PHSL2101 - PHSL2121 - PHSL2501 Dr Richard Vickery

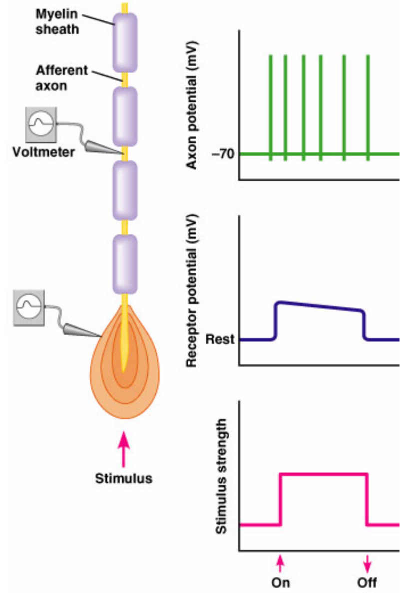
Neurophysiology 2 – Receptors & somatosensory system

Objectives

- Describe how afferent type, location and activity encodes the properties of a skin stimulus.
- Provide an example of each of the receptors and afferents used to signal touch, pain and temperature.
- Outline the dorsal column/medial-lemniscal and spinothalamic pathways to somatosensory cortex.

Transduction and encoding

Receptors transduce a stimulus to a change in membrane potential



from Germann & Stanfield, Principles of Human Physiology

Stimulus

↓

Change in ionic permeability of receptor cell or afferent nerve ending

↓

Change in membrane potential: the receptor potential

↓

Generation of action potentials in afferent nerve terminal if potential crosses threshold

↓

Propagation of action potentials to CNS

Transduction and encoding

Job description of sensory system

There are three major questions that the sensory system has to be able to answer about a stimulus.

1. What is the stimulus? *Is it hot or painful?*
2. Where is the stimulus? *Is it on the toe or the ankle?*
3. What is the intensity and duration of the stimulus? *Is it light or heavy?*

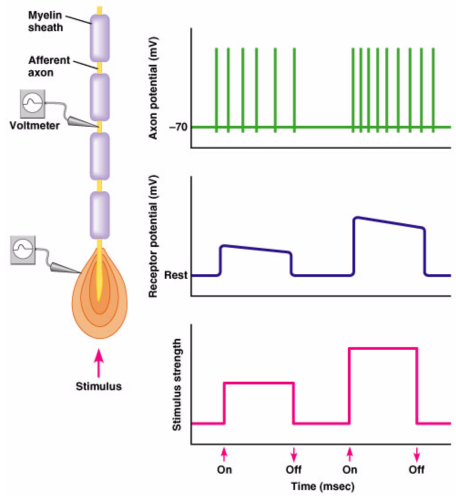
The answer to these questions come from:

1. afferent type: modality
2. afferent location: somatotopy of receptive fields
3. afferent activity: rate code

Extension in time and space (population code) provides a complete description of the stimulus.

Transduction and encoding

Rate coding of stimulus intensity

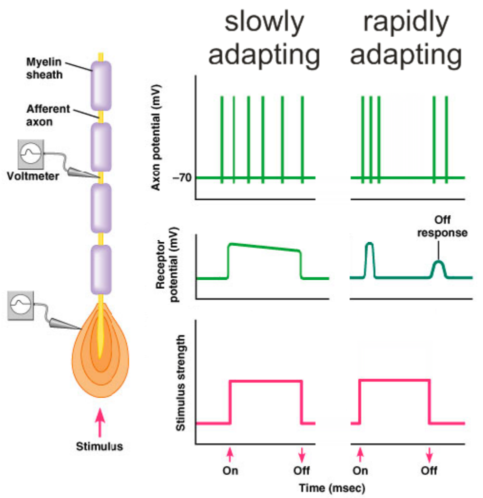


The rate of generation of action potentials depends on the amount of depolarization. Stronger depolarization causes a new action potential earlier in the relative refractory period of the previous action potential.

