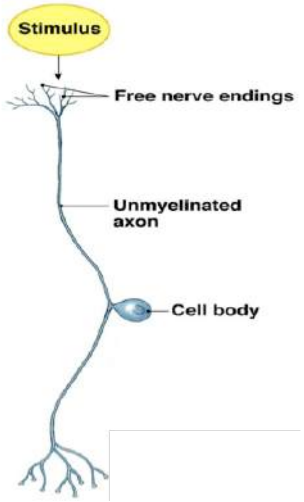
<u>Sensory Physiology</u>

- Stimuli at the conscious level of perception
    - Special senses → vision, hearing, taste, smell, equilibrium
    - Somatic senses → touch, temperature, pain, itch and proprioception
    - Proprioception = the awareness of body movement and postion in space
        - Proprioreceptors in muscles/joints, either conscious or unconsious

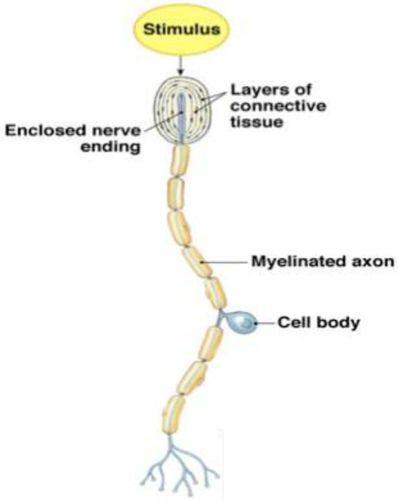
Sensory Pathways

- Stimulus as physical energy → sensory receptor
    - Receptor acts as a <u>transducer</u>
- Transducer converts stimulus into an intracellular signal
    - Is usually a change in membrane potential
- Stimulus must be above threshold
    - Stimulus → threshold → action potential to CNS
- Integration in CNS → cerebral cortex where some stimuli reach are consciously perceived and others acted on subconsciously without our awareness

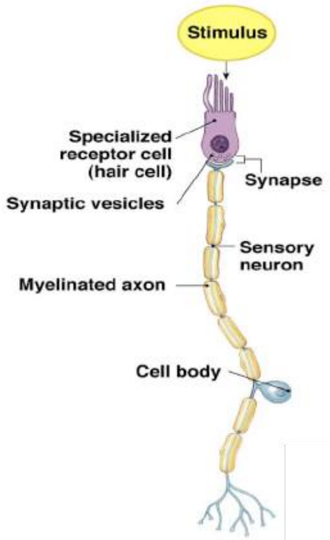
Somatosensory Receptors



Simple receptors are neurons with free nerve endings



Complex neural receptors have nerve endings enclosed in connective tissue capsules Pacinian Corpuscle which senses vibration is a mechanoreceptor

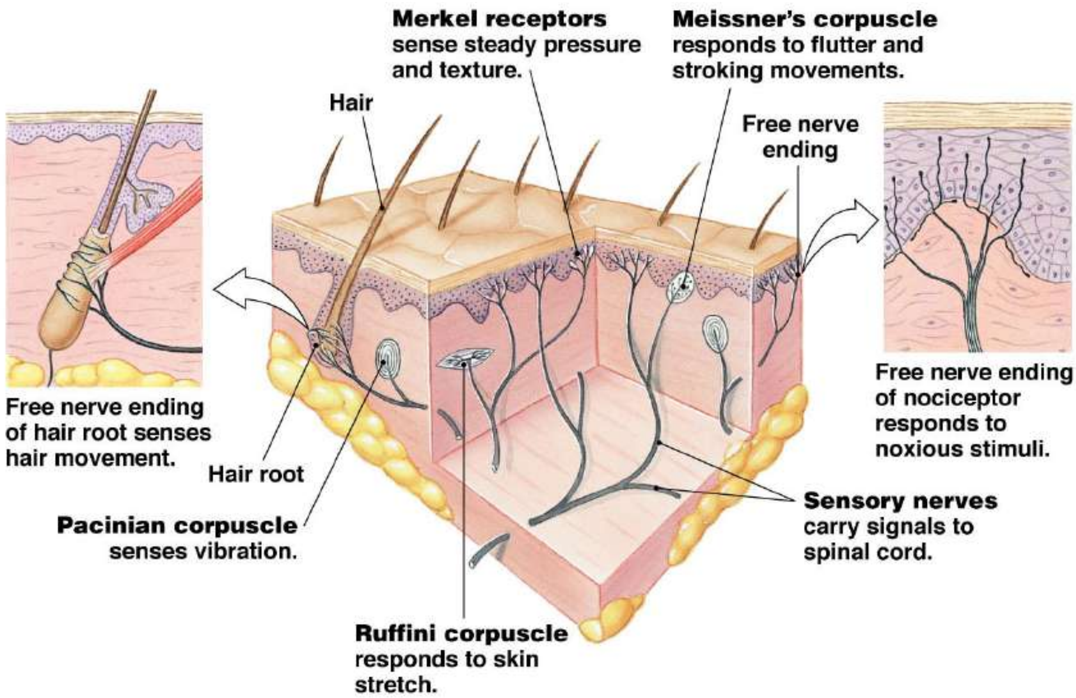


Most special senses receptors are cells that release neurotransmitter onto sensory neurons, initiating an action potential Hair cell found in Ear

- Smell receptors are neurons, other 4 special senses are non-nerual receptor cells
    - When activated, the hair cell releases a neurotransmitter that initiates the action potential
- Non-neural accessory structures enhance info-gathering capacity of receptors
    - E.g. cornea and lens help focus light on photoreceptors
    - E.g. arm hairs help somatosensory receptors sense movement in the air above skin surface

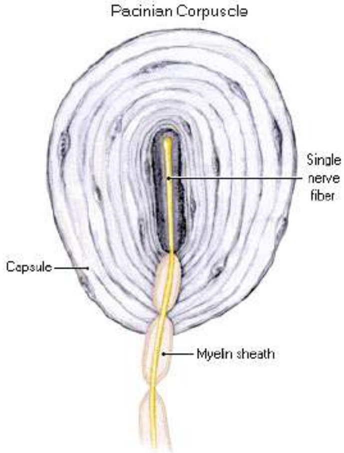
Touch Receptors

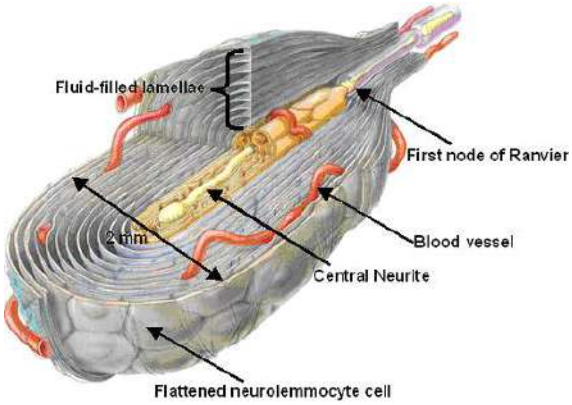
- Found in the skin and in deeper regions on the body



