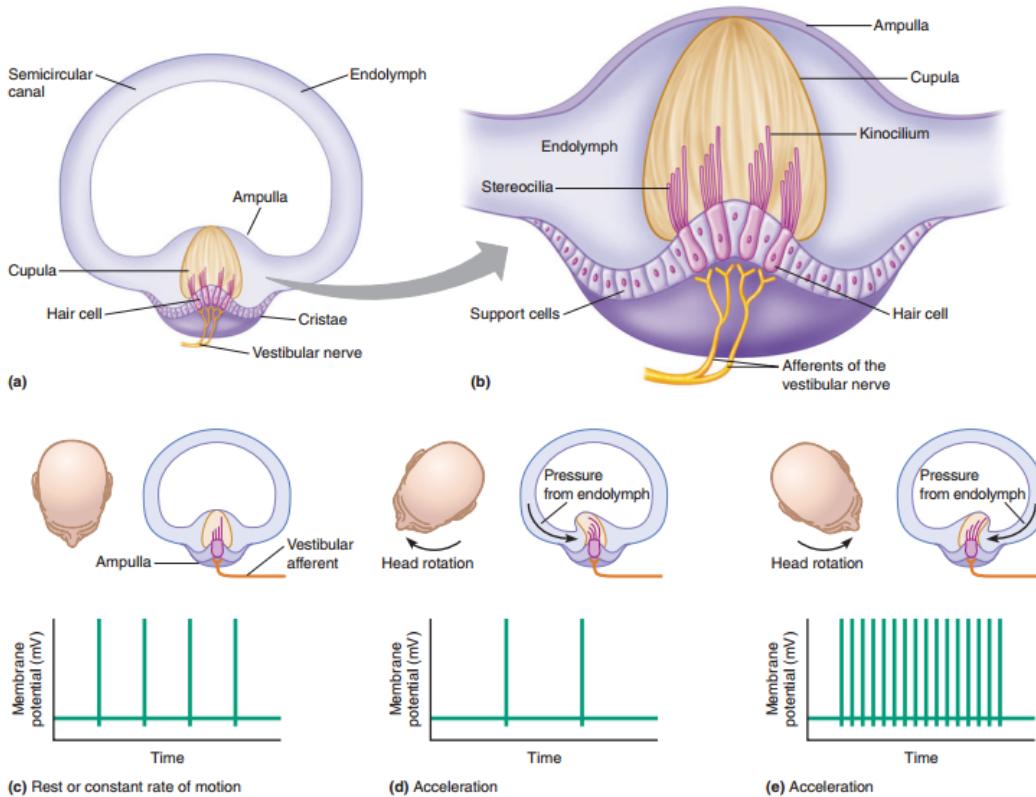
3.4 Explain how the semi-circular canals and the otolith organs both use hair cells to transduce different mechanical signals

3.4.1 Semi-circular canals

- At the base of each **semi-circular canal** is a swelling called the **ampulla**. At the base of each ampulla is the *cristae* containing support/hair cells. Overlying the cristae is the **cupula**, a gelatinous area separated from the endolymph by a membrane. Along the support cells at the base of the cupula are hair cells similar to those in the cochlea, including **stereocilia** that project upward into the cupula. One of the stereocilia is much larger than the others and is called a **kinocilium**.



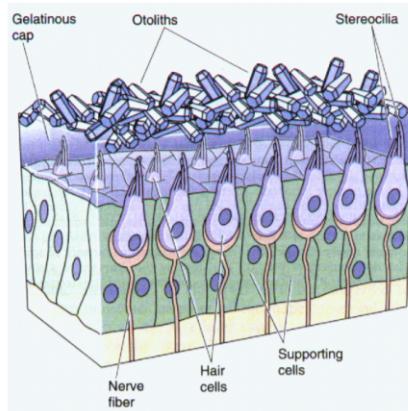
- As in hearing, bending of the stereocilia causes ion channels to open or close, resulting in a change in membrane potential in the hair cells.
- When the head is at rest, no force acts on the cupula, so the stereocilia are upright. The hair cells are tonically partially depolarised leading to a low frequency of action potentials in the associated afferent.
- When the head rotates, the labyrinth rotates with it, but the endolymph lags behind due to Newton's first law, exerting a force on the cupula and causing the stereocilia to bend in the direction opposite that of rotation. Bending towards the kinocilium causes depolarisation and bending away causes hyperpolarisation.
- As the head continues to rotate at a constant speed, the movement of the fluid eventually catches up to the movement of the bony labyrinth meaning that the relative velocity of the bony labyrinth and the endolymph is 0. No force is imparted on the cupula because acceleration is 0 and the stereocilia are no longer bent causing the frequency of action potentials to return to their tonic state.
- The three semicircular canals are **orthogonally** positioned so that they can detect rotational acceleration in all three dimensions.



- Eye movements** are driven by the semi-circular canals. Every time the body is rotated, the eyes move in the opposite direction. When you're spinning in a chair, you can't help but constantly lock onto new targets during the adaptation period until the endolymph catches up and the jumps in eye position plateau because there is no longer a sense of rotation.

3.4.2 Otolith organs: utricle & saccules

- **Otoliths** ($CaCO_3$) crystals are denser than the endolymph.
- Because of this, linear acceleration causes these otoliths to move in the direction of acceleration. As the otoliths are connected to the stereocilia, the stereocilia deform resulting in the same effect as in the cochlea/semi-circular canal, resulting in action potentials being sent to the CNS.