Adaption is the term to describe the gradual reduction in the response of a neuron to a sustained stimulus. Adaptation usually has a physical basis in the receptor such as photoreceptor bleaching in the retina, or fluid displacement inside touch receptor capsules.

from Germann & Stanfield, Principles of Human Physiology

Duration can be coded in two ways



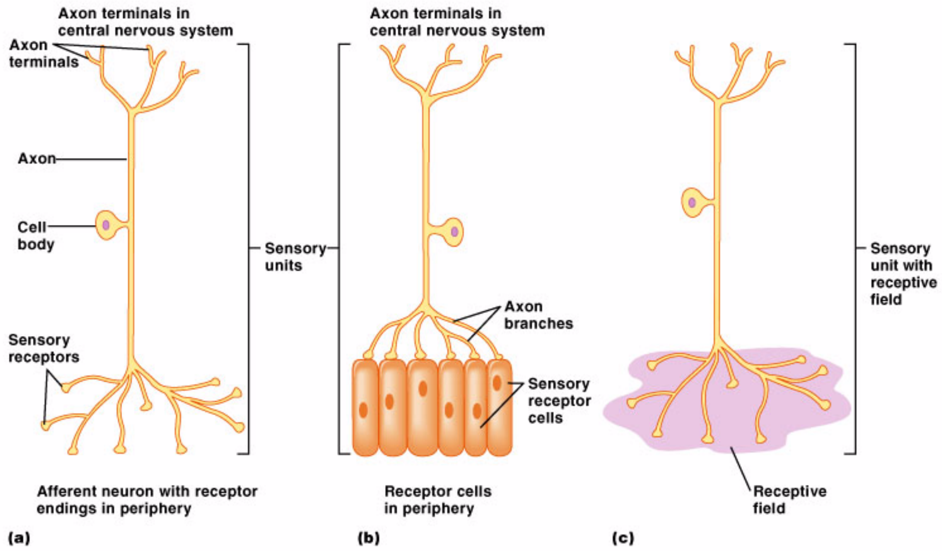
The rate of adaption is usually determined by receptor properties.

Rapidly adapting receptors are good for signalling change such as movement. *Semi-circular canals, many touch receptors.*

Slowly adapting receptors are good for signalling intensity of a steady stimulus. *Joint receptors, otolith organs.*

adapted from Germann & Stanfield, Principles of Human Physiology

Receptive field: region of the stimulus space that activates a neuron

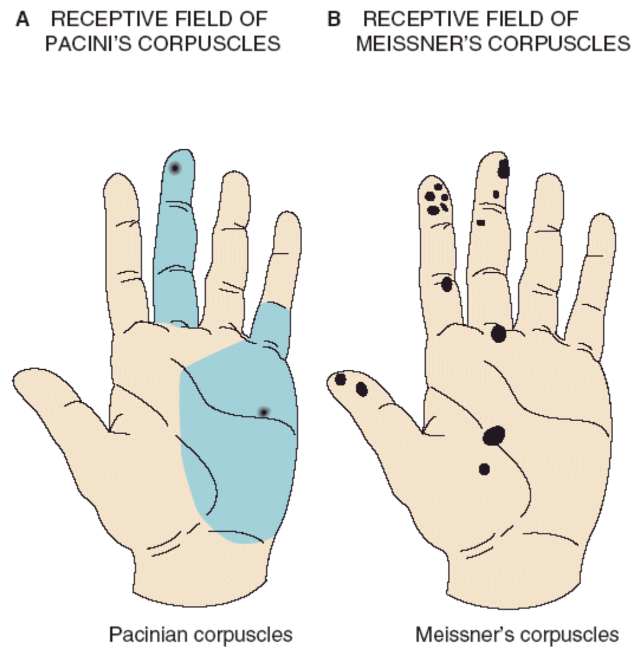


from Germann & Stanfield, Principles of Human Physiology

Receptive fields

- The receptive field is an essential concept in sensory neuroscience.
- Every sensory neuron is best activated by a particular stimulus. The spatial location where that stimulus needs to be applied is called the “receptive field”. All sensory neurons, from those in the periphery to those in cortex, will have a receptive field.
- In somatosensory system the receptive fields are regions of the skin, or parts of deeper tissue such as muscle.
- In the visual system the receptive field is a region of visual space.
- A touch receptor can have a receptive field much bigger than the physical size of the receptor. This occurs if the receptor is so sensitive that touch at a remote location on the skin still activates the receptor.
- Strictly speaking, the receptive field of a neuron should be specified for a particular stimulus type and intensity.

Receptive fields of tactile afferents



from Boron and Boulpaep, Medical Physiology

Modalities

Somatosensory Modalities

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

Aβ fibres: large myelinated; 30-70 ms^{-1}

- **tactile.** Sub-modalities include hair afferents, Pacinian corpuscles, Merkel discs.
- **proprioception.** Limb and joint position (or movement which is **kinaesthesia**). Receptors include: spindle afferents, Golgi tendon organs, joint receptors.