Pacinian Corpuscle

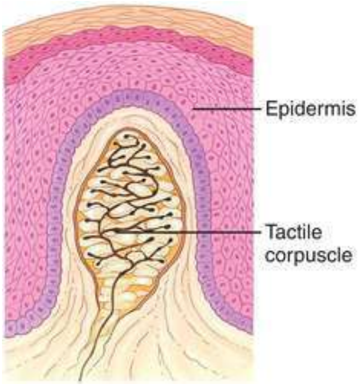
- The Lamellar corpuscle is oval-shaped and approximately 1 mm in length
- The entire corpuscle is wrapped by a layer of connective tissue
- It has 20-60 concentric lamellae composed of fibrous connective tissue and fibroblasts, separated by gelatinous material
- The lamellae are very thin, flat, modified Schwann cells
- In the centre of the corpuscle is the inner bulb, a fluid-filled cavity with a single afferent unmyelinated nerve ending
- These receptors detect vibrations and are rapidly adapting (phasic) receptors
- Pressure sensitive sodium channels located in corpuscle

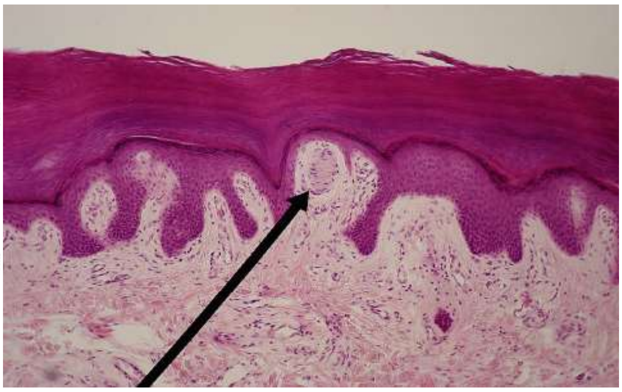




Meissner's Corpuscles

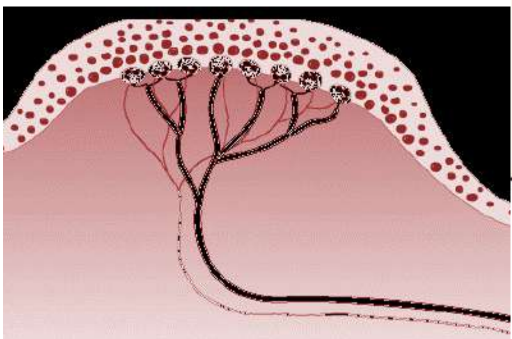
- Encapsulated unmyelinated endings
- Consist of flattened supportive cells arranged as horizontal lamellae surrounded by a connective tissue capsule
- Corpuscle is between 30-140 µm in length and 40-60 µm in diameter
- A single nerve fibre meanders between the lamellae and throughout the corpuscle
- Any physical deformation in the corpuscle will cause an AP in the nerve
- Since they are rapidly adapting or phasic, the APs generated quickly decrease and eventually cease (this is the reason one stops "feeling" one's clothes)
- Sense flutter and stroking movements

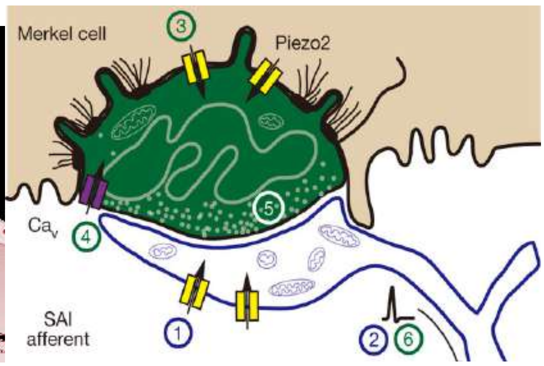




Merkel Receptors

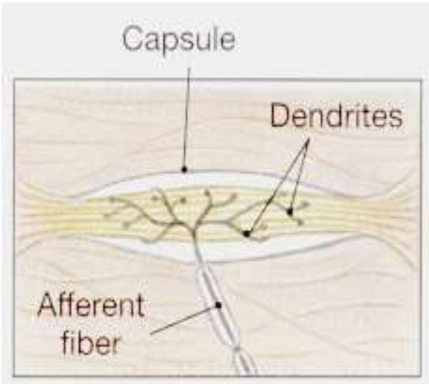
- Merkel nerve endings are mechanoreceptors found in the skin and mucosa of that provide touch information to the brain. Each ending consists of a Merkel cell in close apposition with an enlarged nerve terminal. This is sometimes referred to as a Merkel cell–neurite complex, or a Merkel disk receptor. A single afferent nerve fibre branches to innervate up to 90 such endings. They are classified as slowly adapting (tonic) mechanoreceptors
- Sense steady pressure and texture

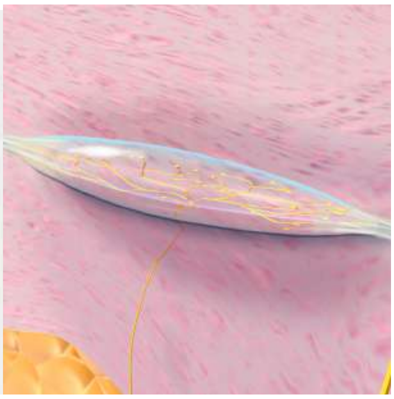




Ruffini or Bulbous Corpuscle

- A slowly adapting (tonic) mechanoreceptor found in the subcutaneous tissue of humans
- Ruffini corpuscles are highly branched nerve endings within a fluid filled capsule in the connective tissue
- Small swellings at the end of each branch of the nerve ending and the receptor is said to respond to displacement of connective tissue fibres that extend through the fluid filled bulb
    - Thought to sense stress or distension in the deeper dermis
- Respond to skin stretch





Types of Sensory Receptors

- Although receptors are specific to one form of energy, they can respond to most other forms if the intensity is high enough