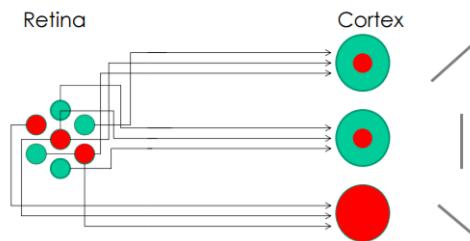


4 Lecture 4

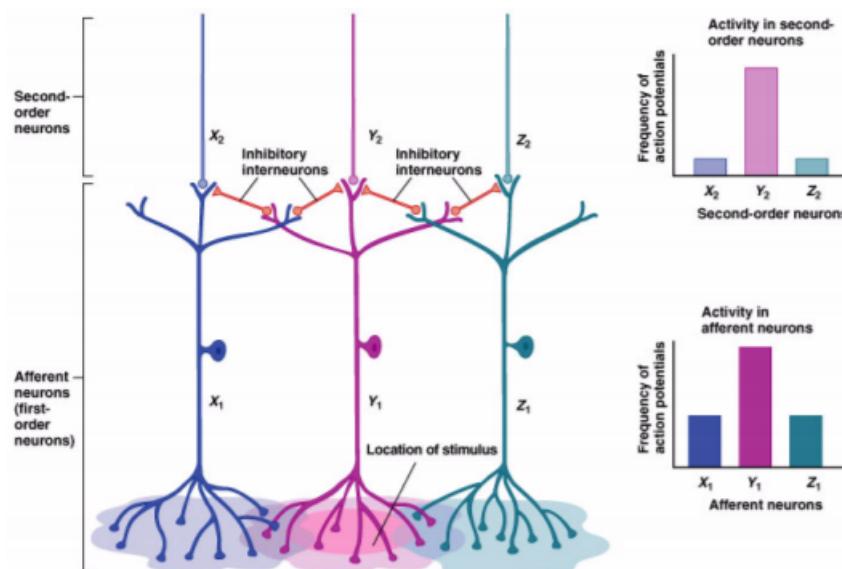
4.1 Describe convergence, divergence and spatial summation in central neural pathways. Give an example of an emergent neural property

4.1.1 Convergence

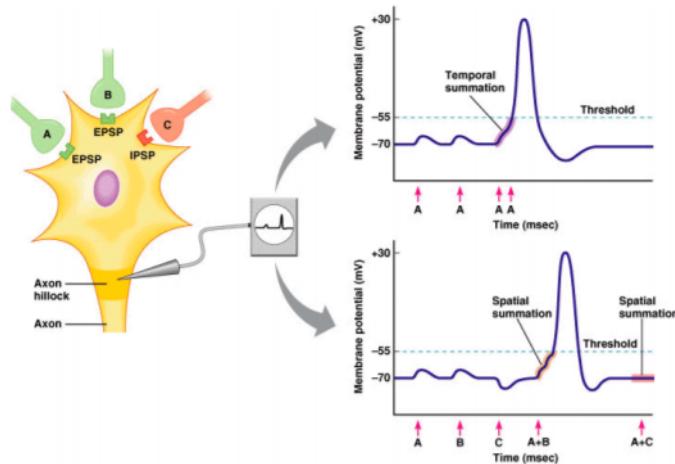
- **Convergence** denotes the transmission of information from two or more neurons to one neuron.
- It is important, because **new properties emerge** when **different inputs converge**. For instance to describe a mintie, the inputs, "white" and "chewy" must converge for you to identify that lolly as a mintie.
- Within the **retina** are **photoreceptors**. Light activates some of these photoreceptors which are represented as spots of light. Each photoreceptor is activated if it is exposed to the line. Each of these neurons converge into three different neurons, each of which reach threshold when viewing a line of a certain orientation. In the example below, different inputs from each of the 7 spots converge onto three different neurons. The first and middle get input from one activated photoreceptor which isn't enough to reach threshold. Only the third one reaches threshold because all three of photoreceptors which converge to form it are activated. This is why **orientation** is considered an **emergent property**. In isolation, the line is activating separate spots in the retina but only if the inputs converge does the property of **orientation selectivity emerge** in the **cortical neurons**.



- Convergence also **sharpens** our responses via **lateral inhibition**. **Lateral inhibition** is the inhibition of the tendency for divergence to spread sensory input over a large number of higher order neurons. Consider being poked in the shoulder. Skin higher up in the back might also have been stimulated, but you want that stimuli to be inhibited in order to maintain a precise representation of what's actually happening in the periphery; i.e. that you got poked in the shoulder and not just "around it".



- Finally, most importantly convergence facilitates **spatial summation** which supports the **integration of information**. This is the crux of the first example. Where for instance a depolarisation caused by A or B alone is insufficient to reach threshold; only their summations results in a sufficient depolarisation that reaches threshold and generates an action potential that signals the CNS that there is a line slanted to the right.