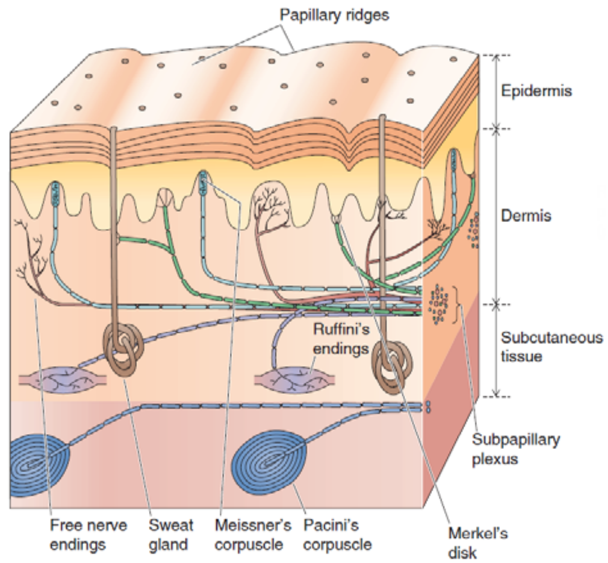
Aδ fibres: small myelinated; 5-30 ms^{-1}

C fibres: unmyelinated; 0.5-2 ms^{-1}

- **thermal.** Sub-modalities: hot and cold receptors.
- **pain.** Sub-modalities are a nociceptors responding to mechanical, chemical or thermal stimuli.

Modalities

Receptors in the skin



glabrous skin is 'finger print' skin found on the fingers and palm.

from Boron & Boulpaep, Medical Physiology, Elsevier

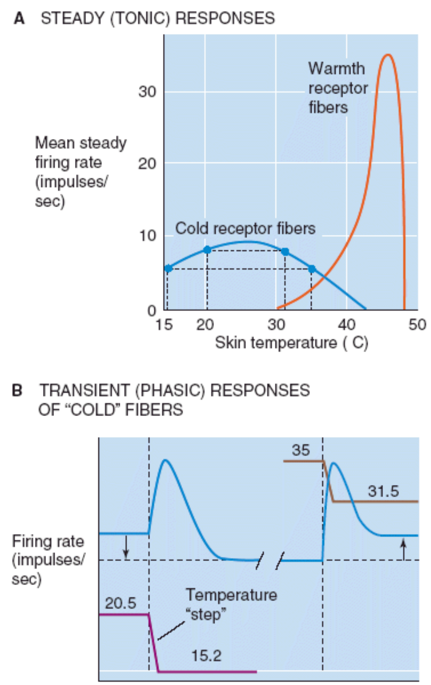
Modalities

Human tactile receptors

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

Modalities

Responses of thermoreceptor fibres



There are cold receptors, with Aδ axons; and warm receptors, with C axons.

from Boron and Boulpaep, Medical Physiology

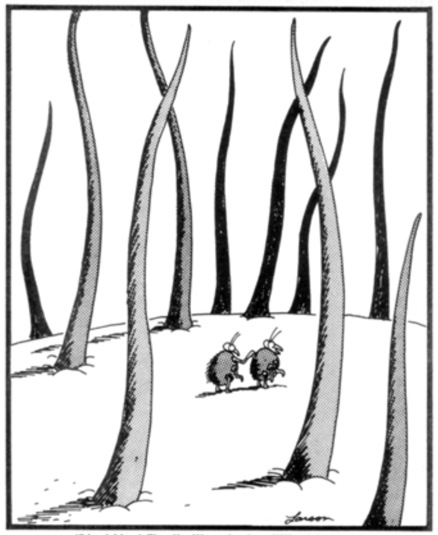
Modalities

Potential ambiguity in rate coding by a single afferent

- The thermoceptive system raises an important question in neural coding. W*hy do we need two types of fibres (warm and cold)?*
- Temperature appears to be encoded in a rate code by the thermoceptive afferents.
- The temperature-response rate curves shown on the previous slide are roughly parabolic with a peak in the middle. This means that a given firing rate in a single afferent can be produced by two different temperatures: one above the mid-point and one below the mid-point. Hence with just one afferent type there is ambiguity about exactly what temperature we are experiencing: is it the one above the mid-point or the one below mid-point?
- Using two different fibres helps solve the ambiguity problem because we now have a firing rate in each fibre type, and considered together, their firing rates uniquely specify the temperature.
- In addition, the phasic responses let us track changes in the skin temperature.