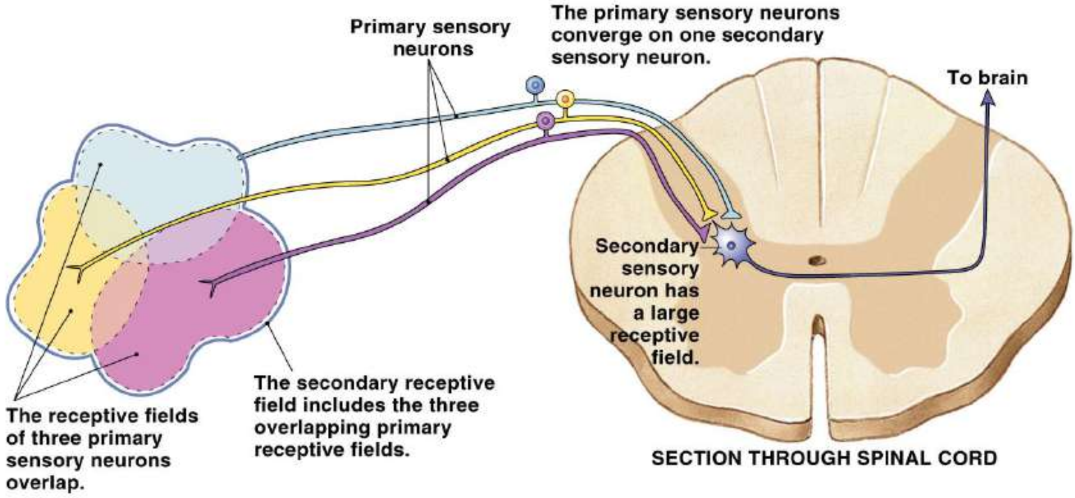
Type of Receptor	Example of Stimuli
Chemoreceptors → respond to chemical ligands that bind to the receptor	Oxygen, pH, various organic molecules such as glucose
Mechanoreceptors → respond to mechanical energy	Pressure (baroreceptors), cell stretch (osmoreceptors), vibration, acceleration, sound
Photoreceptors → respond to light	Photons of light
Thermoreceptors → respond to temperature	Varying degrees of heat

Sensory Transduction

- Transduction = the conversion of stimulus energy into info that can be processed by the CNS
    - E.g. opening and closing of ion channels converts mechanical, light, chemical and thermal energy into a change in membrane potential change
- **Adequate stimulus** → Preferred form of stimulus by receptor e.g. thermoreceptors are more sensitive to temperature whereas mechanoreceptors respond to stimuli that deform the cell membrane
- **Threshold** → Minimum stimulus required to activate a receptor
- Receptor potential = graded potential, change in sensory receptor membrane potential
- Can initiate an AP OR influence the release of neurotransmitter secretion = alters electrical activity in an associated neuron

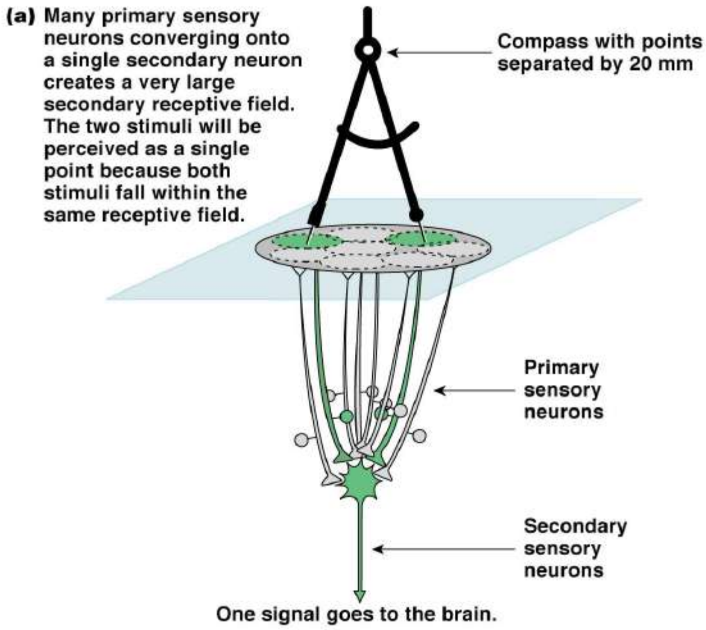
Receptive Fields of Sensory Neurons

- Receptive field → specific physical area in which somatic sensory and visual neurons are activated by stimuli
    - E.g. touch receptive neuron in skin will respond to pressure that falls within its receptive field
- Primary sensory (first-order) neuron → 1RF associated with 1 sensory neuron
- Secondary sensory (second-order) neuron → primary synapses on 1 CNS neuron
- Convergence → multiple presynaptic neurons provide input to a smaller number of post synaptic neurons
    - Allows multiple simultaneous sub-threshold stimuli to sum at the postsynaptic neuron
    - Individual receptive fields merge into a single large (secondary) receptive field
    - Size of 2ndary receptive field determines an area's sensitivity to a stimulus



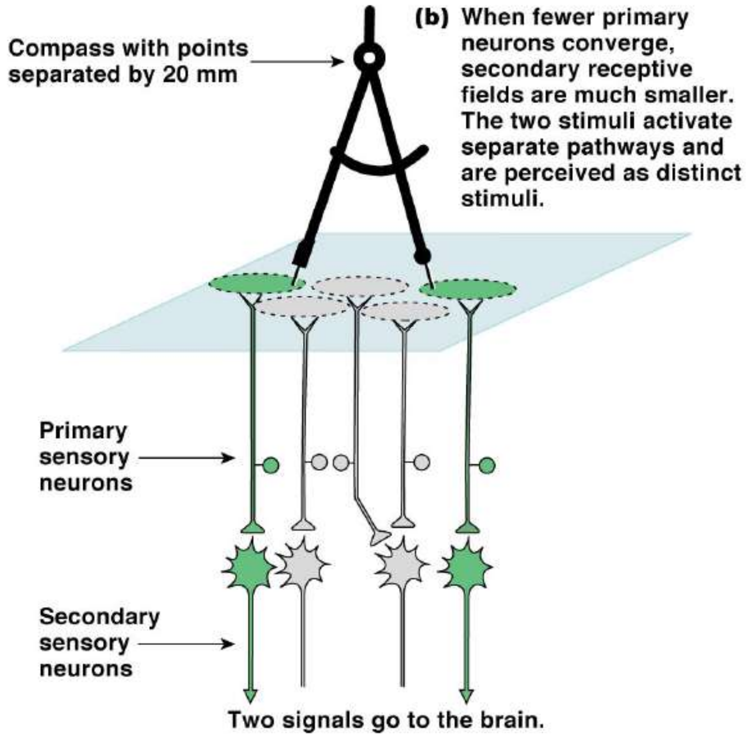
Sensory Neurons: Two-Point Discrimination

- **Less sensitive areas** have larger receptive fields e.g. arms, legs
    - Many primary neurons converge onto a single secondary neuron



- **More sensitive areas** have smaller receptive fields e.g. finger tips

- Convergence shows a 1:1 relationship between primary neurons and secondary neurons