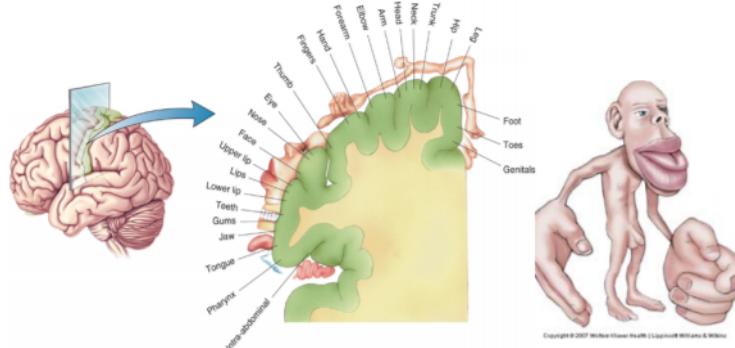
- Note** that spatial convergence tends to make receptive fields larger. From the previous picture, if you have more skin receptors converging onto a central neuron, it is more likely to respond to a larger area of skin because it can respond to receptors from any number of those peripheral neurons.
- Furthermore, spatial summation only works because of **chemical synapses**.

4.1.2 Divergence

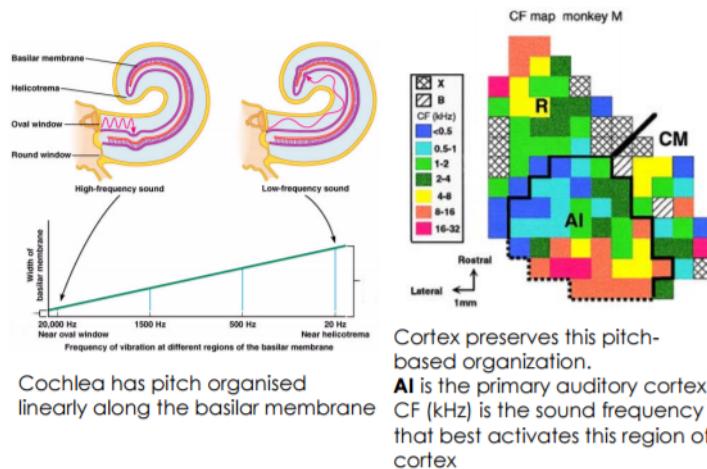
- Decision making** implies that a given input can give rise to different outcomes. This requires divergence of the input so that it goes to neurons that can produce different outcomes.

4.2 Explain topographic organisation and somatotopy, tonotopy and visuotopy

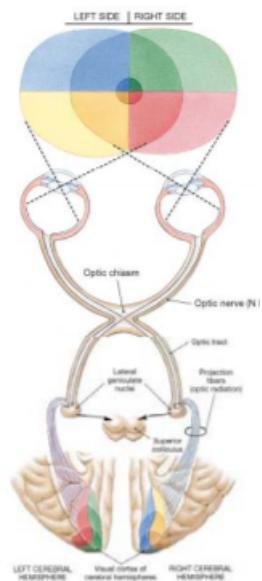
- Neurons do not converge haphazardly or randomly; they converge in a way such that **peripheral neighbours** remains **cortical neighbours**.
- This preservation of the local relationship of afferents is called **topographic organisation**. It is a mapping of neurons from one part of the nervous system to another. The basic mapping is hardwired but detailed connections are adapted based on activity in the connected neurons. Since topograph = map and somato = body, a **somatotopy** is a **body map**.
- The size of the allocated cortical region depends on the density of receptors of its corresponding peripheral region. This is reflected in the **homunculus**.



- The **auditory cortex** is topographically organised by **frequency**. This is called a **tonotopy**.



- The **visual topography** or **visuotopy** reflects the increasingly higher visual acuity as our vision moves medially through the increased cortical representation in the centre of the visual cortex and lesser representation for the lighter lateral colours.

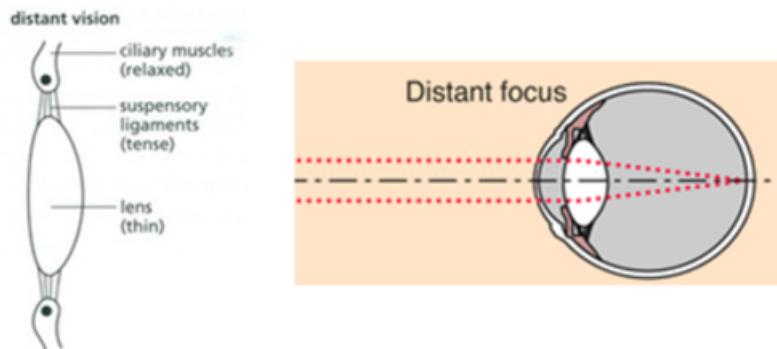


4.3 Describe the contribution of the various parts of the eye to image formation on the retina

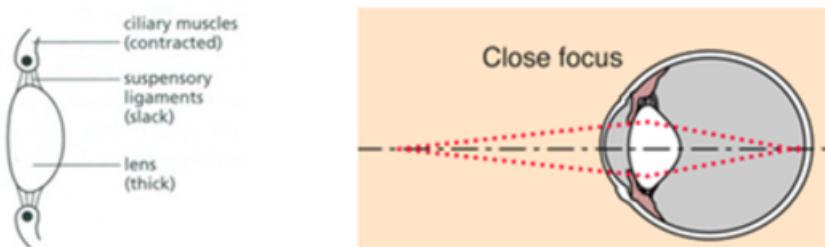
- **Image formation** involves the refraction of light emitted by objects in order to focus them into an image on the back of the retina. The **power** of a lens depends on its **radius** and **refractive index**. Power = 1/focal length.
- The main refracting apparatus is the **cornea**. Even though the **lens** has a higher refractive index, it is less powerful because the **change in refractive index** is smaller (1.00 to 1.38 compared to 1.33 to 1.40). The **aqueous/vitreous humours** are also involved in refraction to a lesser extent.
- **Note** that the inversion of the retinal image is of no significant to the brain; it has never known any other orientation and learns the mapping between stimulus and receptor.