Modalities

Pain is a distinct sense


"Yes! Yes! That's it! ... Just a little higher."

Somatic/skin pain
- fast pricking pain
  readily localized
  Aδ fibres
- slow burning pain/itch
  poorly localized
  C fibres

Deep/visceral pain
- pain with a dull or diffuse character. Mainly C fibre.

Modalities

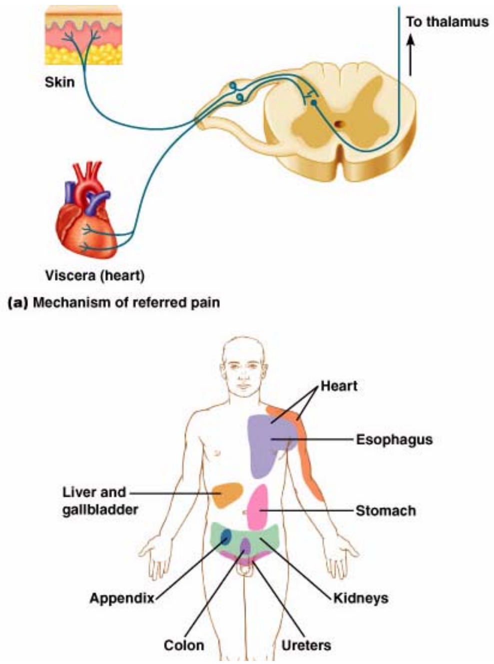
Pain receptors

Pain receptors (nociceptors) are free nerve endings.
Classified by stimulus sensitivity as **mechanosensitive**, **thermosensitive**, **chemosensitive** and **polymodal**

Projected pain - the site at which the noxious stimulus acts is not that at which the pain is sensed. *Phantom limbs*
Referred pain - nociceptive stimulation of the viscera often produces sensation of pain not in the affected organ but rather in distant superficial structures. *Heart attack*

Modalities

Referred pain from the viscera



(a) Mechanism of referred pain

from Germann & Stanfield, Principles of Human Physiology

Modalities

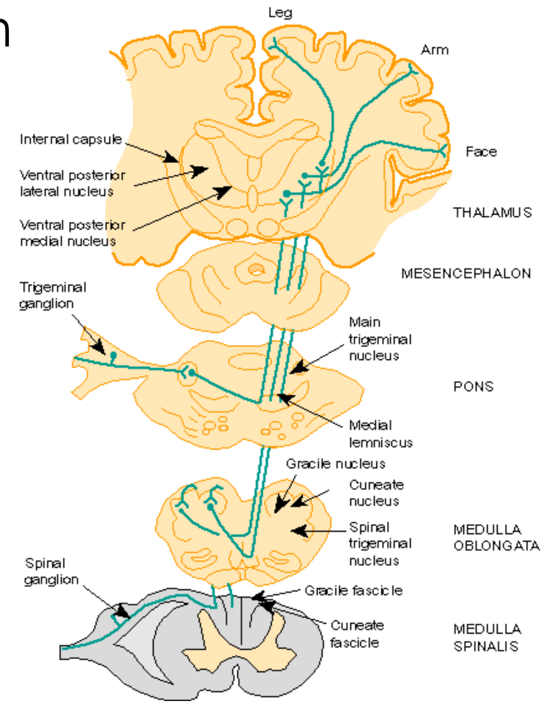
Referred pain

- Referred pain occurs because of “economies” in the design of the pain pathways.
- Most pain arises in the skin, such as when we are crushed / cut / bitten / burnt; pain in our internal organs (viscera) is less common.
- The viscera have their own pain receptors. This is essential as otherwise we would be unaware of problems such as infection. However having neurons at spinal cord, thalamus, and cortex sitting waiting for a very rare event is inefficient.
- Therefore the visceral nociceptors converge onto neurons in the spinal cord that are also used by skin nociceptors. Cortex has learned that the skin is the usual source of pain along this pathway, and hence pain from the viscera is referred to the skin site providing the converging input.
- The *gate theory* of pain shows that innocuous tactile stimuli can inhibit propagation of nociceptive stimuli, so rubbing the skin can help reduce the pain from visceral receptors like giving a neck massage to help relieve the pain from a head ache.

Pathways

Tactile system

Tactile & proprioceptive afferents travel in the ipsilateral dorsal column. Decussate at medulla and form medial lemniscus.

