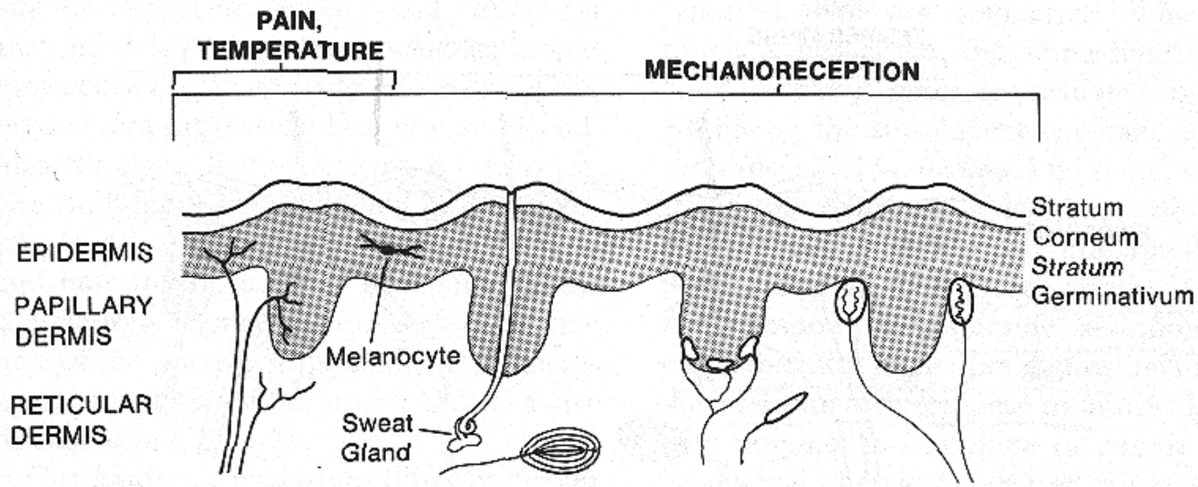
The somatic senses

The Greek word for body is soma and the sensory modalities that are signaled by the receptors at the body surface are referred to as the somatic senses.

Main modalities	Form of energy
-touch	- mechanical
-pressure	- thermal
-heat and cold	- chemical
-pain	

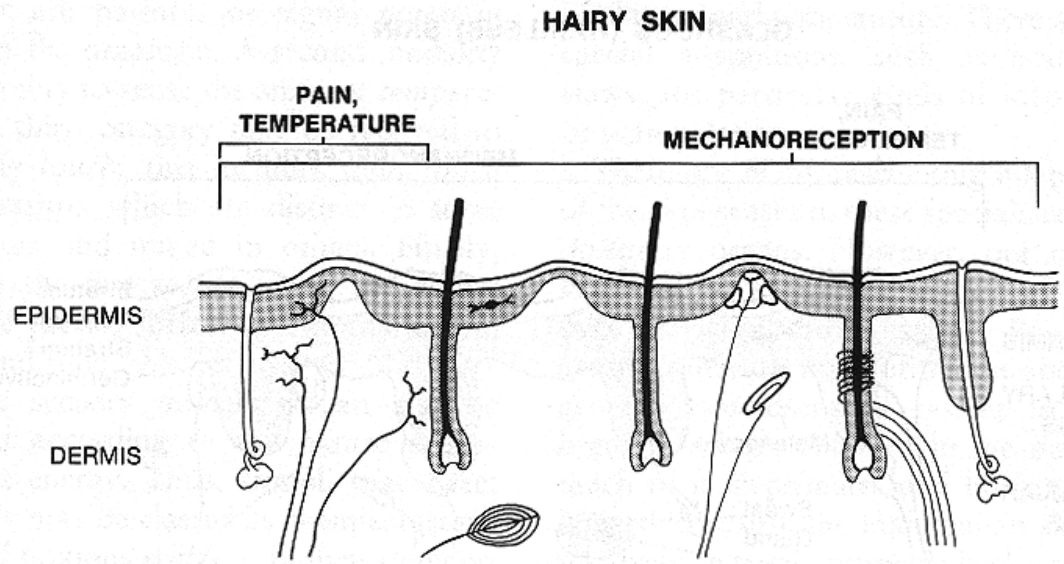
Sensory receptors in the glabrous skin

GLABROUS (HAIRLESS) SKIN



	FREE NERVE ENDINGS	PACINIAN CORPUSCLE	MERKEL'S DISCS (RUFFINI ENDINGS)	MEISSNER'S CORPUSCLE	
A-beta (6-12 μm, 30-70 m/s)	———	Pressure, Vibration (250-300 Hz) (Tickle?)	Touch, Pressure	Touch, Vibration (30-40 Hz)	Stimuli
A-delta (1-5 μm, 5-30 m/s)	Cooling, Pricking Pain	———	———	———	Stimuli
C (0.2-2 μm, 0.5-2 m/s)	Warming, Burning Pain, Itch	———	———	———	Stimuli
ADAPTATION	Very Slow	Very Fast	Slow	Fast	
MODALITY	Temperature, Pain	Touch-vibration (Acceleration Detector)	Touch-pressure (Velocity and Intensity Detector)	Touch-flutter (Velocity Detector)	

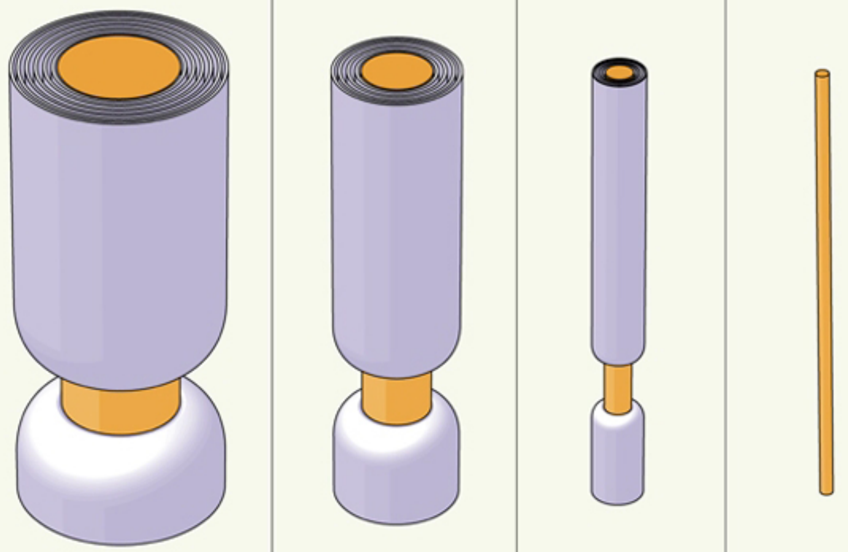
Sensory receptors in the hairy skin



	FREE NERVE ENDINGS	PACINIAN CORPUSCLE	MERKEL CELLS PINCUS DOMES (RUFFINI ORGANS)	HAIR FOLLICLE ENDINGS
A-beta	—	Pressure, Vibration (250-300 Hz) (Tickle?)	Touch, Pressure	Light Touch, Vibration (30-40 Hz)
A-delta	Cooling, Pricking Pain	—	—	—
C	Warming, Burning Pain, Itch	—	—	—
ADAPTATION	Very Slow	Very Fast	Slow	Fast
MODALITY	Temperature, Pain, Mechanoreception	Touch-vibration (Acceleration Detector)	Touch-pressure (Velocity and Intensity Detector)	Touch-flutter (Velocity Detector)

Fiber groups

Axons from skin	Aα	Aβ	Aδ	C
Axons from muscles	Group I	II	III	IV

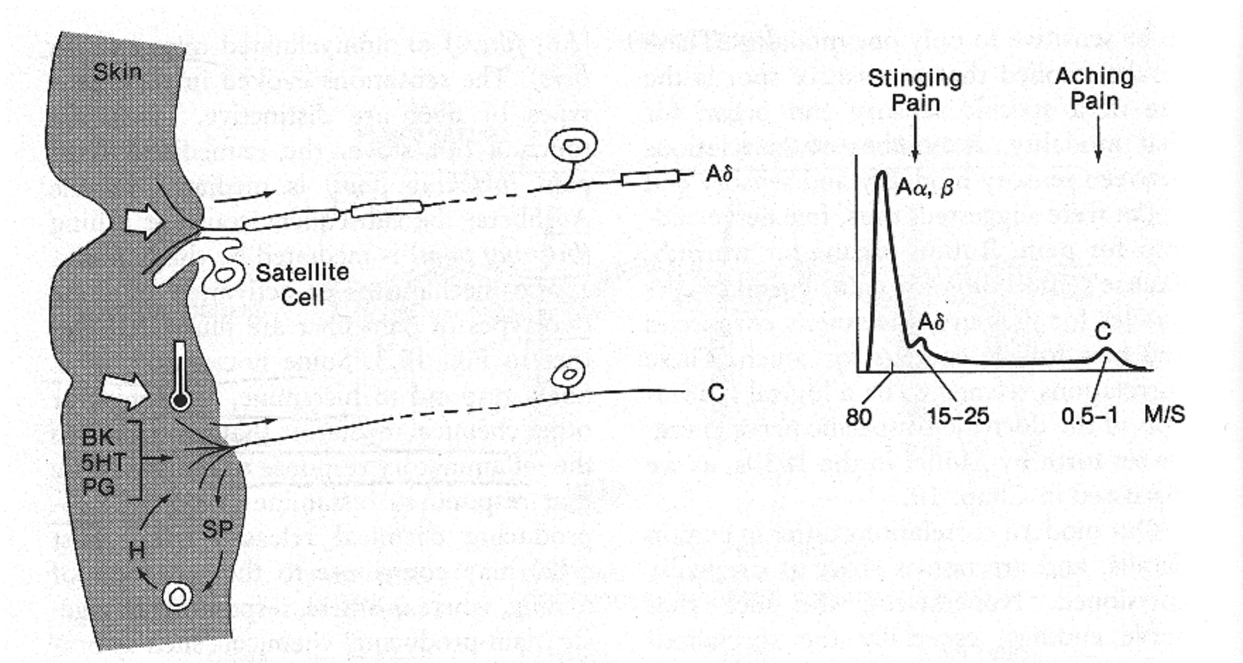


Diameter (µm)	13–20	6–12	1–5	0.2–1.5
Speed (m/sec)	80–120	35–75	5–30	0.5–2
Sensory receptors	Proprioceptors of skeletal muscle	Mechanoreceptors of skin	Pain, temperature	Temperature, pain, itch

Free nerve endings

The simplest type of sensory receptor in the skin is the free nerve ending. They respond to:

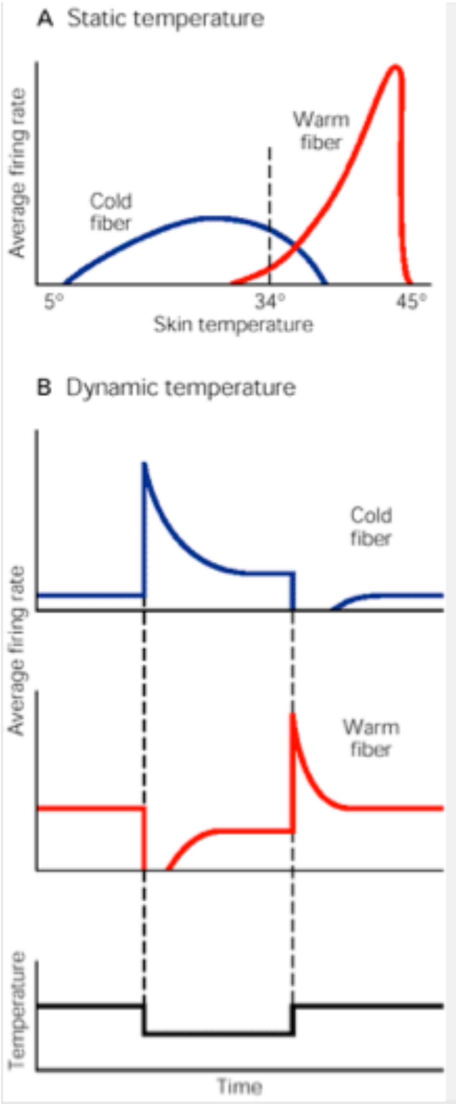
- mechanical stimuli (mechanoreceptors)
- heating and cooling (thermal receptors)
- noxious stimuli (nociceptors – pain receptors)



Activation of receptors mediating pain. Recording of the compound action potential from a peripheral nerve in response to a single electric shock, showing different components of fast conducting (Aα, β), medium conducting (Aδ) and slow conducting (C) fibers. The immediate sharp pain is mediated by Aδ fibers, the subsequent constant aching is mediated by the C fibres.