4.3.1 Accommodation

- The purpose of the lens is to refract incoming light such that the focal point corresponds to the retina. The lens is attached to the **ciliary body muscles** via the **zonular ligaments**.
- Light rays from distant objects are nearly parallel and require little refraction to bring them to focus on the retina. In this position, the ciliary body muscles are at rest and the zonular ligaments are taut. The lens is **relatively flat**.

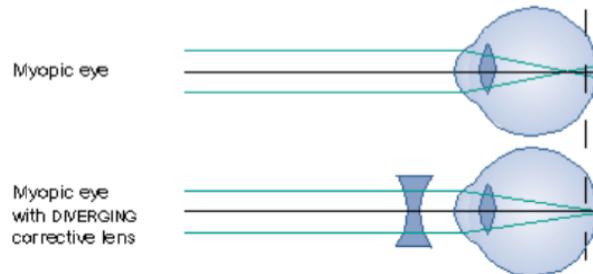


- Light rays from close objects diverge and require more refraction for focusing. The eye **accommodates** for this by contracting the ciliary body muscles, causing the zonular ligaments to loosen, such that the curvature of the lens and thus power increases to refract the rays so that the focal point corresponds with the retina.

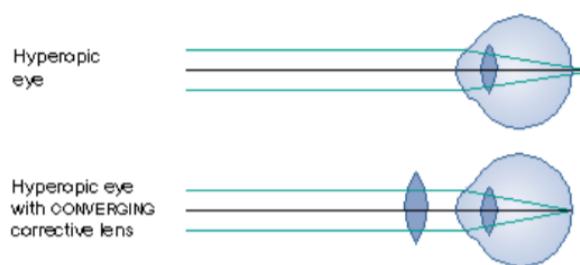


4.4 Describe myopia, hyperopia and presbyopia and the lenses used to correct them

- **Myopia** is a condition where the eye is **too long**, or the cornea has **too much power**, leading to the focal point existing in front of the retina. Leads to **distant objects** seeming blurry. Fixed using a **bi-concave lens** that causes light to **diverge**.



- **Hyperopia** is a condition where the eye is **too short**, or the cornea **lacks power**, leading to the focal point existing behind the retina. Leads to **close objects** seeming blurry. Fixed using a **bi-convex lens**.



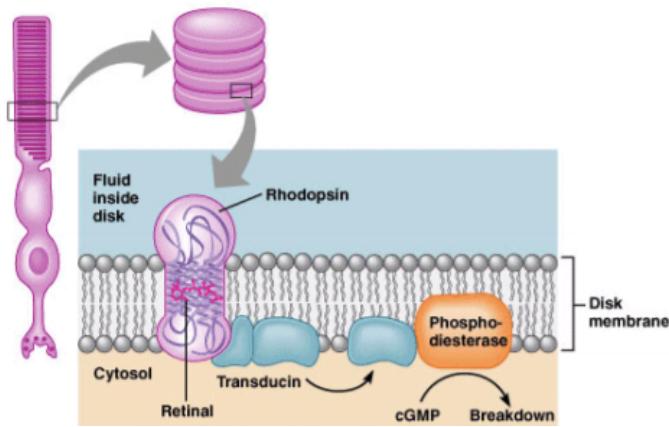
- **Presbyopia** is a condition where the lens loses its ability to effectively deform to increase the extent of refraction, limiting the effectiveness of the accommodation mechanism. This has the same effect and is fixed the same way as hyperopia.

5 Lecture 5

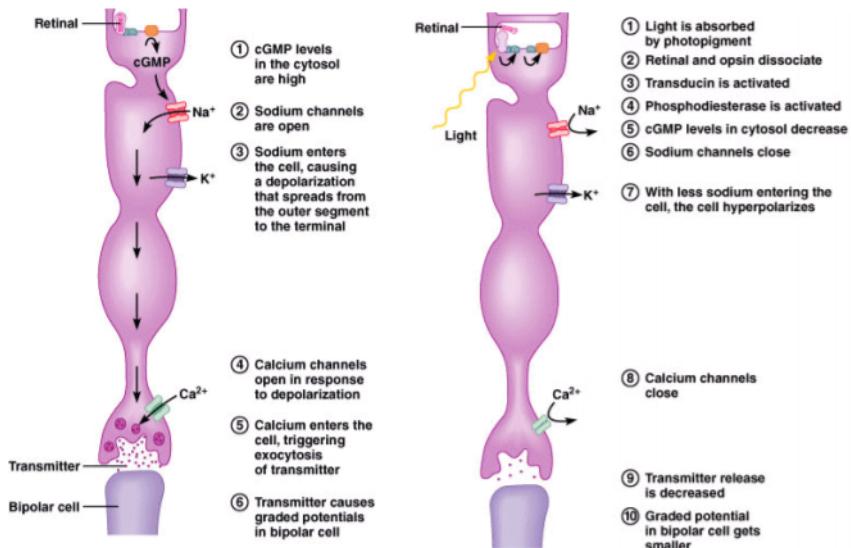
5.1 Describe the retinal distribution of rods and cones and how this distribution affects visual perception