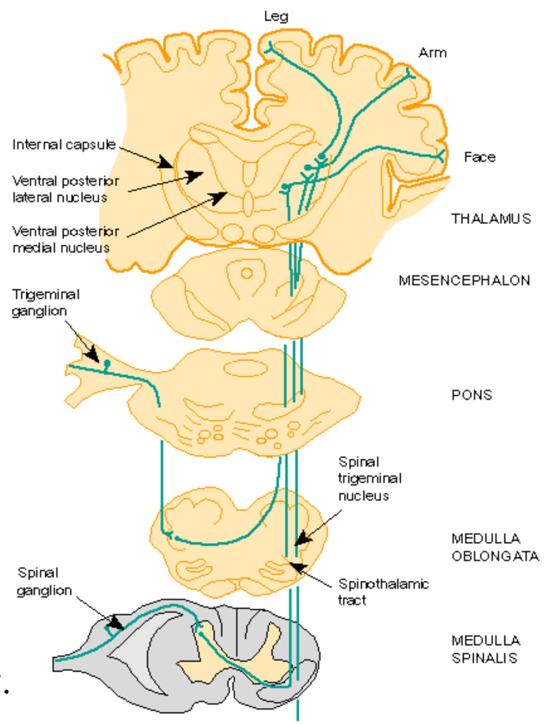


from Pocock & Richards, Human Physiology

Pathways

Pain and Temperature

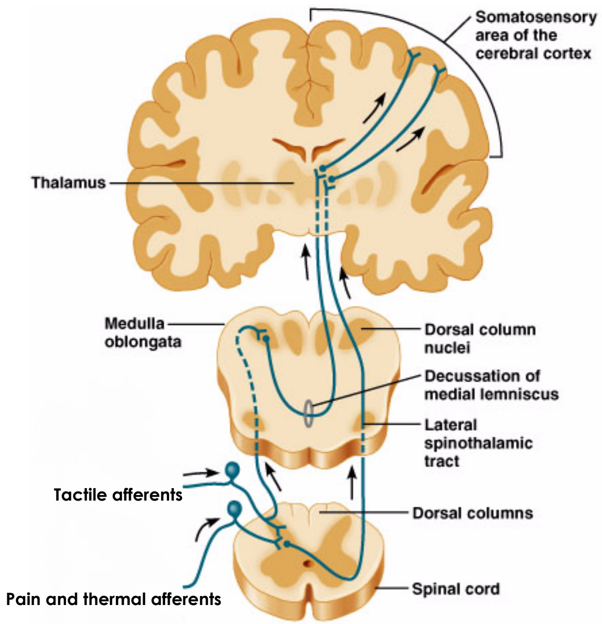
Pain, temperature and crude touch synapse in the spinal cord. Decussate and travel in the contralateral spinothalamic tract.



from Pocock & Richards, Human Physiology

Pathways

Spinal hemi-lesions may affect contralateral & ipsilateral

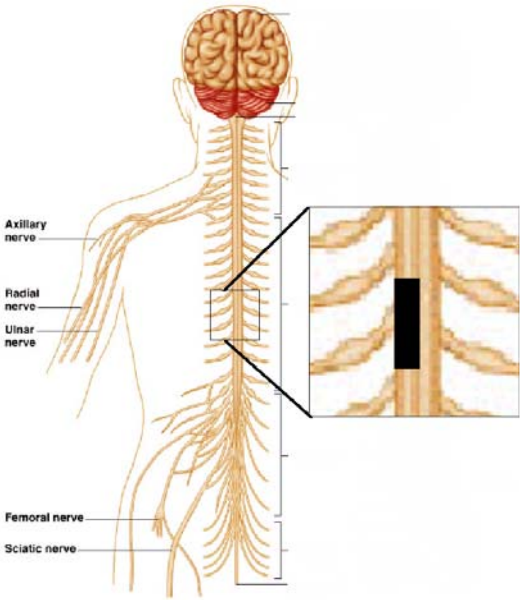


Because pain and touch travel on opposite sides of the spinal cord, it is possible to have spinal cord damage where a patient may only be able to feel touch stimuli in one leg, but they cannot detect painful stimuli in that leg (and they will have the opposite signs in the other leg).

from Germann & Stanfield, Principles of Human Physiology

Pathways

Spinal hemi-lesions may affect contralateral & ipsilateral differently



A lesion affecting the left half of the spinal cord at around level T9 will cause:

- no change for upper limb sensation
- loss of touch and proprioceptive sensation from the left leg
- loss of pain and temperature sensation from the right leg

from Germann & Stanfield, Principles of Human Physiology