Free nerve endings – thermal receptors

Skin temperature is coded by warmth and cold receptors.

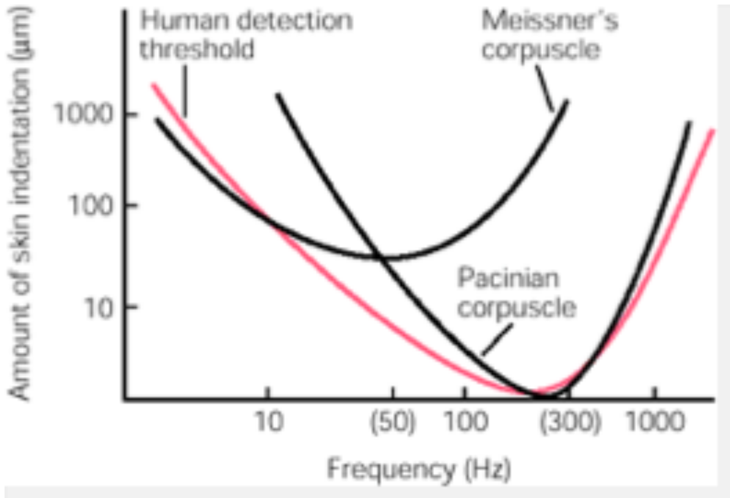


A. Static temperatures. Cooling and warming receptors are defined by the fact that they have peak sensitivities that are cooler and warmer than the skin temperature. The overlaping ranges of warming and cooling receptors are part of the mechanism for enhancing the ability to discriminate small changes in temperature near skin temperature.

B. Dynamic temperatures. Both receptors are more sensitive to **changes** in skin temperatures than to constant temperatures. Rapid changes in the skin temperature evoke dynamic response. If contact with the object is maintained for several seconds, the firing rate of the receptors drops to a lower rate. The adaptation of the spike discharge corresponds to the phenomenon of sensory adaptation.

Pacinian Corpuscle

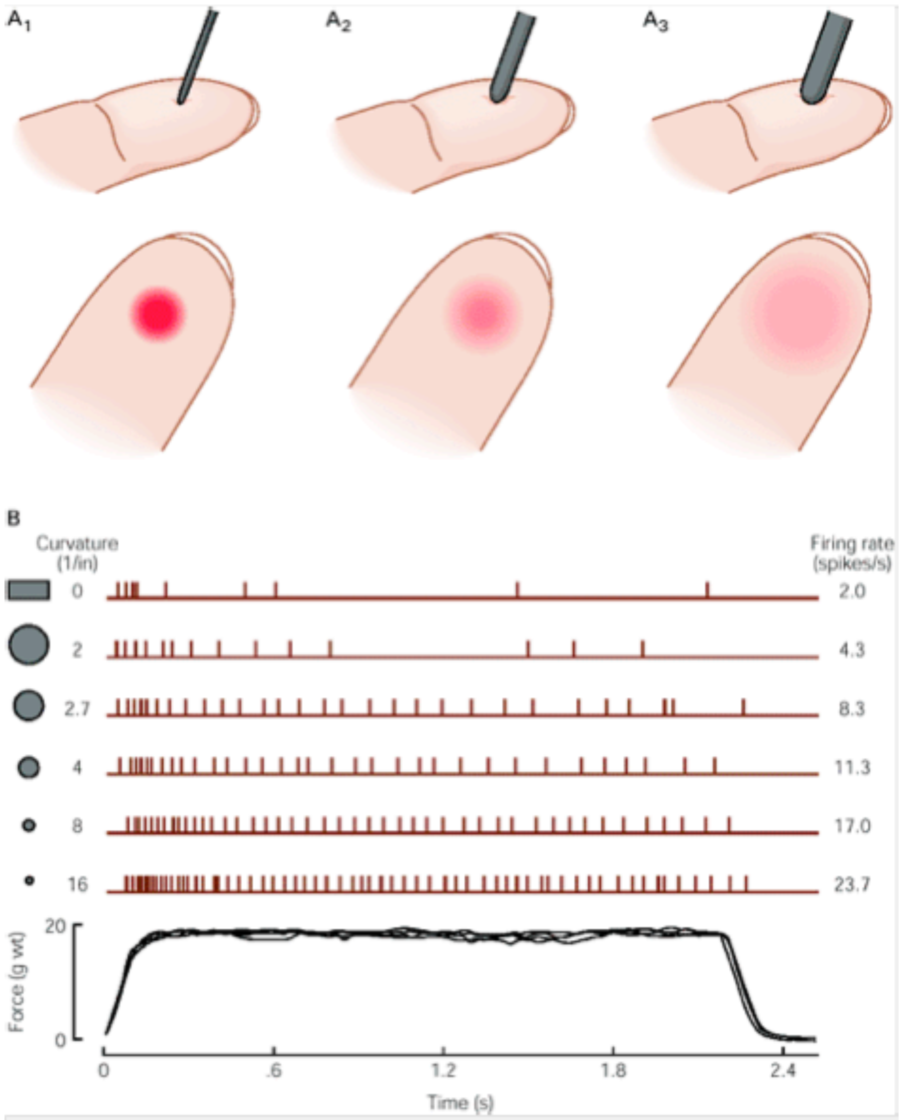
Pacinian corpuscle is one of the largest of the end organs. It is constructed to signal rapid changes in the touch and pressure.



Sensitivity of Pacinian corpuscle and Meissner's corpuscle to vibratory stimulation at different frequencies. The Pacinian corpuscle is most sensitive mechanoreceptor. The Meissner's corpuscle is particulary sensitive to abrupt changes in the shape of objects that occur at the edges or corners or small irregularities on the surface.

Merkel disk receptors

The shape and size of objects touching the hand are encoded by populations of Merkel disk receptors.

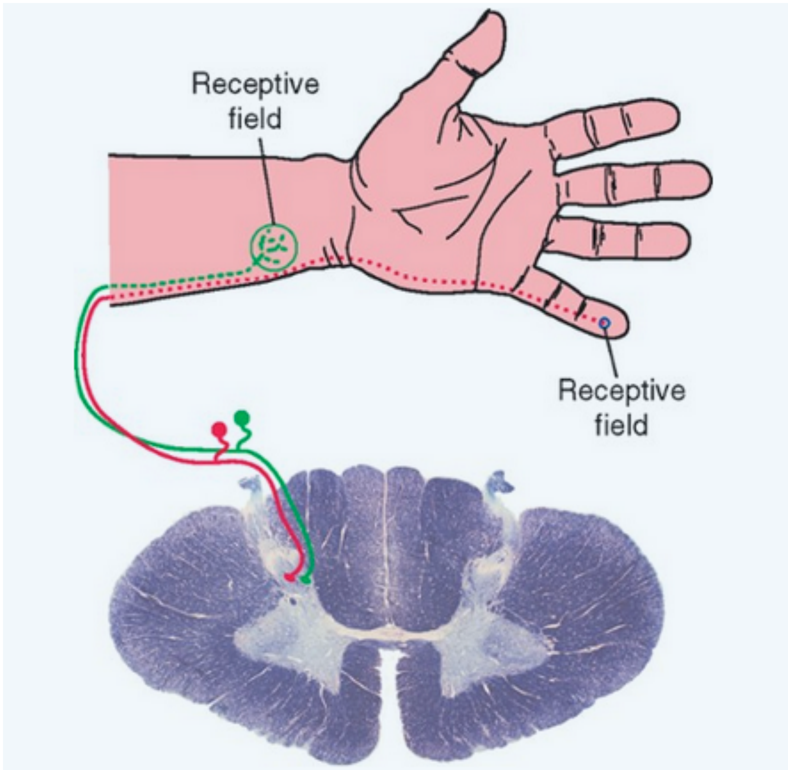


A. The area of contact with the skin determines the total number of stimulated Merkel disk receptors in the population. Sharp objects strongly activate a small population of Merkel disk receptors. Large diameter probe activates a large population of receptors firing with a low rate.

B. Responses of the individual Merkel disk receptors. The responses are proportional to the surface curvature and are slowly adapting.

Receptive field

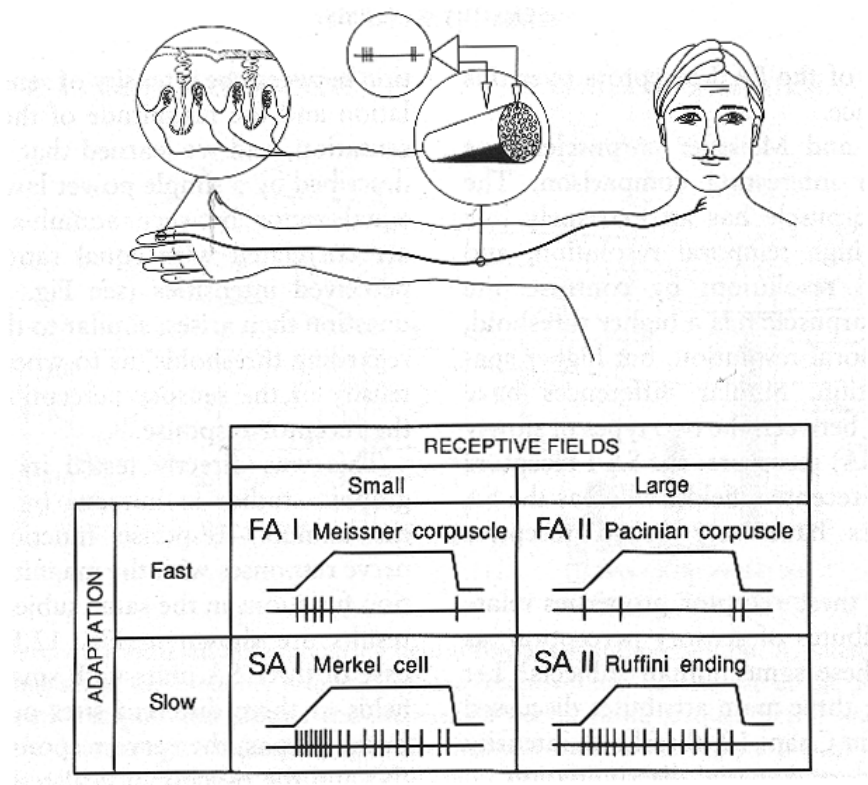
The **receptive field** of a receptor (or sensory neuron) is a region of space in which the presence of a stimulus will alter the firing of that neuron.



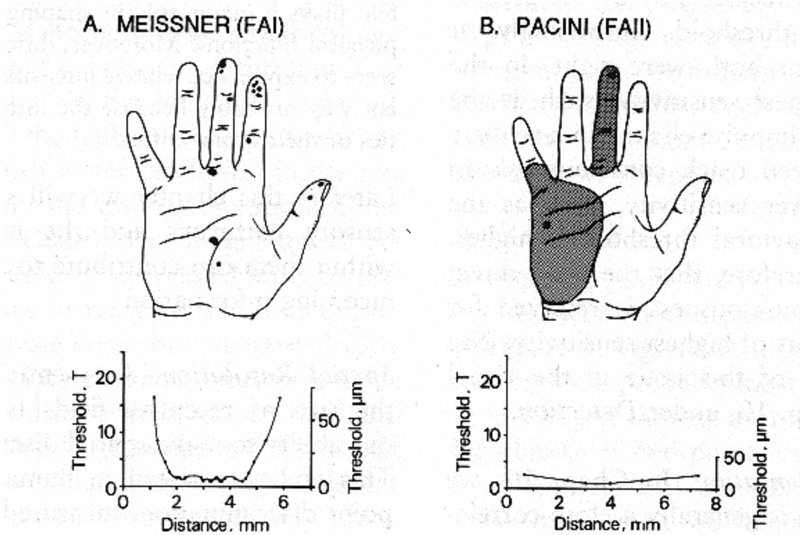
Receptive fields of two somatosensory receptors

Summary of the four main types of responses in mechanoreceptors

Two basic response properties of mechanoreceptors are rate of adaptation and size of receptive field.