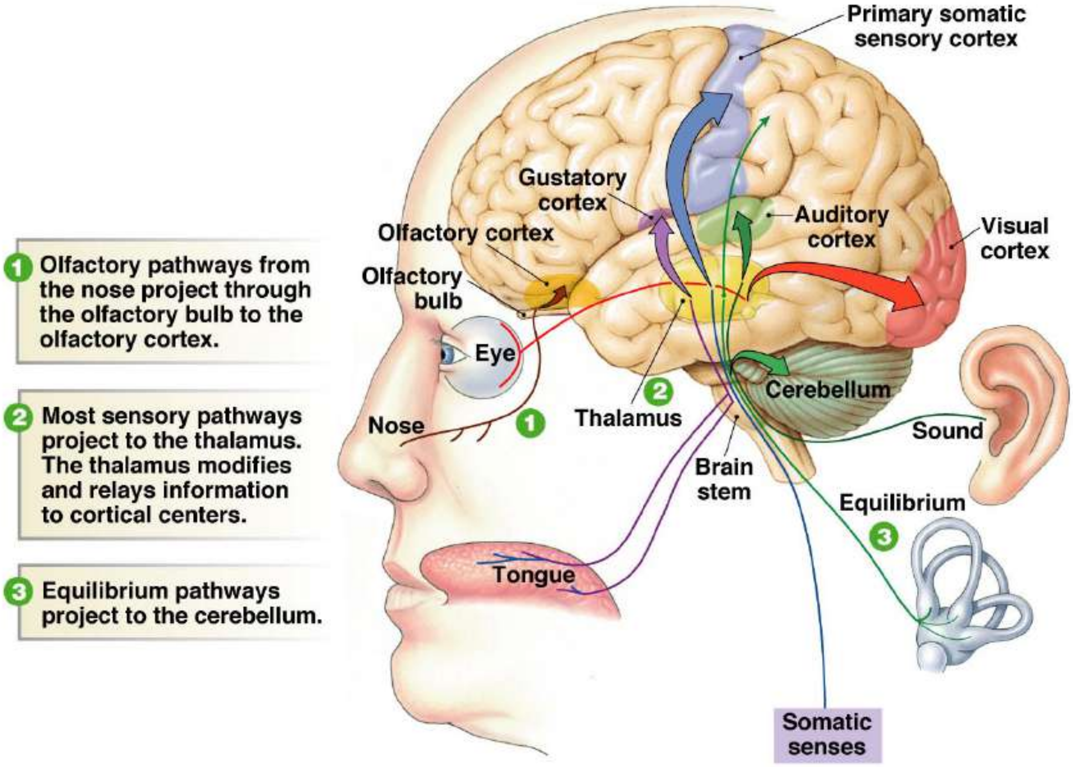


Integration by CNS

- Sensory information either:
    - Spinal cord to brain by ascending pathways
    - Directly to brain stem via cranial nerves
- Visceral reflexes integrated in brain stem or spinal cord usually do not reach conscious perception
    - E.g. of unconscious visceral reflex is control of blood pressure by brain stem
    - Mid-brain receives visual info
    - Medulla oblongata receives input for sound and taste
    - Cerebellum processes info about balance and equilibrium
        - These pathways project to the thalamus → relay before passing info to cerebrum
            - Olfactory info is not routed through the thalamus
            - Travels: olfactory bulb → 1st cranial nerve → cerebrum
- **Perceptual threshold** → Level of stimulus intensity necessary for you to be aware of a particular sensation
    - Brain can 'turn off' some stimuli to avoid being overwhelmed
- Noise can adequately stimulate sensory neurons (e.g. ear) but neurons higher in the brain can dampen the perceived signal so that it does not reach the conscious brain
    - E.g. studying with the radio in the background or zoning out during a lecture
- Inhibitory Modulation → decreased perception of a stimulus below perceptual threshold
    - Diminishes a suprathreshold stimulus until it is below the perceptual threshold
    - Often occurs in the secondary and tertiary neurons
    - Inhibitory modulation can be overcome

Sensory Pathways in the Brain

- Most pathways except the olfactory pass through the thalamus on their way to the cerebral cortex



Stimulus

- CNS can distinguish four properties of a stimulus:
  - Modality/nature
  - Location
  - Intensity
  - Duration

Modality or Nature

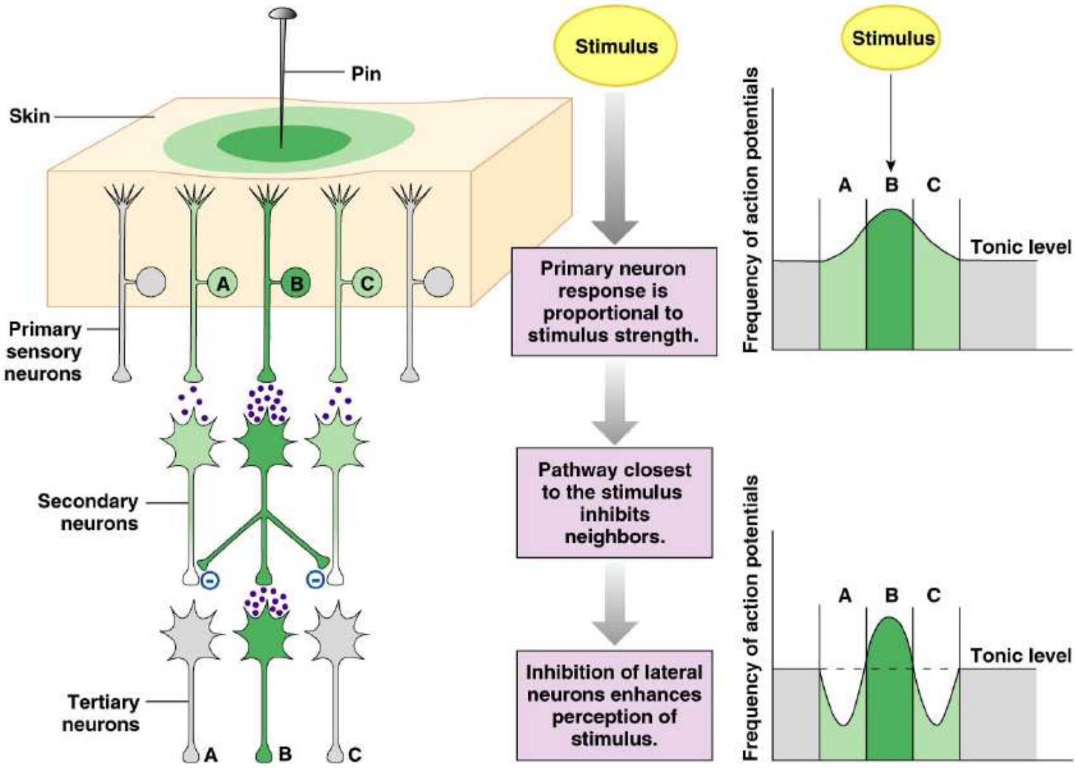
- Indicated:
  - By which sensory neurons are activated
  - By where the pathway of activated neurons terminate in brain
- Each receptor type is most sensitive or specific to a particular modality of stimulus
  - E.g. some neurons respond more to touch, others to changes in temp
- Each sensory modality can be subdivided
  - E.g. colour vision detected by red, blue and green wavelengths
- **Labeled line coding**
  - The brain associates a signal coming from a specific group of receptors with a specific modality
  - 1:1 association of receptor with sensation
    - e.g. stimulation of a cold receptor will always be perceived as cold

Location

- The location of a stimulus is coded according to which receptive fields are activated
- Sensory regions of cerebrum are highly organised with respect to incoming signals
  - Input from adjacent sensory receptors is processed in adjacent regions of the cortex