5.1.1 Transduction

- The membrane of a rod consists of multiple **invaginations** which stack. It has a **soma** and releases **neurotransmitter** from its foot.
- Inside the membrane are **membrane spanning proteins** called **opsins**. Each opsin contains **retinal** which changes shape and exits the opsin molecule after capturing a photon. But how is **one photon** sufficient to stimulate the photoreceptors? One opsin can interact with multiple **transducins**. Each transducin can then activate multiple **phosphodiesterases** which break down **cGMP**. Thus, there is an amplification at each step.

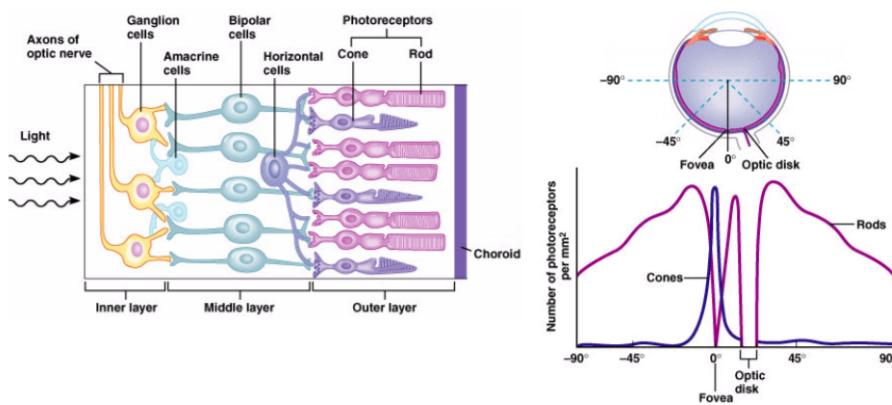


- In the **dark**, transmitter is released. Ligand (cGMP) gated Na^+ channels remain open in the dark because the concentration of cGMP is high.
- However when stimulated by light, the phosphodiesterases break down cGMP, causing the Na^+ and Ca^{2+} channels to close, halting the exocytosis of neurotransmitter.



5.1.2 Arrangement of cells in the retina

- Before reaching the photoreceptors, light must pass through a number of cells resulting in **scattering**. The photoreceptors are at the back because they are very metabolically active and require O_2 and glucose from vasculature that would otherwise cast shadows if they were the first layer through which light passed.
- The **fovea** only has cones. Cones have **one to one convergence** facilitating the highest **visual acuity**.
- Rod density** increases either side of the fovea and then drop off towards the periphery. There are **no receptors** at the **optic disc**.
- There are more rods in the periphery but hundreds of them converge on to one neuron.
- Rods** are slightly taller than cones because they are more sensitive and can capture more photons allowing them to work better in low light levels.

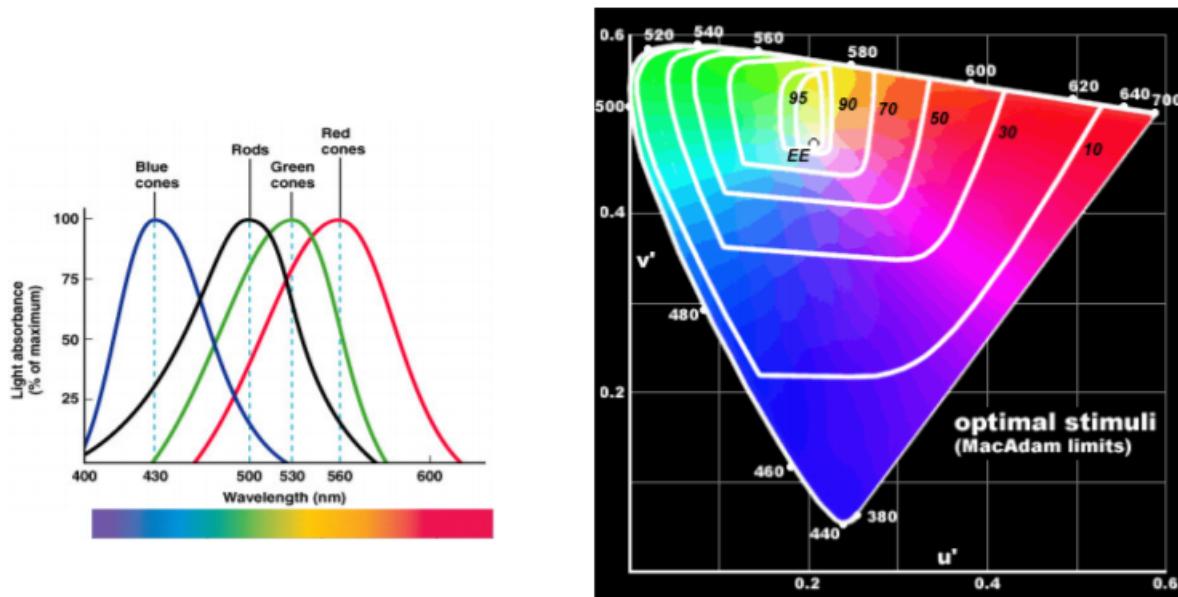


5.1.3 Colour sensitivity

- In different light levels, there is a balance of activity of the rods and cones.
- Because **cones** are less sensitive than **rods** requiring a few thousands photons for them to function compared to one, in very low light only **rods** contribute (**scotopic vision**).
- In slightly brighter light, some cones are stimulated but the rods still have the majority of the contribution (**mesopic vision**).
- At higher light levels, the rods become **saturated** and the rate of neurotransmitter exocytosis have already peaked. Hence at higher levels of light, only the **cones** contribute (**photopic vision**).