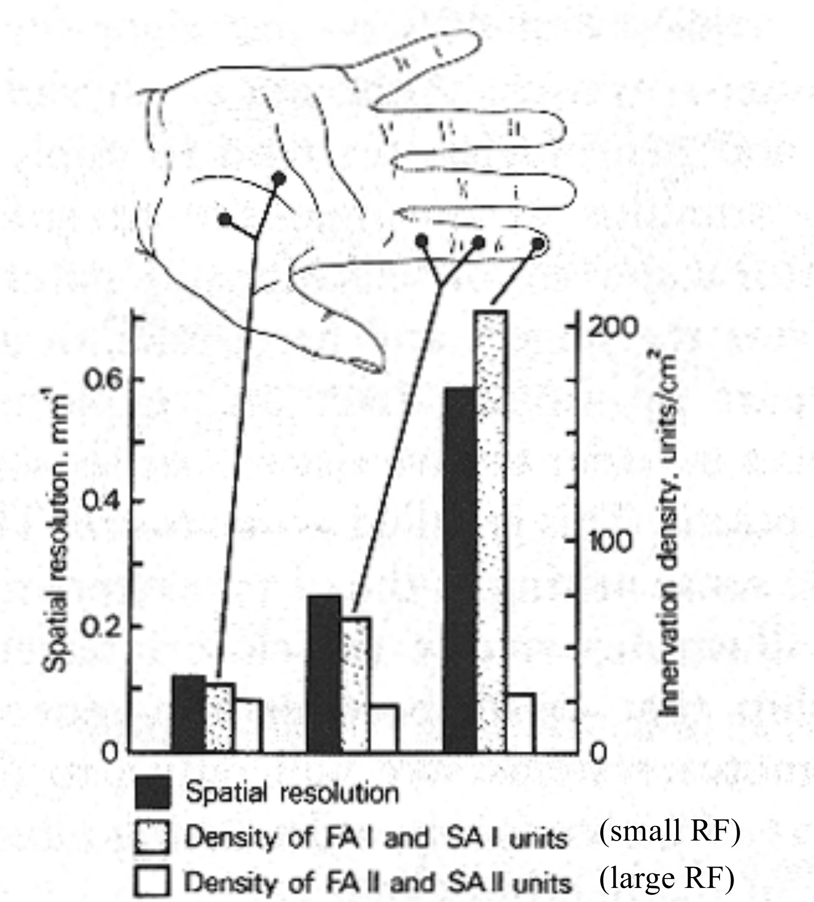


The adaptation of the tactile receptors falls into two groups, fast (FA) or slowly (SA) adapting. Type I receptors have small receptive fields whereas the type II receptors have very broad receptive fields.



Receptive fields of Meissner and Pacinian corpuscles. Centres of highest sensitivity are marked by dots.

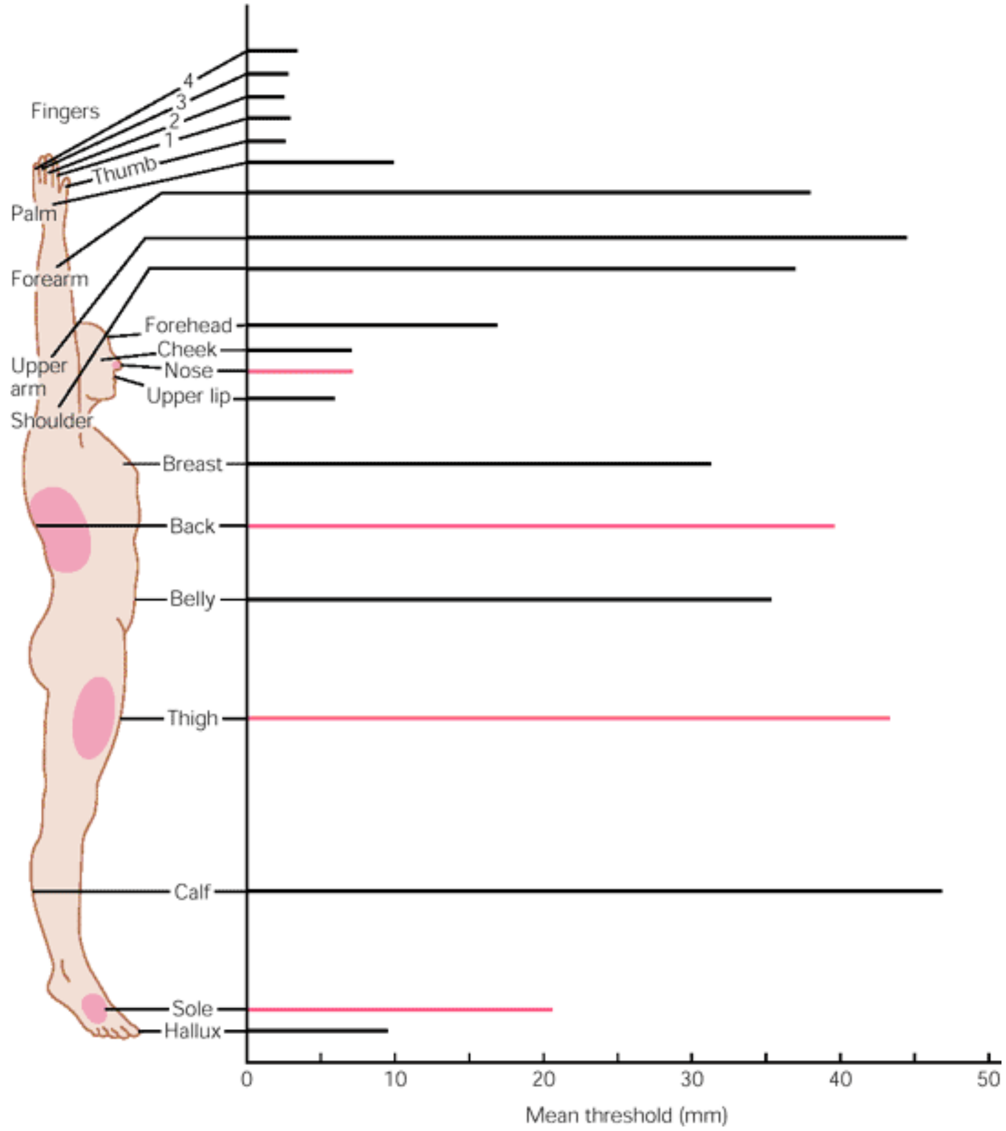
Mechanoreceptors - spatial discrimination



(small RF)
(large RF)

Spatial discrimination does not depend on the size of the receptive field (receptive field size is simillar accross the body while spatial discrimination is different). It depends on the density of small field receptors which varies accross the body. By contrast the density of large receptive field receptors is constant.

Two – point discrimination



Two – point threshold are meausred clinically using a calibrated two-pins compass. Two – point threshold varies for different body regions; it is about 2 mm on the finger tip and 40 mm on the arm. Two – point thresholds highlighted in pink match the diameter of the corresponding receptive fields shown in pink on the body.

Spinal cord circuits

The information from sensory receptors is transmitted by impulse codes in the sensory nerves to the spinal cord. The sensory fibers terminate in the dorsal horn.

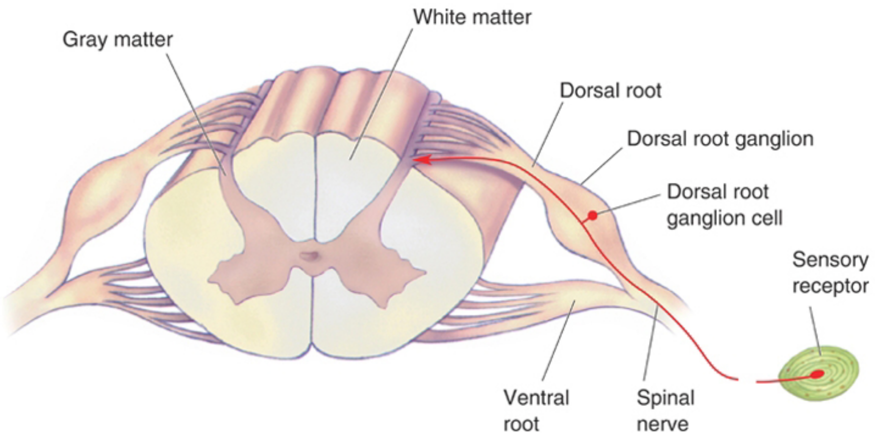
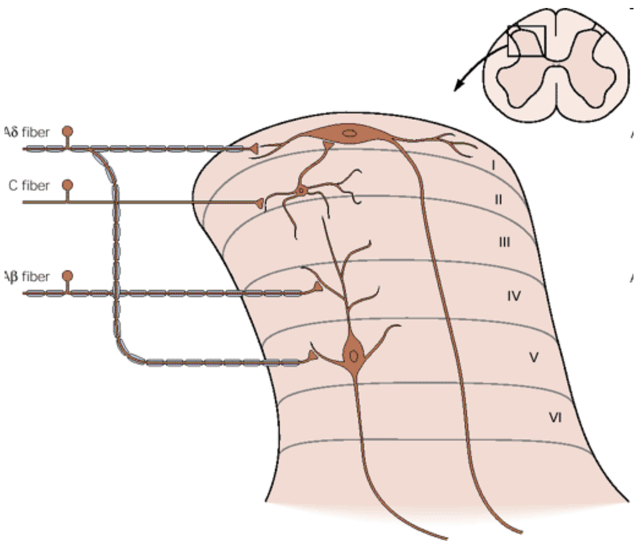


Diagram of cross section of spinal cord



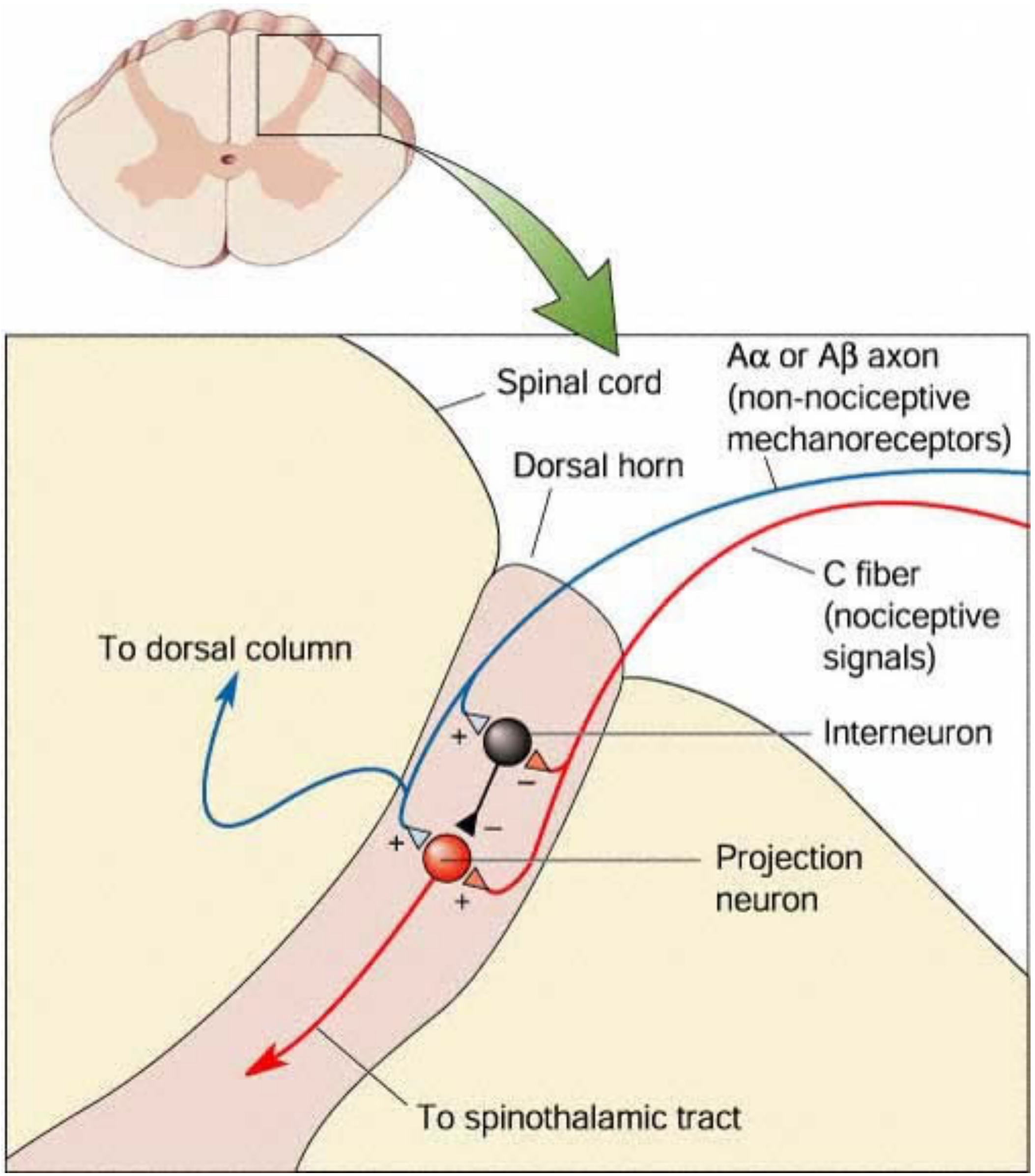
Properties of the dorsal horn circuits

-serial transmission, separate for each modality (pain, touch)