        - E.g. touch receptors in the hand project signals to a specific area of the cerebral cortex
- Stimulation of that part of the cerebral cortex during brain surgery is interpreted as a touch to the hand, even if there was no contact
- Phantom pain occurs when secondary neurons in spinal cord become hyperactive resulting in the sensation of pain in limb that is no longer there
- Auditory information is an exception
    - Neurons in ear sensitive to different frequencies, have no receptive fields and provide no information about the location of the sound
    - Difference in time it takes for sound stimuli to reach the two sides of the auditory cortex is registered by brain and used to compute the sounds source
        - Sound from directly in front will reach ears simultaneously
        - Sound placed off to one side will reach the closer ear several milliseconds before
- Brain uses timing differences rather than specific neurons to localise sound

- **Lateral inhibition** → Increases contrast between activated receptive fields and inactive neighbours and so isolates the location of the stimulus
    - Used in visual system to sharpen edges
- E.g. pressure stimulus to the skin:
    - Pin pushing on skin activates 3 primary sensory neurons
    - Each release neurotransmitters onto secondary neuron
    - Not all respond in the same way
        - Neuron B (closest to stimulus) suppresses the response of the lateral neurons, where the stimulus is weaker ∴ allowing its own pathway to proceed without interference
            - Inhibition of lateral neurons = more localised sensation



- Also demonstrates population coding → multiple receptors functioning together to send the CNS more info

Intensity

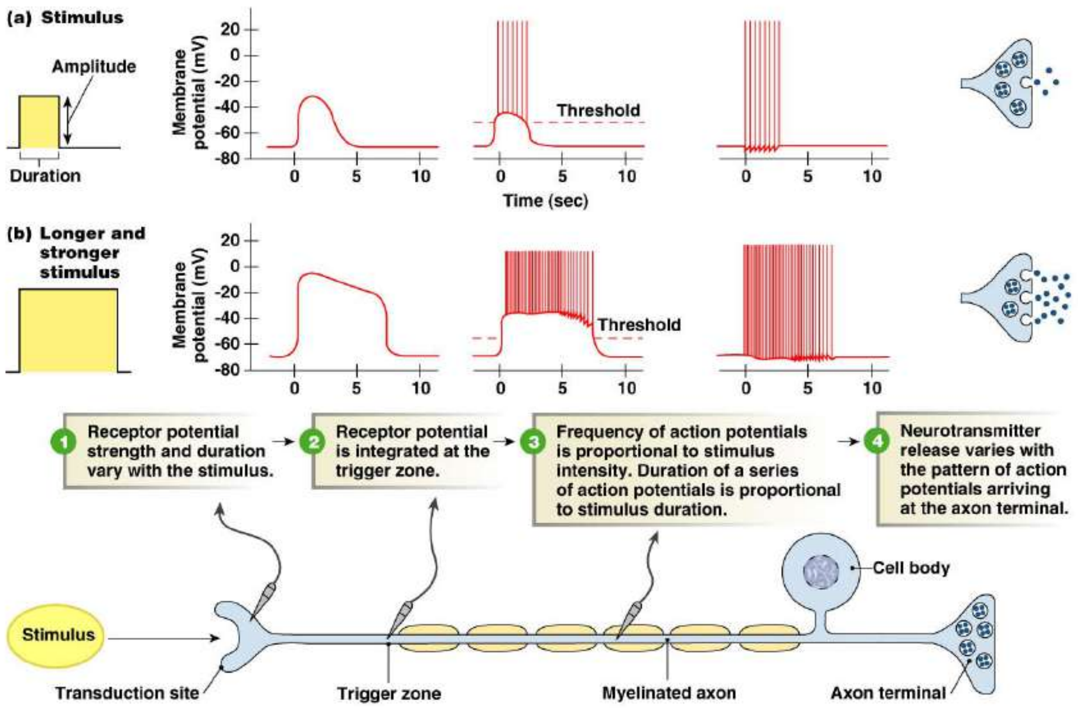
- Coded by:
  - Number of receptors activated (population coding)
  - Frequency of action potentials coming from those receptors (frequency coding)
- Population coding for intensity occurs because not all receptors have the same threshold to their preferred stimulus
  - E.g. only most sensitive receptors respond to low threshold intensity
- ↑ stimulus intensity = ↑ receptors activated
- CNS translates the number of active receptors into a measure of stimulus intensity

Properties of Stimulus

- Once stimulus reaches threshold action potentials fire
- As stimulus intensity increases, the receptor potential amplitude (strength) increases in proportion and the frequency of action potentials in the primary sensory neurons increases up to a maximum rate
- Receptor potential is an initial response of a receptor cell to a stimulus, consisting of a change in voltage across the receptor membrane proportional to the stimulus strength
- The intensity of the receptor potential determines the frequency of action potentials travelling to the nervous system

Duration of Stimulus

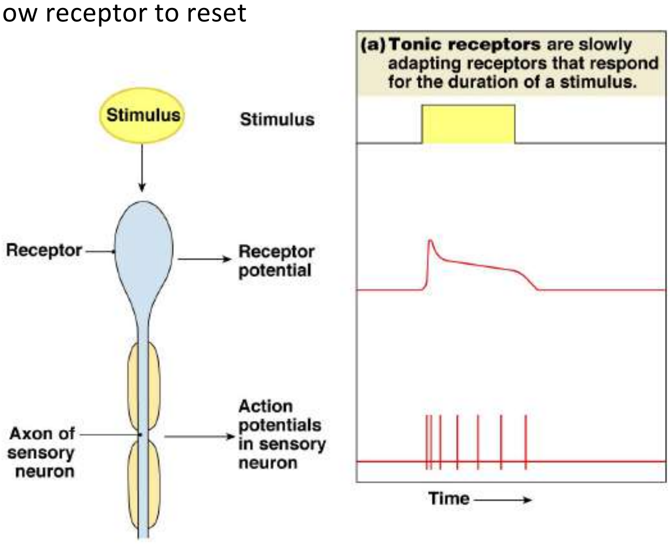
- Coded by duration of action potentials
  - Longer stimulus = longer series of action potentials in the primary neuron
- However, some receptors can **adapt** or cease to respond

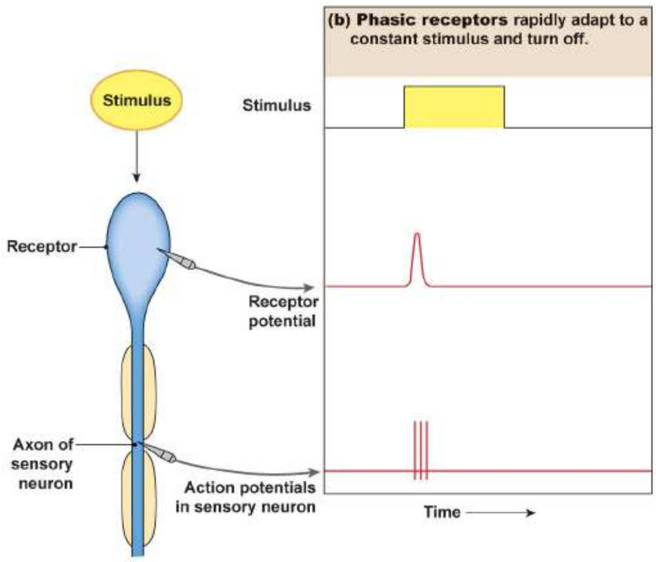


Tonic and Phasic Receptors

- Receptors fall into 2 classes depending on how they adapt to continuous stimulation
  - In some receptors, K+ channels open = repolarisation, in others, Na+ channels inactivate