5.2 Explain the basis of colour vision, and of anomalous trichromacy (red/green colour blindness)

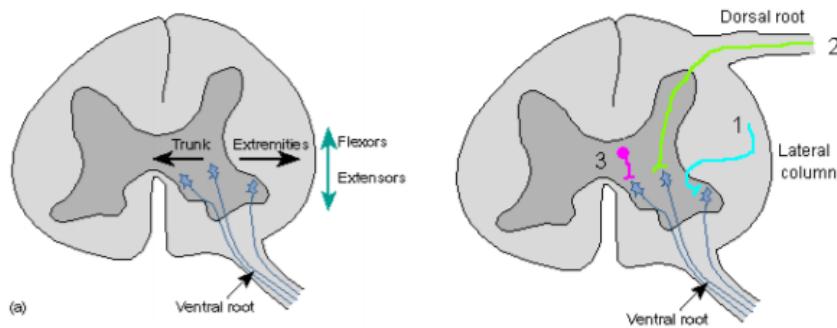
- Each colour in the spectrum relates to its **wavelength**.
- Each photoreceptor absorbs photons to different extents and every photoreceptor has a particular wavelength that is **preferentially absorbs**.
- At night, because the cones aren't active, colour is ambiguous. There can be two different frequencies that produce the same absorbance.
- This issue is solved during brighter light by using the ratio of the three different cones (red, green, blue) cones in order to specify a certain colour in the spectrum.



- In **anomalous trichromacy**, both **red** and **green** cones are present, but the **peak absorbance** of one of the opsins has been shifted closer to the other. This leads to **reds** and **greens** seem more similar than to normal viewers, as do **purples** and **greys**. Most colours are still distinguishable. This is coded on the **X chromosome** meaning makes are more likely to have this condition.
- **Protanopia** is a lack of **red cones**. **Tritanopia** is a lack of **blue cones**. **Deuteranopia** is a lack of **green cones**.

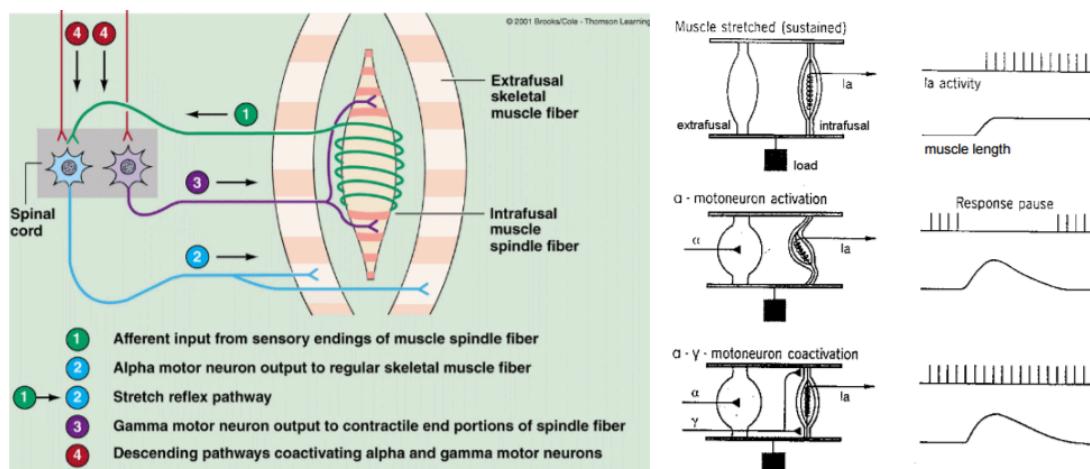
5.3 Describe the organisation of a motor unit, and the control of contractile force in skeletal muscle

- A **motor unit** consists of a **motor neuron** and the entire group of muscle fibres which vary in size innervated by the branches of its **axon**.
- **Contractile force** is regulated by:
 1. **Frequency of action potentials** in the motor unit (rate code)
 2. **Number of motor units activated** ⇒ The smallest units are recruited first (population code).
- As in the sensory system, the motor system also uses **topographic organisation**. The peripheral connection is not to a sheet of receptors, but to **muscle fibres**. Motor neurons innervating muscle fibres in the same muscle will be neighbours in the spinal cord. **Dermatomes** are evident for this organisation. The neurons controlling the activity of these spinal motor neurons will also be neighbours.
- There are 3 **classes of input** to the lower (spinal) motor neurons. The only efferent connection is skeletal muscle is these lower motor neurons.
 1. **Upper (cortical) motor neurons:** Particularly for our fingers
 2. **Spindle afferents:** Direct connection to motor neuron allowing fast reflex.
 3. **Spinal interneurons:** Most motor neurons are controlled by indirect inputs from higher motor centres that arrive via these neurons.