-interaction between modalities

-modulation of sensory information by descending axons

Gate control theory of pain



Ronald Melzack and Patrick Wall proposed (1962) that a pain gating mechanism exists within the dorsal horn of the spinal cord. Both thin (pain) and large diameter (touch, pressure, vibration) nerve fibers carry information from the site of injury. The activity in the large nerve fibers would activate the inhibitory interneuron that would then block the projection neuron and therefore block the pain.

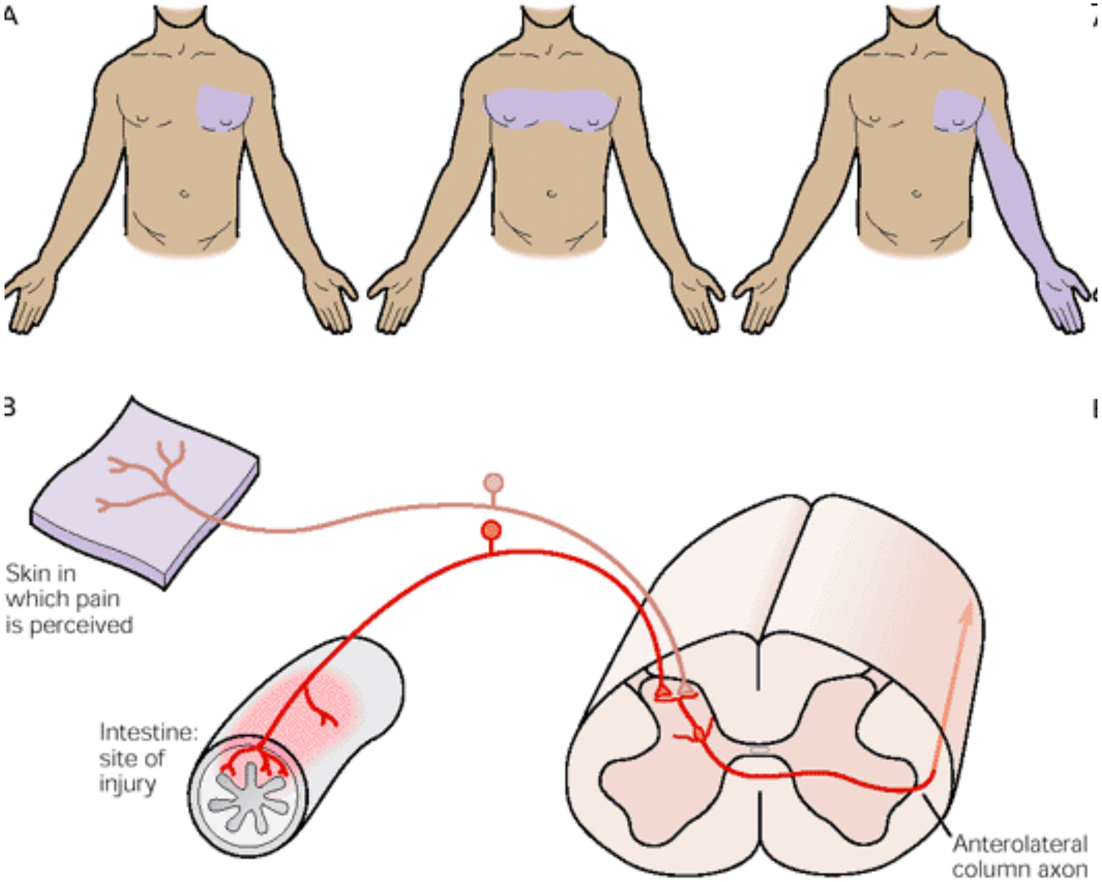
The theory is:

-good in general

-false in detail

Referred pain

Referred pain, also called reflective pain, is pain perceived at a location other than the site of the painful stimulus.

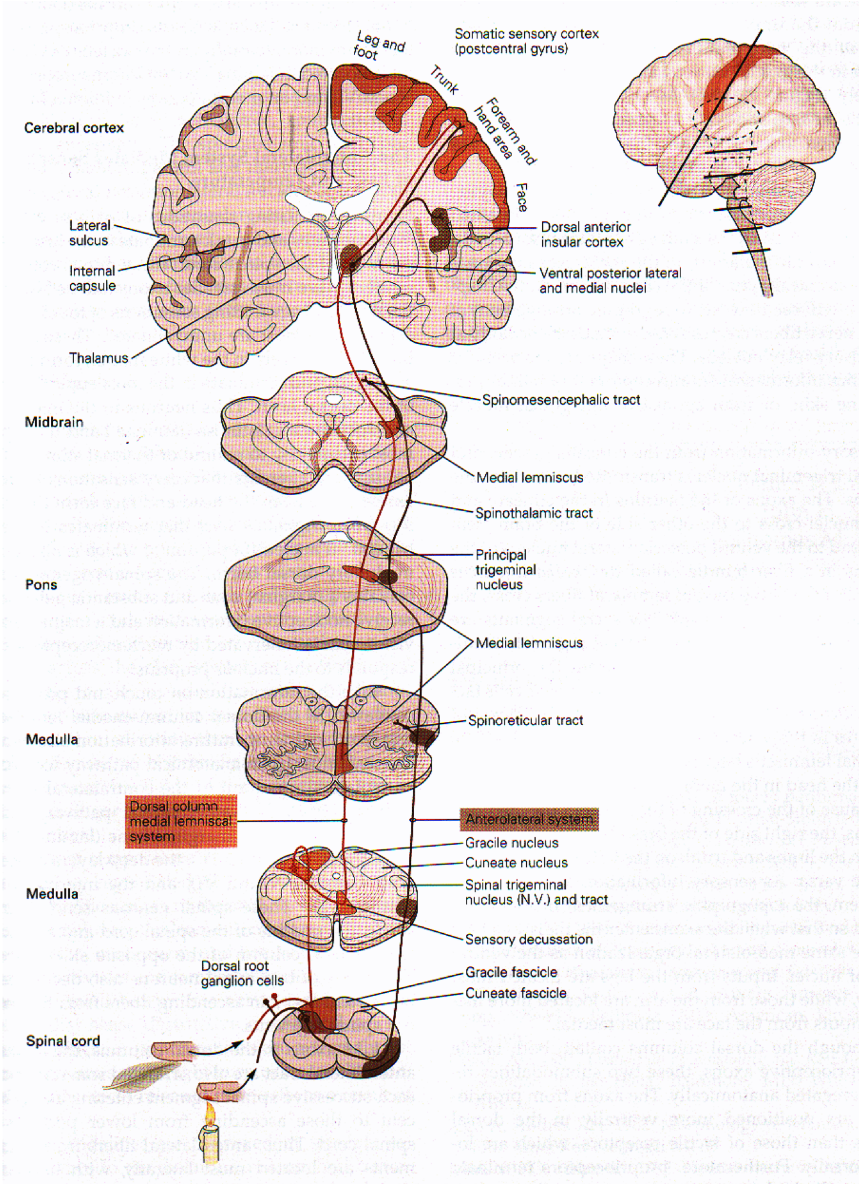


A. Ischemia (shortage of oxygen) brought on by a heart attack, or angina can be experienced as deep pain in the chest and left arm rather than in the chest, the site of the injury.

B. Convergence of visceral and somatic afferent fibers may account for referred pain. According to this hypothesis nociceptive afferent fibers from the viscera and afferents from specific somatic areas of the periphery converge on the same projection neurons in the dorsal horn. The brain has no way of knowing the actual source of the noxious stimulus and mistakenly identifies the sensation with the peripheral structure.

Somatic sensory pathways

Sensory information from the limbs and trunk is conveyed to the thalamus and cerebral cortex by two ascending pathways.



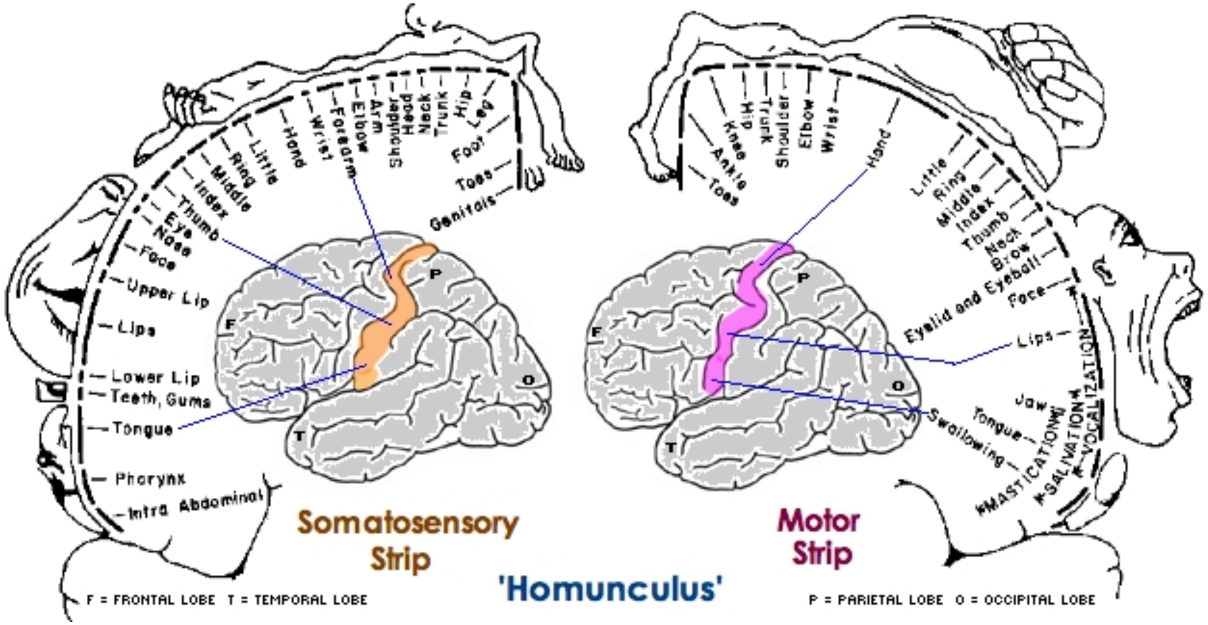
Spinothalamic pathway – pain and temperature

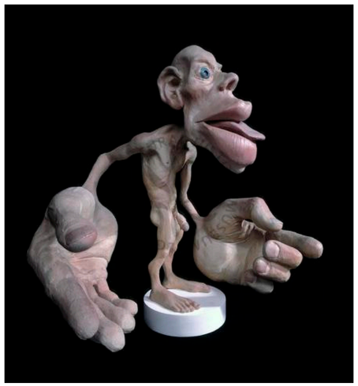
Lemniscal pathway – touch and proprioception

Tactile sensation and limb proprioception (sense of position of one's own body parts) are transmitted to the thalamus by the lemniscal pathway (**orange**). Painful and thermal sensations are transmitted to the thalamus by the evolutionary younger, spinothalamic pathway (**brown**).