- Tonic receptors:
  - Slowly adapting → fire rapidly when first activated, then slow and maintain their firing as long as the stimulus is present
    - E.g. baroreceptors, irritant receptors, tactile receptors, proprioceptors (generally parameters under constant monitoring)
- Phasic receptors:
  - Rapidly adapting → fire when they first receive a stimulus but cease firing if the strength of the stimulus remains constant
    - E.g. sense of smell. Can smell cologne in the morning when applied but as day goes by olfactory receptors adapt
  - Allows the body to ignore info that has been evaluated as not being a threat to homeostasis
  - Only way to create new signal → increase intensity or remove stimulus and allow receptor to reset





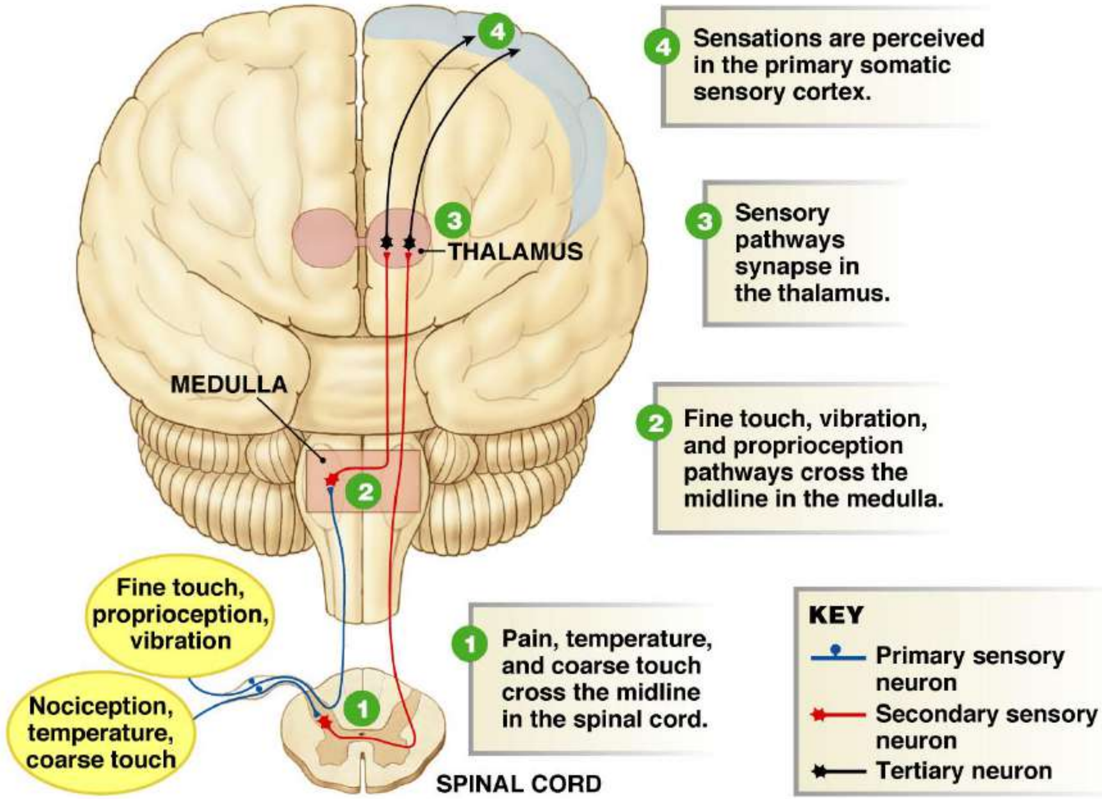
- Accessory structures → may decrease the amount of stimulus reaching a receptor
  - E.g. tiny muscles in ear contract + dampen vibration of ossicles in response to loud sounds = ↓ sound signal before reaching auditory receptors

Somatic Senses: Modalities

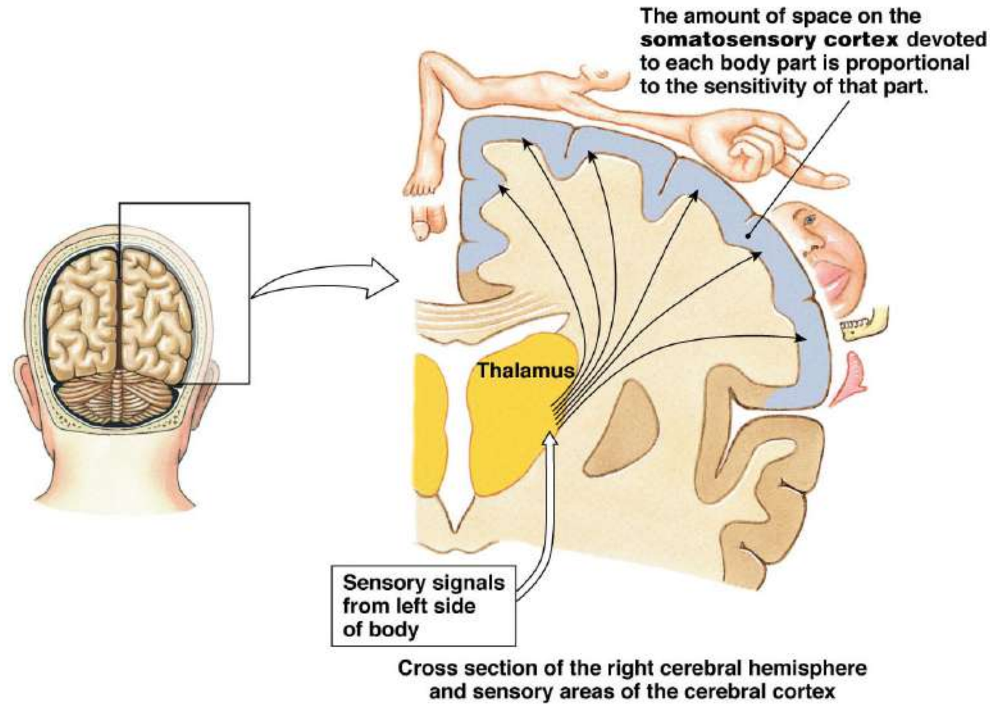
- Touch

- Proprioception – tells brain information about location of limbs in space. Muscle spindles and Golgi tendons inform about muscle length and tension
- Temperature
- Nociception
    - Pain
    - Itch