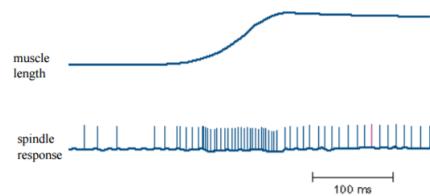


5.4 Describe a muscle spindle and its response to muscle stretch and contraction

- Regular muscle fibres are called **extrafusal fibres**.
- Muscle spindle afferents are called **intrafusal fibres**.
- Muscle spindle afferents detect the **length** of a muscle and the **rate** at which it is lengthening.
- The **alpha motor neurons** synapse onto the extrafusal fibres causing them to contract allowing **rapid reflex reaction** in response to changes in the activity of the spindle afferent.
- The **gamma motor neurons** adjust the tension of the **intrafusal muscle fibres** so that the muscle spindles stay within their operating range regardless of whether the main muscle is contracted or extended.



- In response to **lengthening**, the spindle fires has a **transient/phasic** response of heightened AP frequency and then settles to an increased steady state tonic rate.
- In response to **contraction**, the same thing happens except the initial tonic rate decreases.



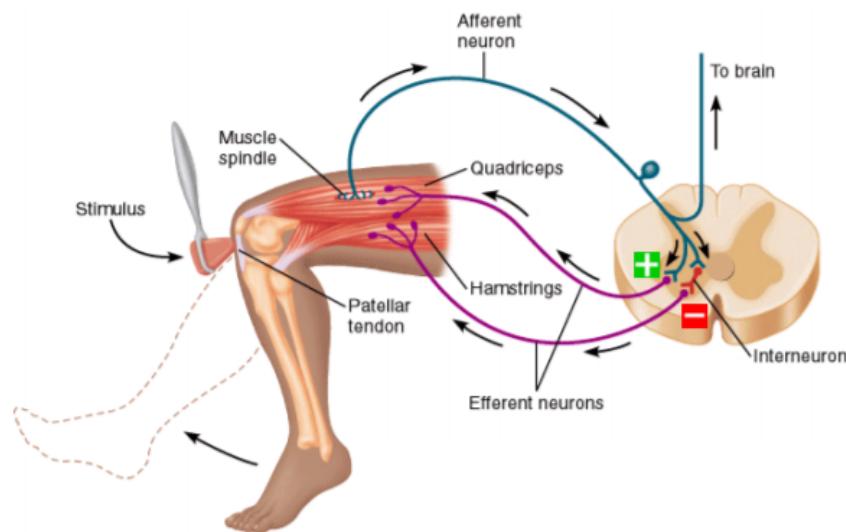
6 Lecture 6

6.1 Draw the neural circuits for the myotatic, Golgi tendon organ, and withdrawal reflexes

6.1.1 Myotatic (monosynaptic) reflex

Main purpose: Homeostasis of muscle length.

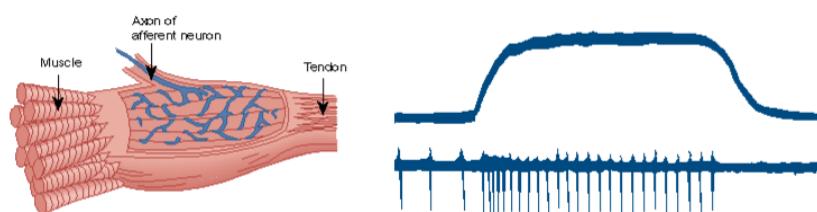
1. Tap patella slightly lengthening patellar tendon
2. Although the change in tendon length is small, the rate of change is big, triggering the **muscle spindles in parallel** with the extrafusal muscle fibres to fire APs through the afferent neurons which enter through the dorsal horn.
3. The afferent neurons then make synapses with an excitatory and inhibitory interneurons that connect to efferent neurons which synapse onto the quadriceps and hamstrings respectively.
4. This causes the quadriceps to contract, opposing the change in length and causes the hamstrings to relax to facilitate the contraction of the quadriceps.