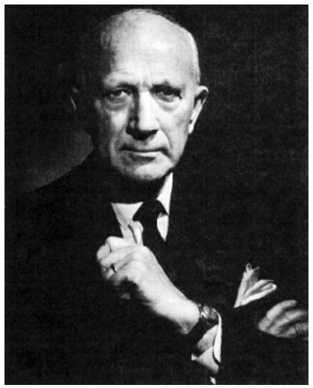
Somatosensory cortex

Somatic sensory projections from the body surface and muscle are arranged in an orderly way in the cortex (somatotopy).

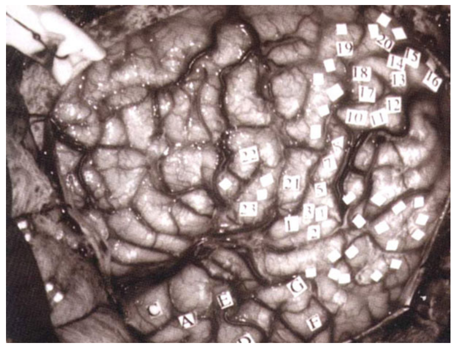




3D sensory homunculus

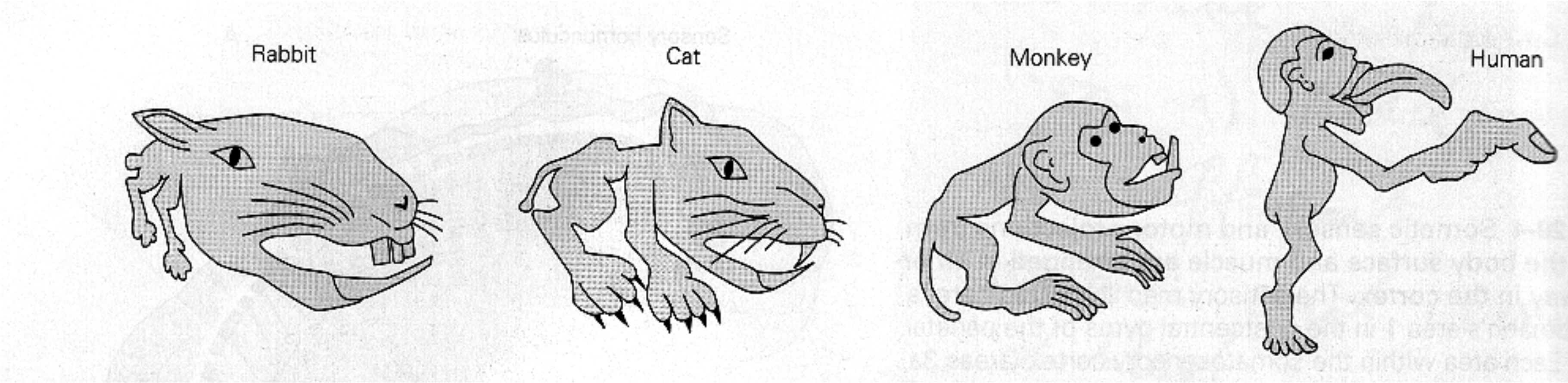


Wilder Penfield (1891-1976)



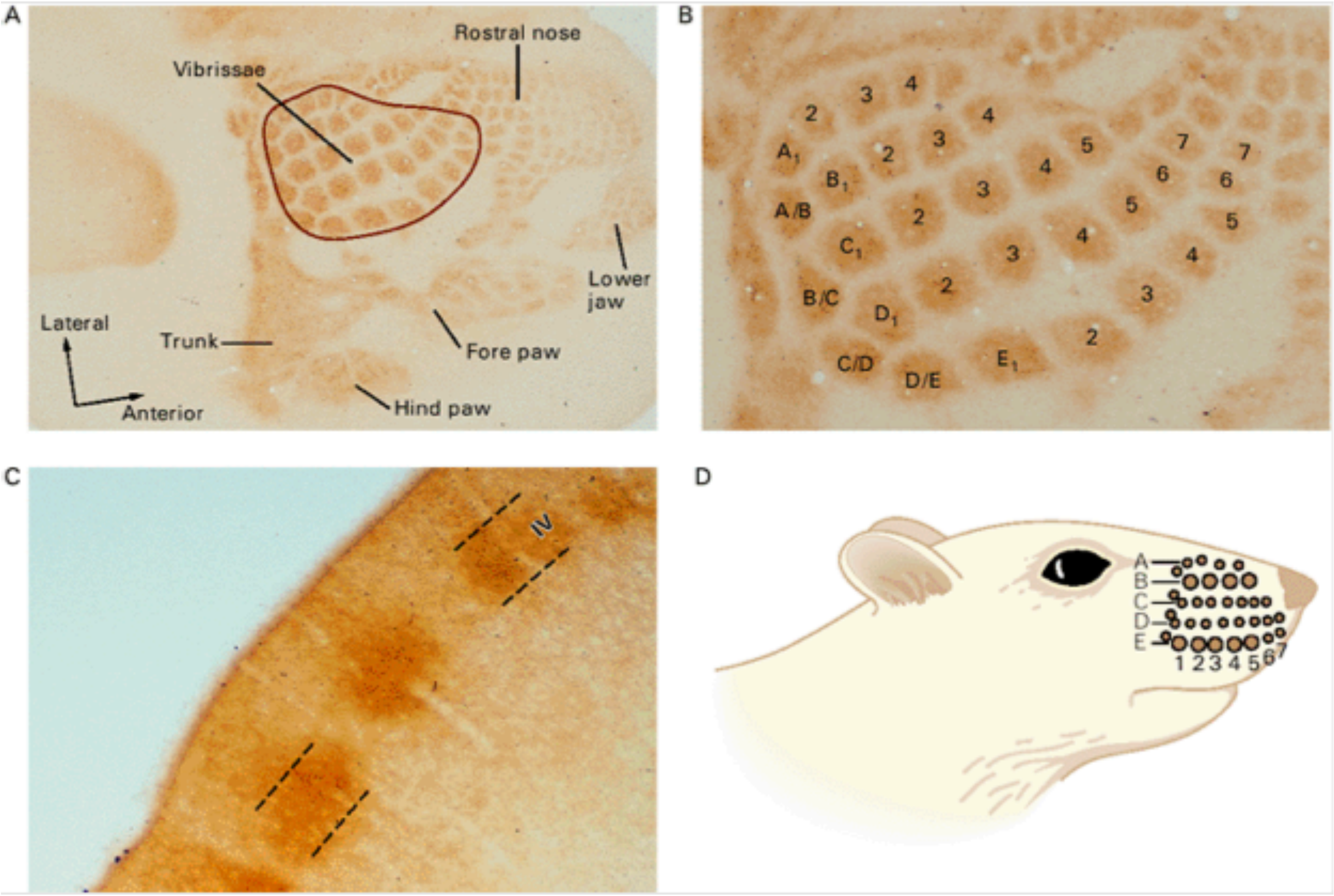
Brain during Penfield experiment

Body representations in animals



Different species rely on different parts of the body for adaptive somatosensory information. These drawings show the relative importance of body regions in the somatic sensibilities of four species, based on studies of evoked potentials in the thalamus and cortex. This distortion reflects differences in innervation density in different areas of the body.

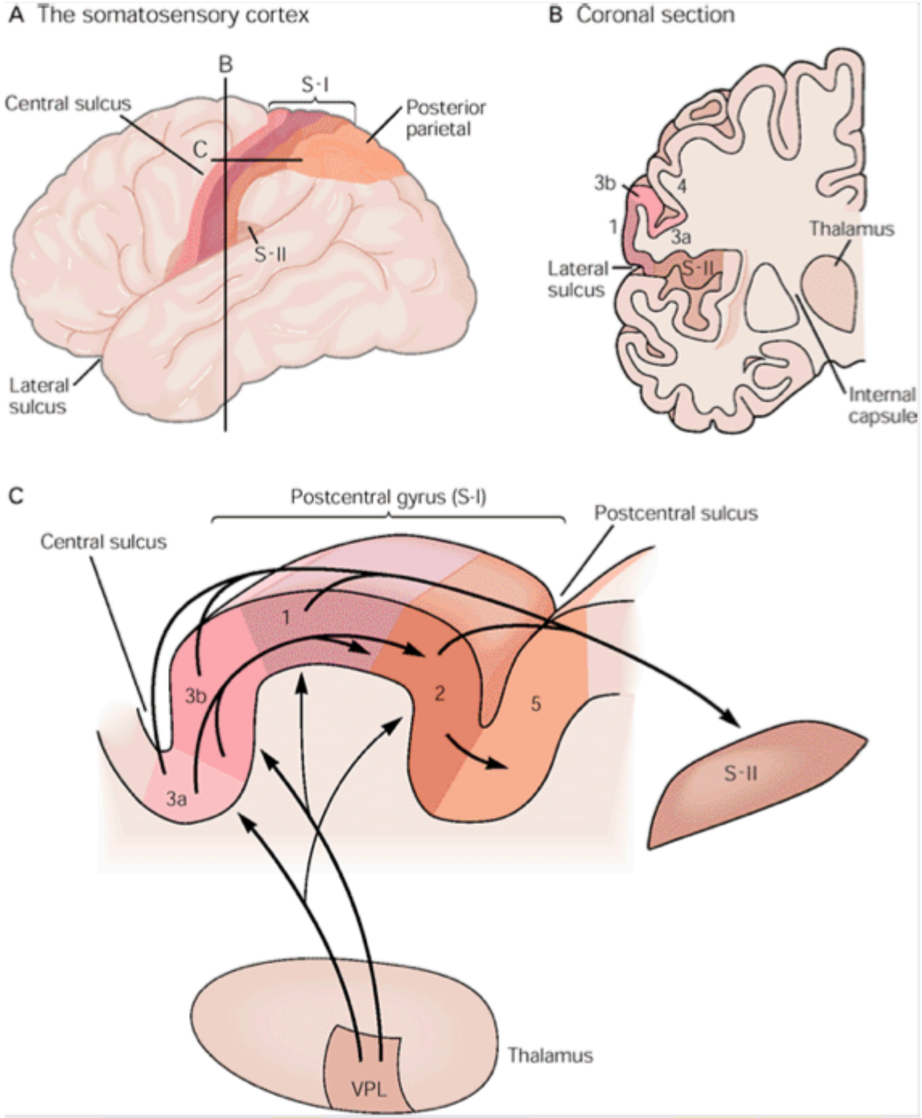
‘Barrels’ in somatosensory cortex of rodents



A. Photomicrograph of a horizontal section through layer IV of the somatosensory cortex of a juvenile rat that has been stained for serotonin. The largest part of the cortical map is devoted to the face representation (whiskers, nose, and lower jaw).
B. Enlarged view of the whisker representation. Neurons that receive projections from the whisker fields are arranged in discrete circular units called *barrels.* Each barrel is most responsive to a single whisker.
C. Coronal section through the rat somatosensory cortex. The barrels form dense patches localized to layer IV of the cortex.
D. The topographic arrangement of the barrels in the cortex corresponds to the spatial arrangement of the whiskers in discrete rows and columns on the face

The divisions of the somatic sensory cortex

The somatic sensory cortex has three major divisions: the primary and secondary somatosensory cortices and the posterior parietal cortex.



A, B. The anatomical location of the three divisions of the somatic sensory cortex; SI, SII and posterior parietal cortex.