Somatic Senses: Pathways

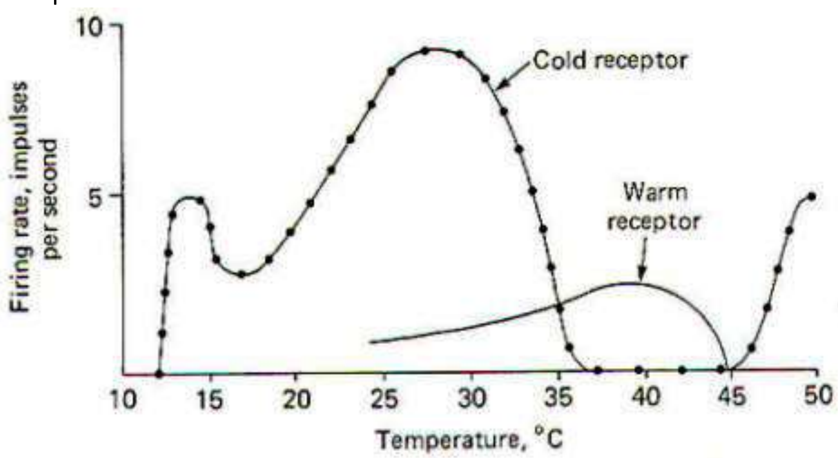


The Somatosensory Cortex → part of the brain that recognises where ascending sensory pathways originate



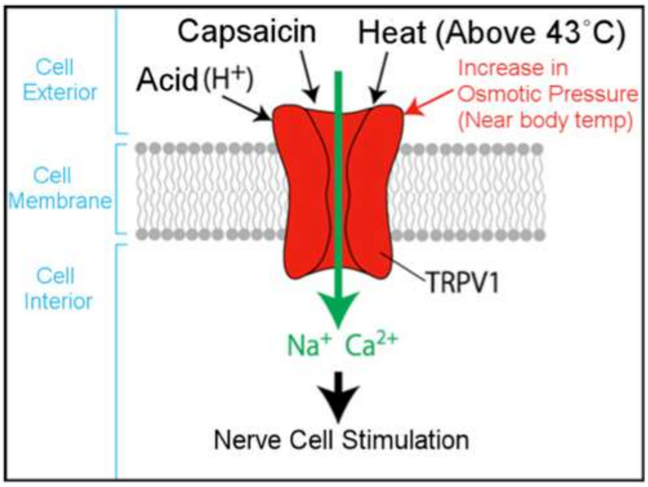
Temperature Receptors

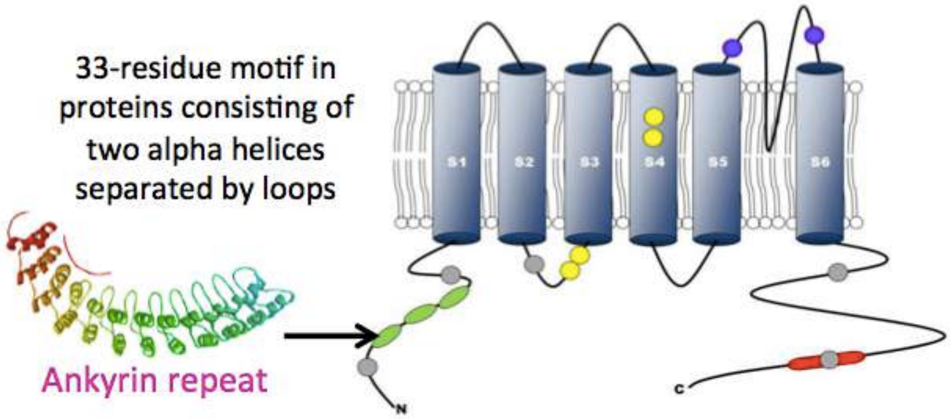
- Free nerve endings that terminate in subcutaneous layers of skin
- *Heat receptors* start to perceive heat above 30°C and continue to perceive heat until the maximum receptor stimulation which occurs at 45°C
    - Over 45°C, pain receptors take over to avoid damaging the skin and body
- *Cold receptors* only start to perceive cold below 35 °C
    - Normal core body temperature is 37 °C
    - So you start to feel cold pretty quickly
- There is obviously a 5° cross-over where both hot and cold receptors are operating
- Temperature receptors slowly adapt between 20-40°C and their sustained response tells us about the ambient temperature
- Outside this range, where the likelihood of tissue damage is high, the receptors do not adapt



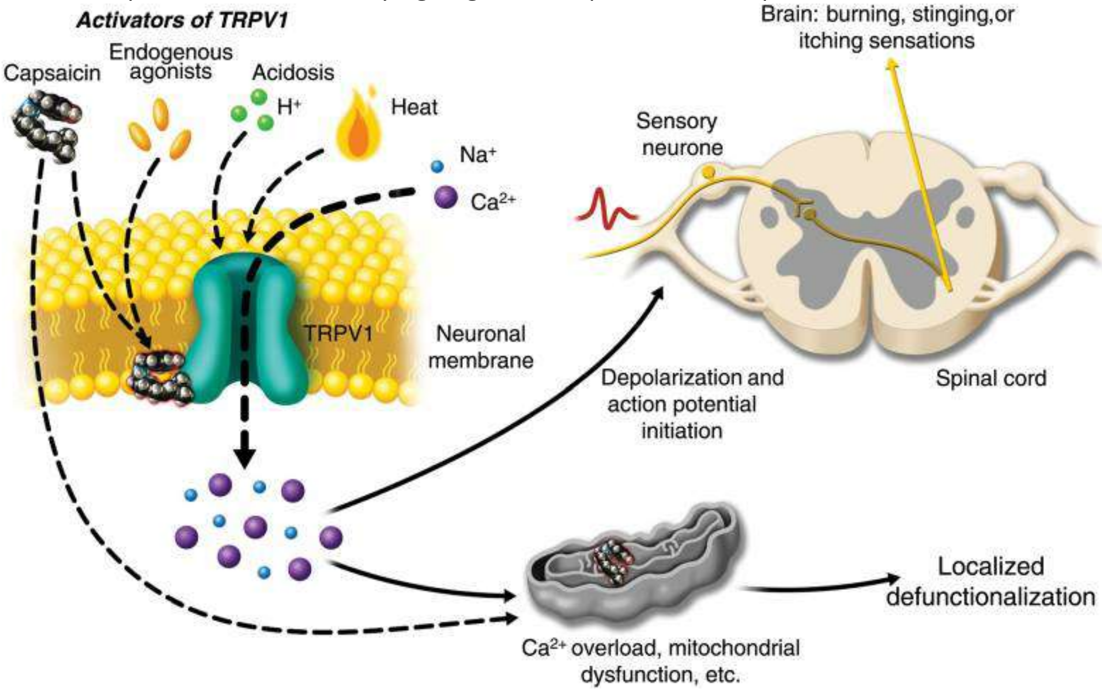
TRPV1 (Vanilloid Receptor)

- Responsible for detection and regulation of body temperature
- Provides sensation of scalding heat and pain (nociception)





- Capsaicin inhibits to varying degrees complex I and complex III of the electron chain



Cold Receptor

- The transduction of temperature in cold receptors is mediated in part by the TRPM8 channel

- This channel passes a mixed inward cationic (predominantly carried by Na^+ ions although the channel and is also permeable to Ca^{2+}) current of a magnitude that is inversely proportional to temp
  - The channel is sensitive over a temperature range spanning about 10-35°C
- TRPM8 can also be activated by the binding of an extracellular ligand
  - Menthol can activate the TRPM8 channel in this way
  - Since the TRPM8 is expressed in neurons whose physiological role is to signal cooling, menthol applied to various bodily surfaces evokes a sensation of cooling
- The feeling of freshness associated with the activation of cold receptors by menthol, particularly those in facial areas with axons in the trigeminal (V) nerve, accounts for its use in numerous toiletries incl. toothpaste, shaving lotions, facial creams etc.