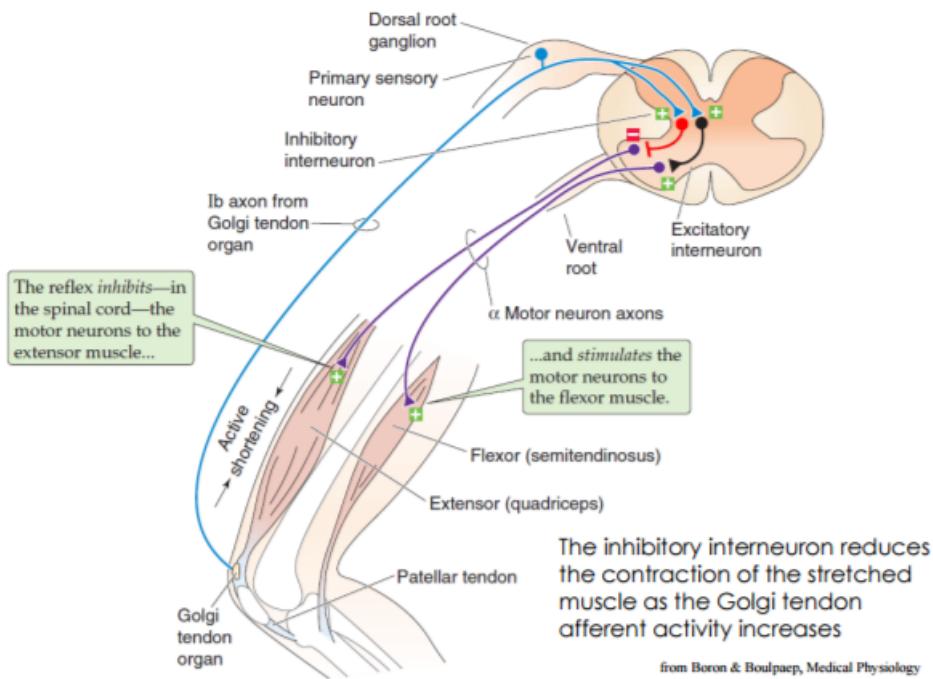


6.1.2 Golgi tendon organ

Main purpose: Homeostasis of muscle tension (spindles only tell you about length which is useless during isometric contractions).

1. Huge force stretches tendon, triggering the **Golgi tendon organs in parallel** with the quadriceps.
2. The Golgi tendon organ fires action potentials causing the excitation of the hamstrings and inhibition of the quadriceps so that force on the tendon is decreased.

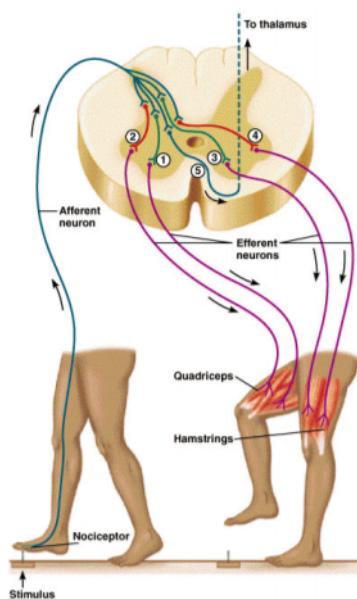




6.1.3 Withdrawal reflex

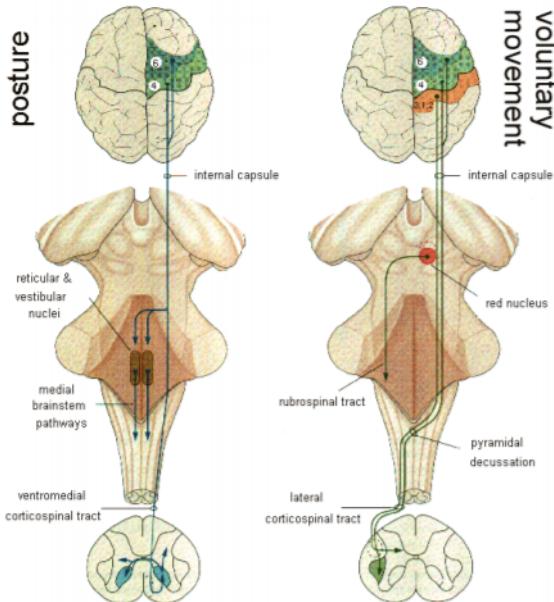
Main purpose: Not dying lol

1. Nociceptor is directly attached to motor neurons in spinal cord. Treading on nail activates nociceptor causing burst of APs up the afferent neuron.
2. The afferent neuron synapses onto the excitatory interneuron that excites the alpha motor neuron causing the hamstring to contract, lifting the leg up. The quadriceps in the same leg are inhibited simultaneously.
3. The quadriceps on the other leg are excited and the hamstrings are inhibited so that you don't fall over. Also branches off to CNS telling it about everything.



6.2 Distinguish the function and general course of the pyramidal and extrapyramidal motor pathways

- The **pyramidal tracts/pathway** is for **postural reflexes**.
- The **extra-pyramidal tracts/pathway** is for **voluntary movement**.
- 90% of the corticospinal axons decussate and control the contralateral limbs via the lateral corticospinal tract. The remaining 10% from the ventromedial corticospinal tract and remain ipsilateral, controlling posture.
- Voluntary movement involves more somatosensory activation because you are expecting touch for instance from something you are expecting to pick up.



6.3 Describe the roles of the higher motor areas, and the topographic organisation of the motor cortex

- **Motor cortex:** Output directly to lower motor neurons or indirectly via the brainstem motor nuclei. Integration of information from other motor areas. It is **topographically** organised the exact same way as the **somatosensory cortex**.
- **Cerebellum:** Control of posture/muscle tone, motor learning, ensures smooth execution of rapid goal directed movement.
- **Basal ganglia:** Plan and initiate movements.

6.4 List the sequence of events in a movement, from initial planning through to execution

1. Movement initiated at highest level by interactions between **sensory input (possibilities)**, **limbic system (desires)** and **pre-frontal cortex (decision)**.
2. The basic plan of action is **translated into a motor program**. This involves the **basal ganglia**, **cerebellum** and the **supplementary and pre-motor cortices**.
3. The **primary motor cortex** is given the "go" signal by the basal ganglia and sends the motor program to the motor neurons directly and via the brain stem nuclei.
4. The motor neurons fire APs, depolarise muscle fibrse at the NMJ and cause muscle contraction which ultimately causes the desired action.