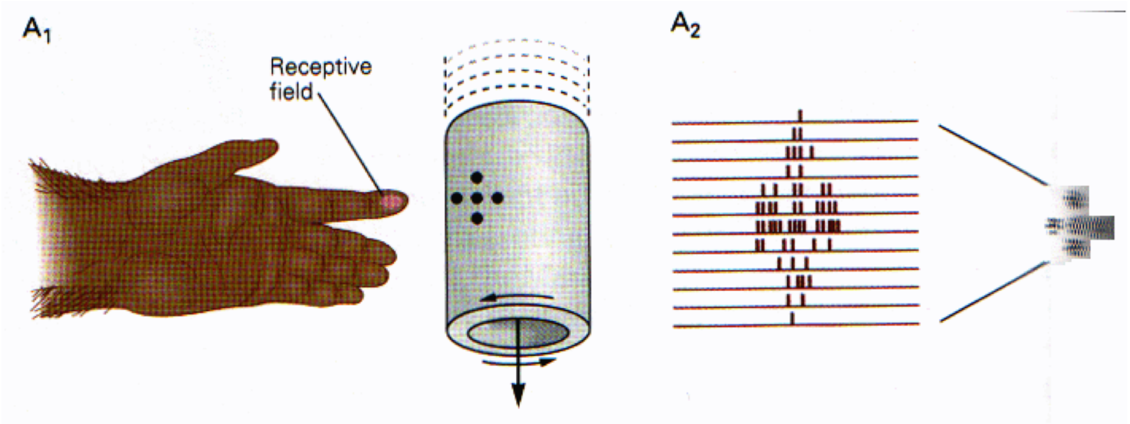
C. S-I is subdivided into four distinct cytoarchitectonic regions (Brodmann's areas): 1, 2, 3a, 3b .

Areas 3b and 1 receive information from receptors in the skin, whereas areas 3a and 2 receive proprioceptive information from receptors in muscles and joints.

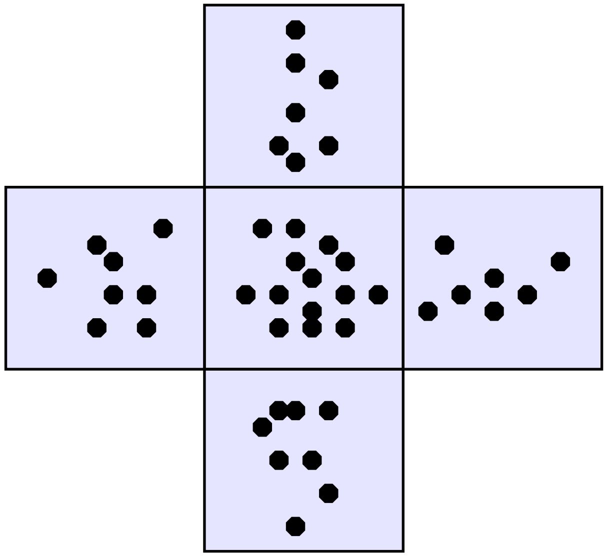
The S-II cortex projects to the insular cortex, which in turn innervates regions of the temporal lobe believed to be important for tactile memory.

The posterior parietal cortex (Brodmann's areas 5 and 7) receives input from S-I as well as input from the thalamus and have an associational function. Area 5 integrates tactile information from mechanoreceptors in the skin with proprioceptive inputs from the underlying muscles and joints. This region also integrates information from the two hands. The posterior parietal cortex projects to the motor areas of the frontal lobe and plays an important role in sensory initiation and guidance of movement.

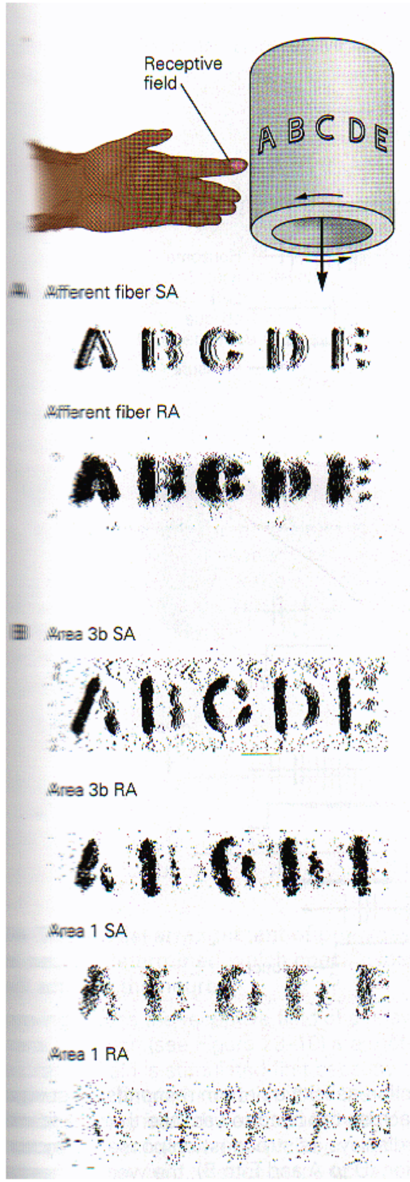
Texture representation by neurons in 3b and 1 areas



The nerve responses to textures are measured with the hand immobilized. The pattern moves horizontally over the receptive field as the drum rotates. The pattern is moved vertically on successive rotations.

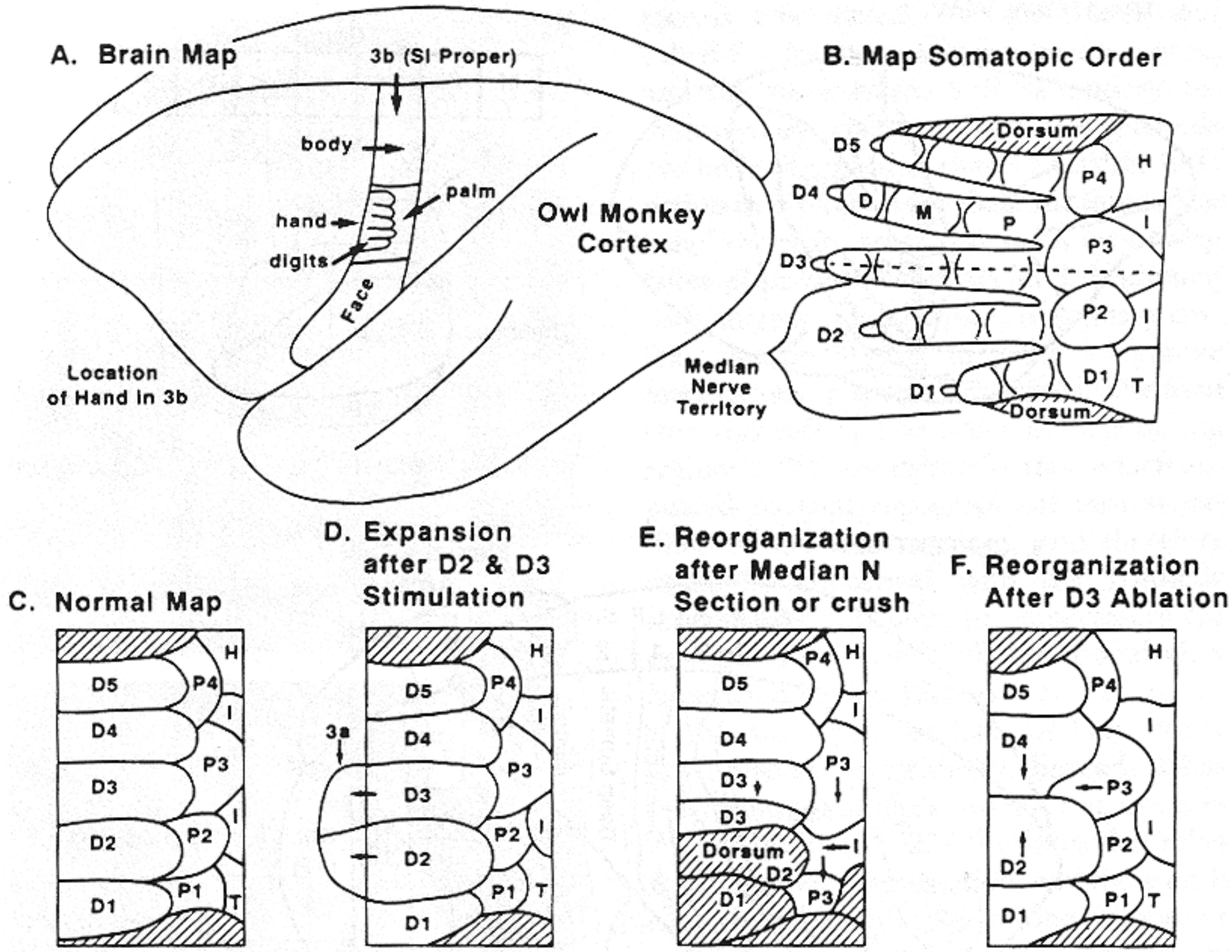


Spatial event plot. Sequential action potentials discharged by individual receptors during each revolution of the drum are represented in spatial event plots in which each action potential is a small dot, and each horizontal row of dots represents a finger scan during single revolution.



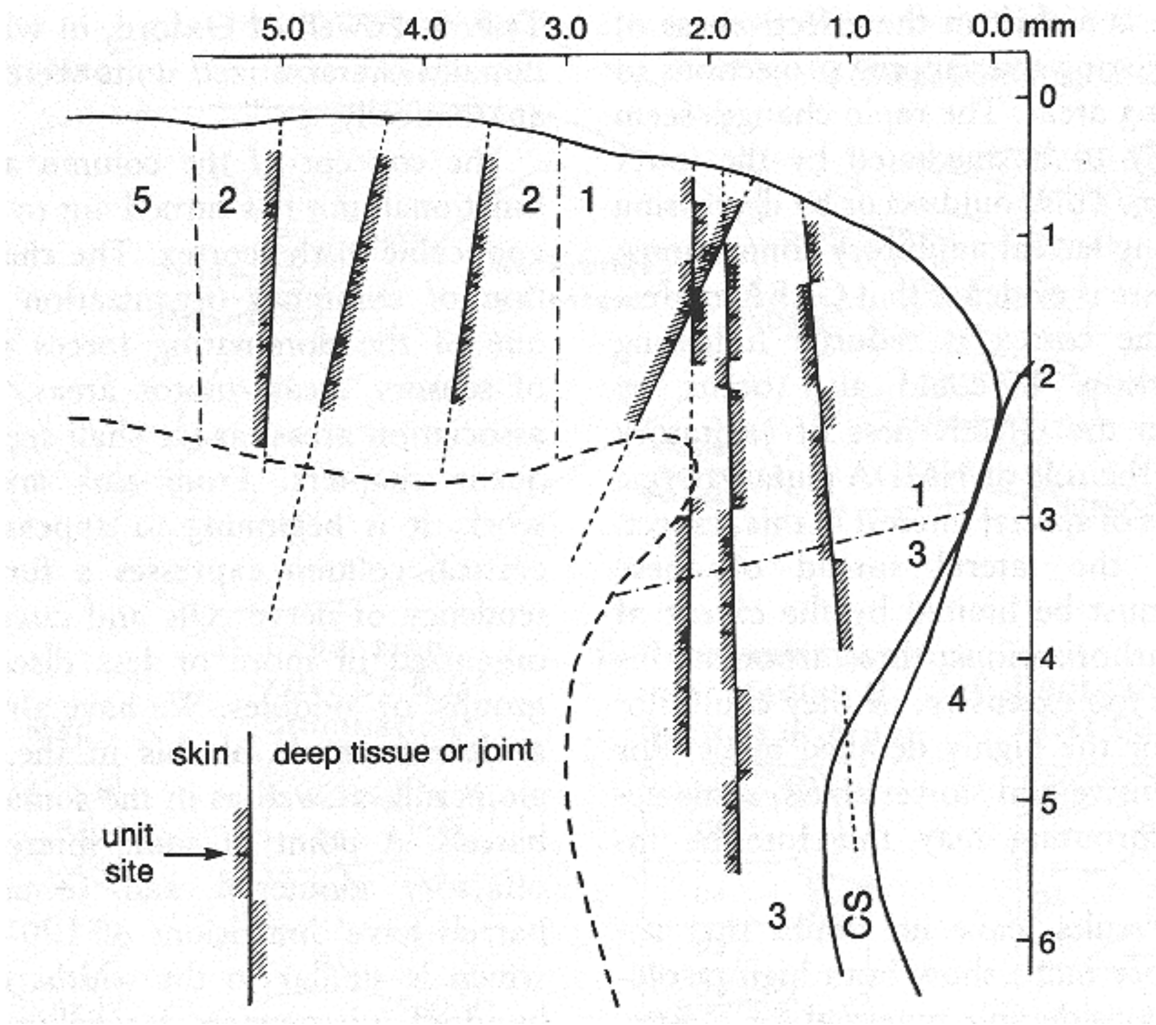
Neurons in area 3b of the somatic sensory cortex preserve sharp sensory images.