Nociceptors (Pain Receptors)
- Free nerve ending of sensory neuron
- Many stimuli have been found to activate ion channels present on nociceptor terminals that act as molecular transducers to depolarise these neurons, thereby setting off nociceptive impulses along the pain pathways
- Respond to strong noxious stimulus that may damage tissue
  - Chemical, thermal (heat) or mechanical
- TRPV1 → Ion channels are non selective cation channels (mainly Na)
  - Found on nerve endings and mediate a pain response
  - These respond to heat e.g. stove and capsaicin in hot chilli peppers
  - Nociceptor activation is modulated by local chemicals that are released upon injury
    - E.g. histamine, prostaglandins, serotonin, platelets, substance P
    - i.e. mediate inflammatory response
  - These chemicals can activate the pain receptors or sensitise them by lowering their activation of threshold
  - Inflammatory pain → increased sensitivity to pain at sites of tissue damage
- Nociceptors activate 2 pathways
  - Reflexive protective response
    - Integrated in spinal cord
    - Withdrawal reflex
  - Ascending pathway to cerebral cortex
    - Becomes conscious sensation (pain or itch)

Somatosensory Nerve Fibers

TABLE 10-5 Classes of Somatosensory Nerve Fibers

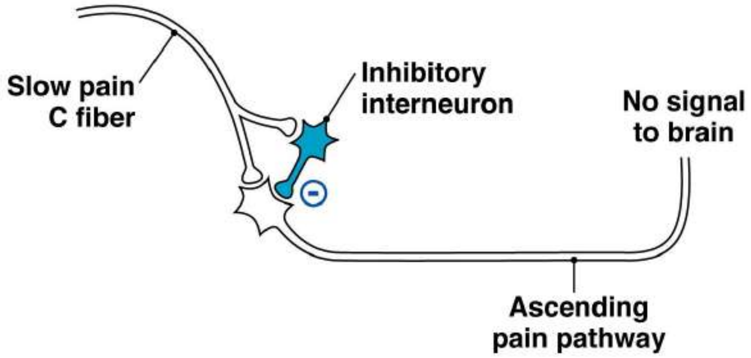
FIBER TYPE	FIBER CHARACTERISTICS	SPEED OF CONDUCTION	ASSOCIATED WITH
Aβ (beta)	Large, myelinated	30–70 m/sec	Mechanical stimuli
Aδ (delta)	Small, myelinated	12–30 m/sec	Cold, fast pain, mechanical stimuli
C	Small, unmyelinated	0.5–2 m/sec	Slow pain, heat, cold, mechanical stimuli

Nociceptors: Pain and Itch
- Itch (puritis)
  - Receptors in skin
  - Histamine activates C fibers causing itch

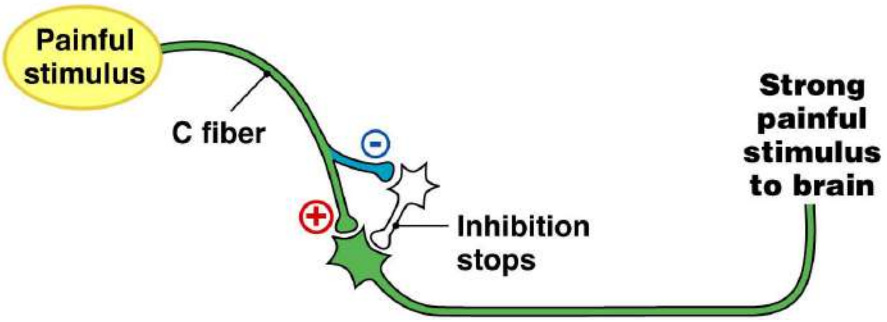
- Pain
    - Subjective perception
    - Fast pain
        - Sharp and localised → by Aδ fibers
    - Slow pain
        - More dull or diffuse → by C fibers
        - E.g. stubbed toe → quick stabbing sensation (fast pain) followed shortly by dull throbbing pain (slow pain)

The Gate-Control Theory of Pain

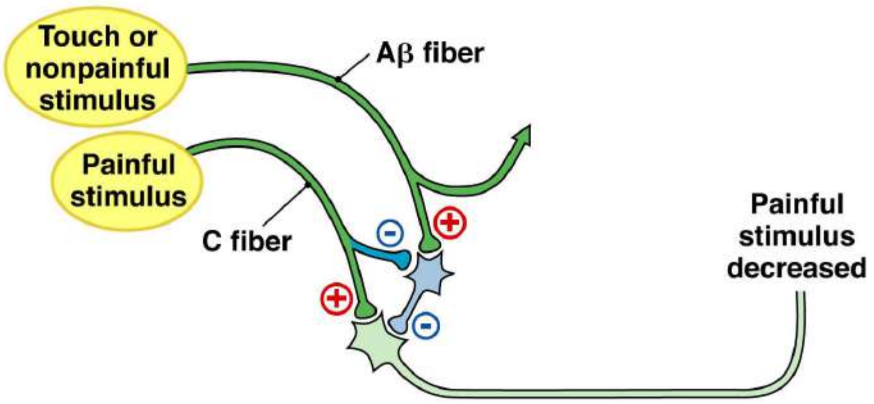
- In absence of input from C fibers, tonically active inhibitory interneuron suppresses pain pathway



- With strong pain, C fiber stops inhibition of the pathway, allowing a strong signal to be sent to the brain



- Pain can be modulated by simultaneous somatosensory input
    - This theory explains why rubbing a bumped elbow or shin lessens your pain



Referred Pain

- Occurs because multiple primary sensory neurons converge on a single ascending tract

- Brain cannot distinguish visceral signals from the more common signals arising from somatic receptors
    - ∴ it interprets pain coming from the somatic regions rather than the viscera

(b) **One theory of referred pain says that nociceptors from several locations converge on a single ascending tract in the spinal cord. Pain signals from the skin are more common than pain from internal organs, and the brain associates activation of the pathway with pain in the skin. Adapted from H.L. Fields, *Pain* (McGraw Hill, 1987).**