Cortical maps are plastic



Experiments demonstrating the detailed representation of the digits of the monkey and the plasticity of this representation after different procedures. Rearrangement of cortical inputs is thought to be responsible for some types of phantom limb sensation.

Discovery of columnar organization of the cortex - Vernon Mountcastle, 1959

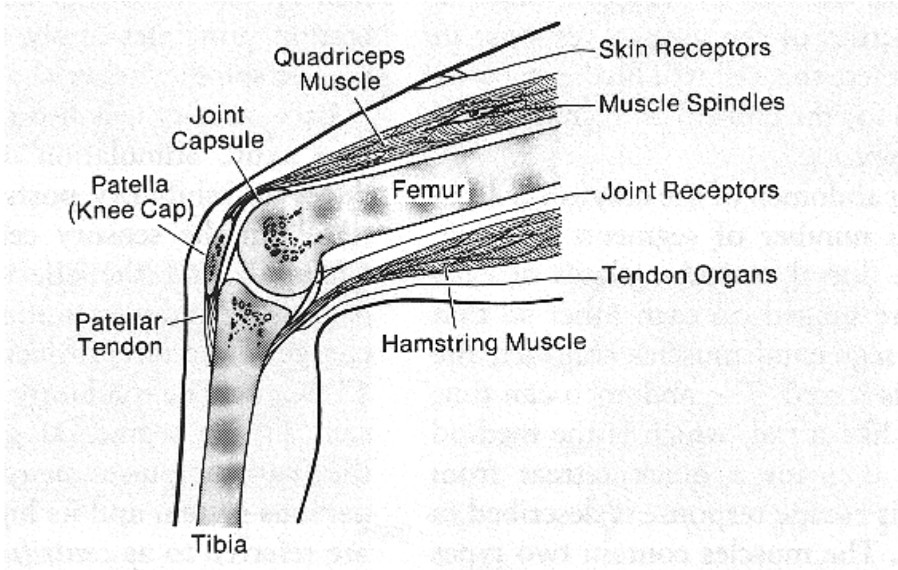


Experiment of functional properites of the organization of somatosensory cortex in monkey. Electrodes moved perpendicularly to the cortical surface responded to activation of only one modality (shown by shading). Electrodes moved at angle to the cortical surface responded to activation of more than one modality. It led to the discovery of columnar organization of the somatosensory cortex. The neurons which lie in narrow vertical columns, make up an elementary unit of organization because they are activated by stimulation of the same single class of peripheral receptors.

Proprioception and kinesthesia

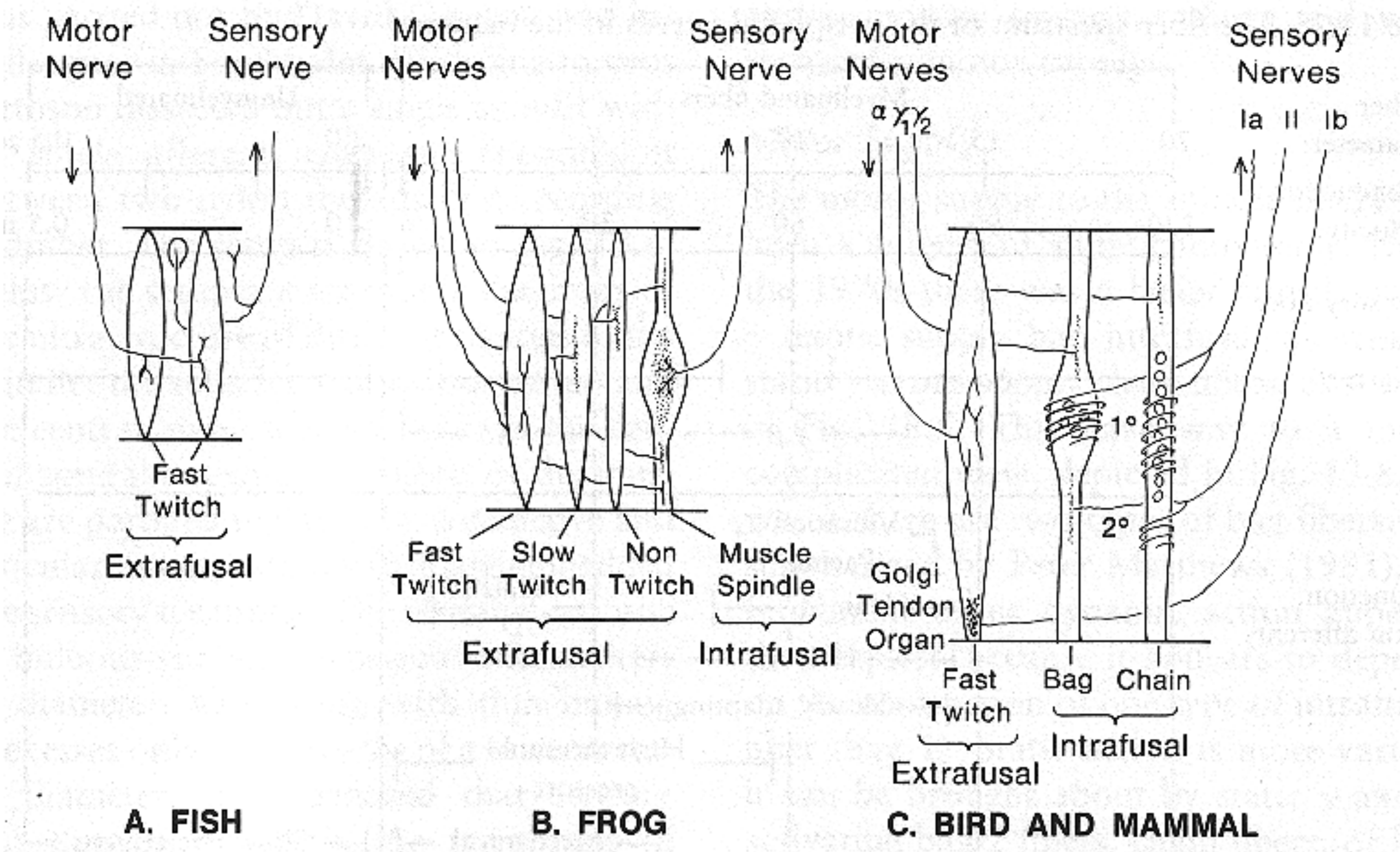
Proprioception – all sensory inputs from the musculoskeletal system:
-muscle receptors
-joint receptors
-tendon receptors

Kinesthesia – sense of the position and movement of the limbs and sensation of effort, force and weight. It involves:
-skin receptors
-proprioreceptors
-brain signals (e.g. from motor cortex)



Sites of sensory receptors for muscle sense and kinesthesia in the knee joint.

Evolution of proprioreceptors



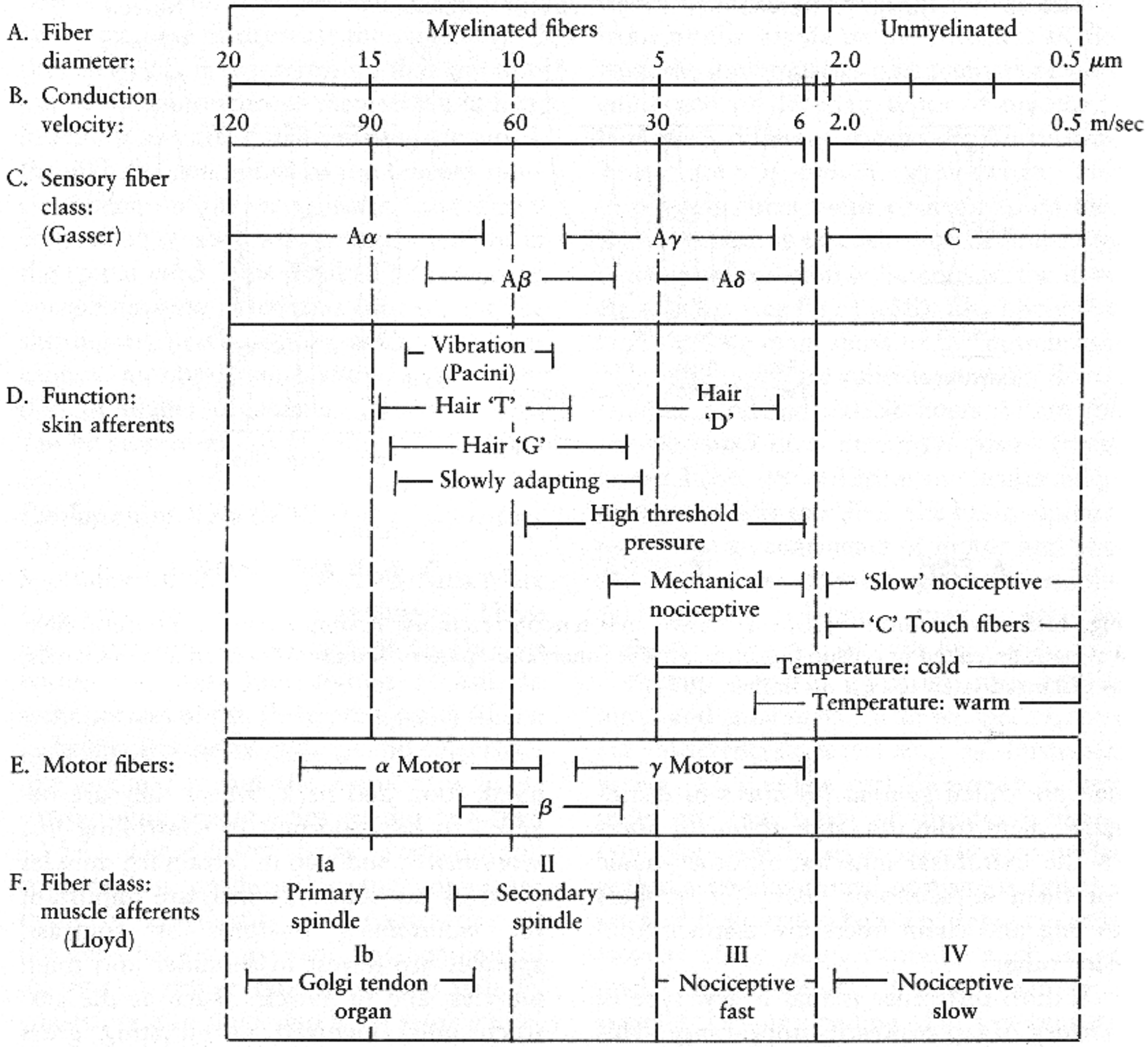
A. There are no sensory nerve endings in the muscle of the fish.

B. In amphibians muscle spindles appear in legs. The muscles are called extrafusal muscle fibers and the modified muscle within a spindle are called intrafusal muscle fibers.

C. In birds and mammals there are two types of muscle receptors – nuclear bag fiber and nuclear chain fiber.

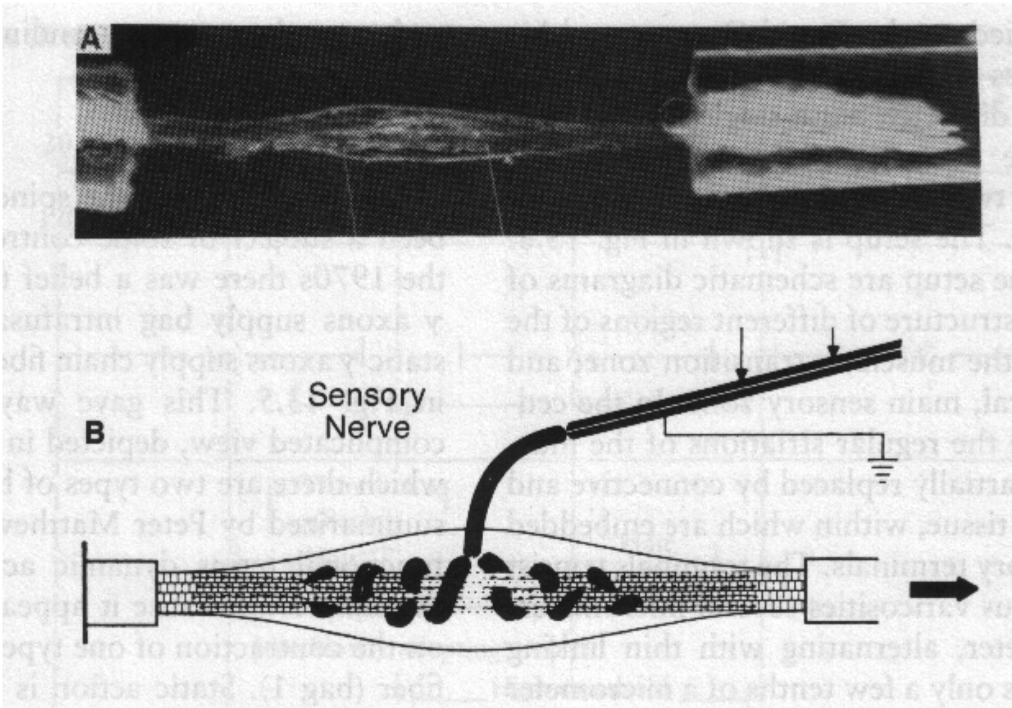
Peripheral nerves - summary

Table 13.2 The fiber spectrum of the peripheral nerves in the mammal



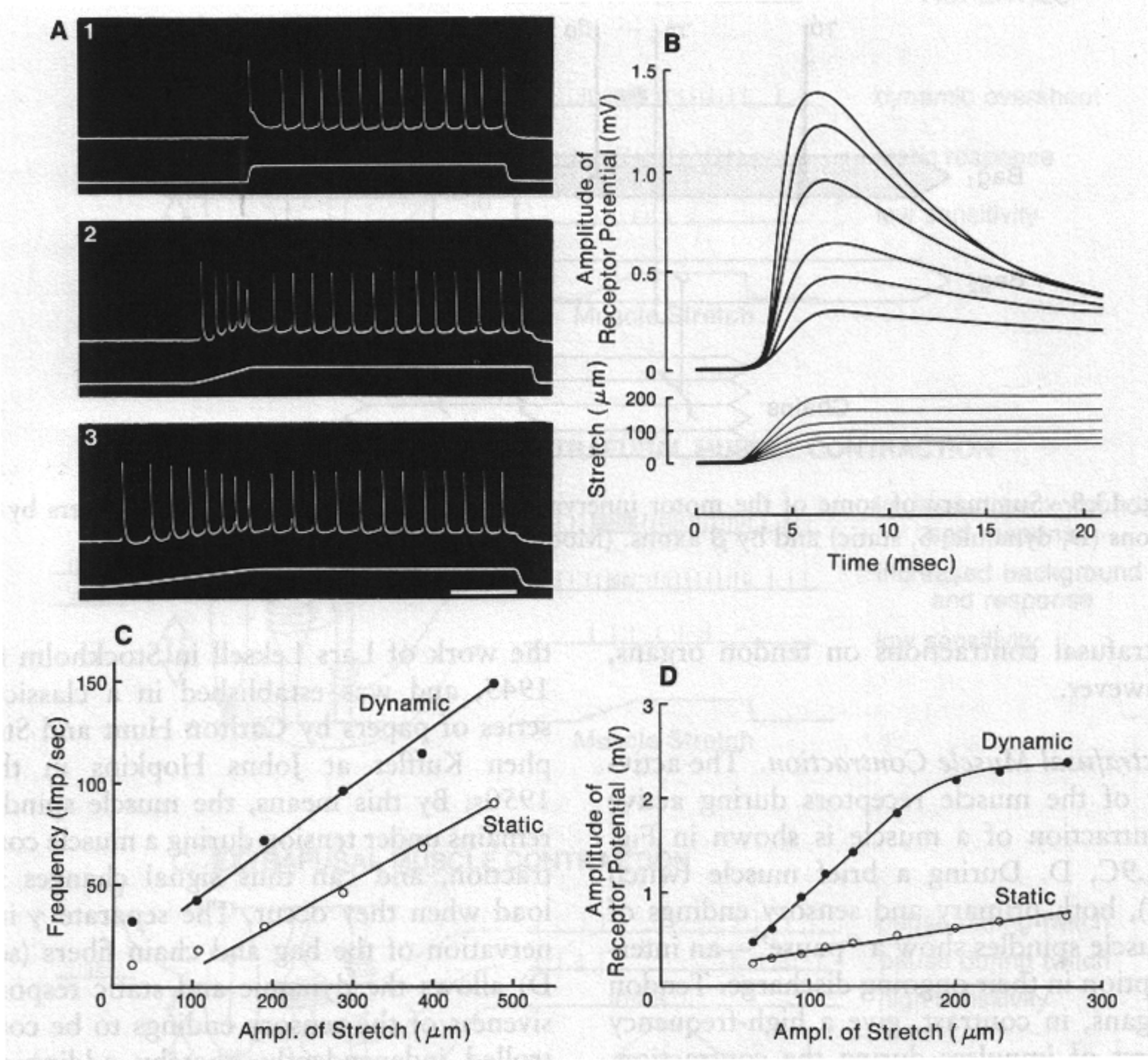
After Somjen (1972)

Muscle spindle



A, B. A single muscle spindle dissected out of the frog and mounted between two nylon rods, together with its single afferent axon.

Responses of the muscle spindle



A. Responses to different rates of extension.

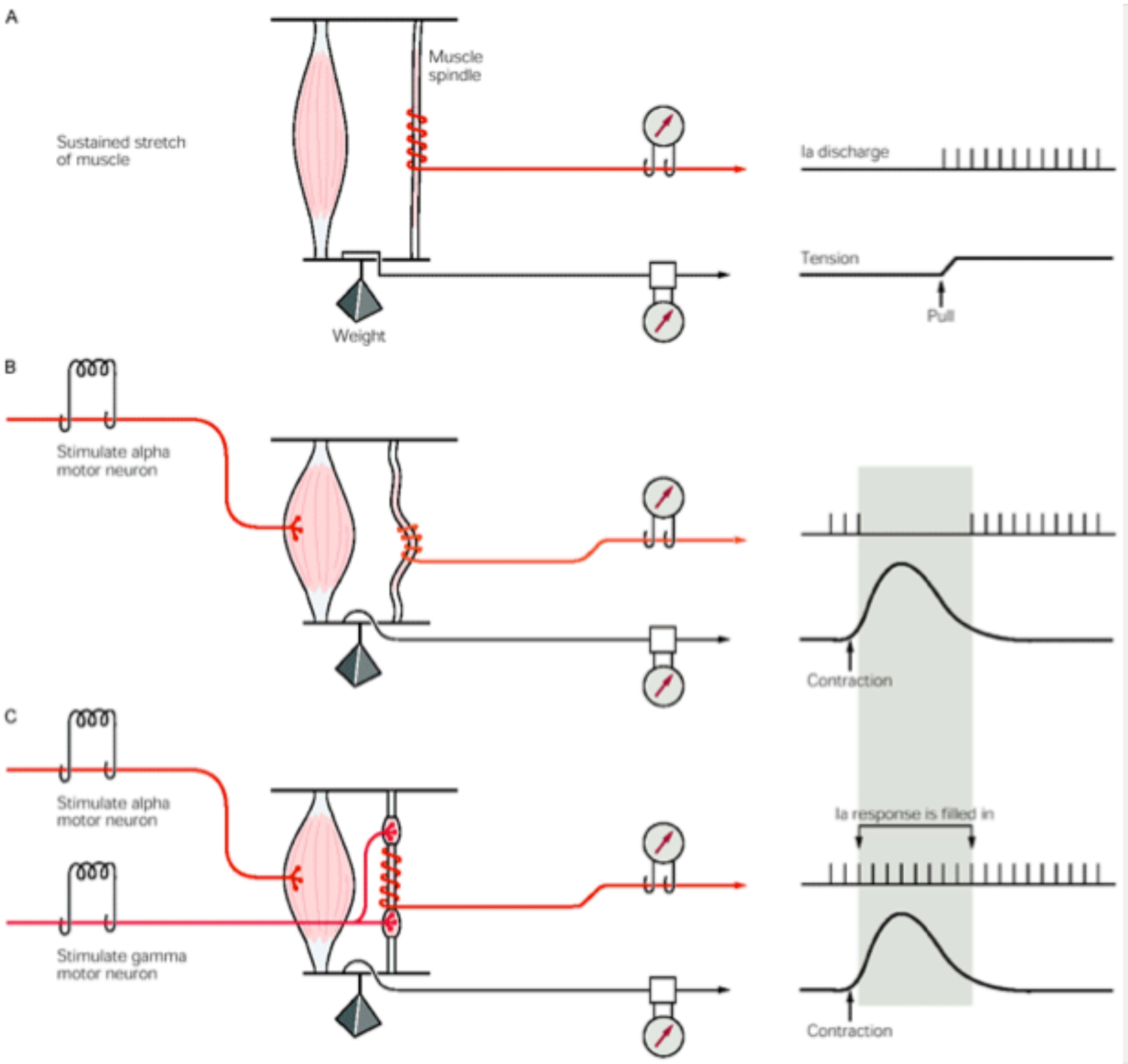
B. Receptor potential recorded from sensory nerve after blocking of the impulses.

C. Firing frequencies at the dynamic peak and the static plateau of the reponse.

D. Amplitude of the receptor potential for the dynamic and static phase of the stretch.

The results show the ability of the spindle to signal the muscle length and the speed at which the muscle is stretched with high precision.

Responses of the muscle spindle

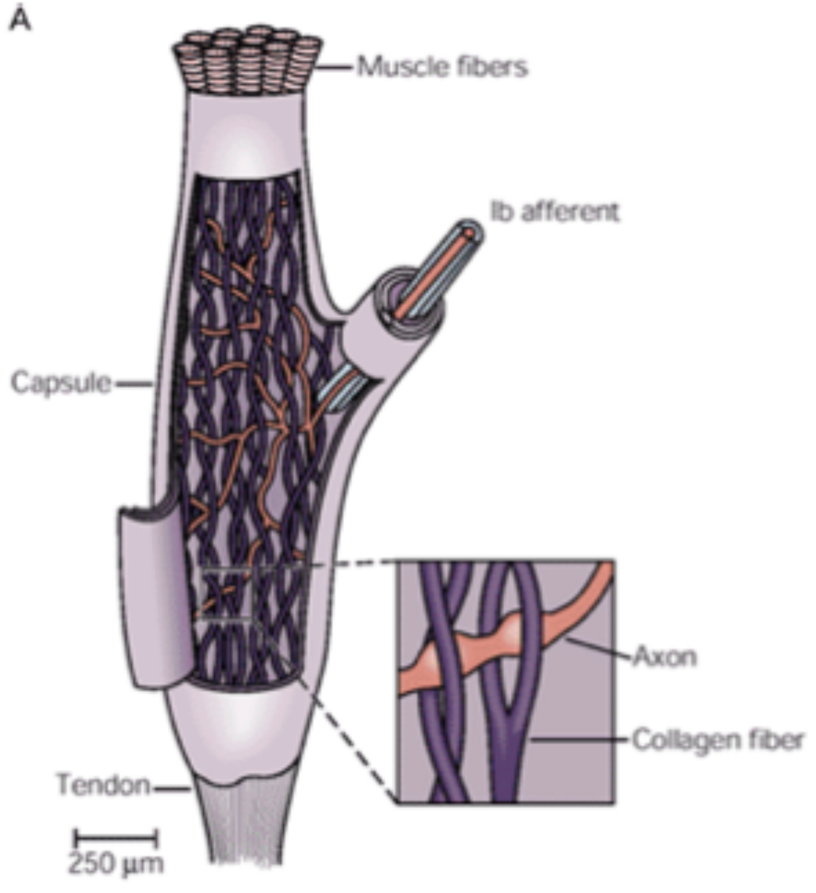


A. Sustained tension elicits steady firing in the Ia sensory fiber.

B. A characteristic pause occurs in the ongoing discharge of the Ia fiber when the alpha motor neuron alone is stimulated. The Ia fiber stops firing because the spindle is unloaded by the resulting contraction.

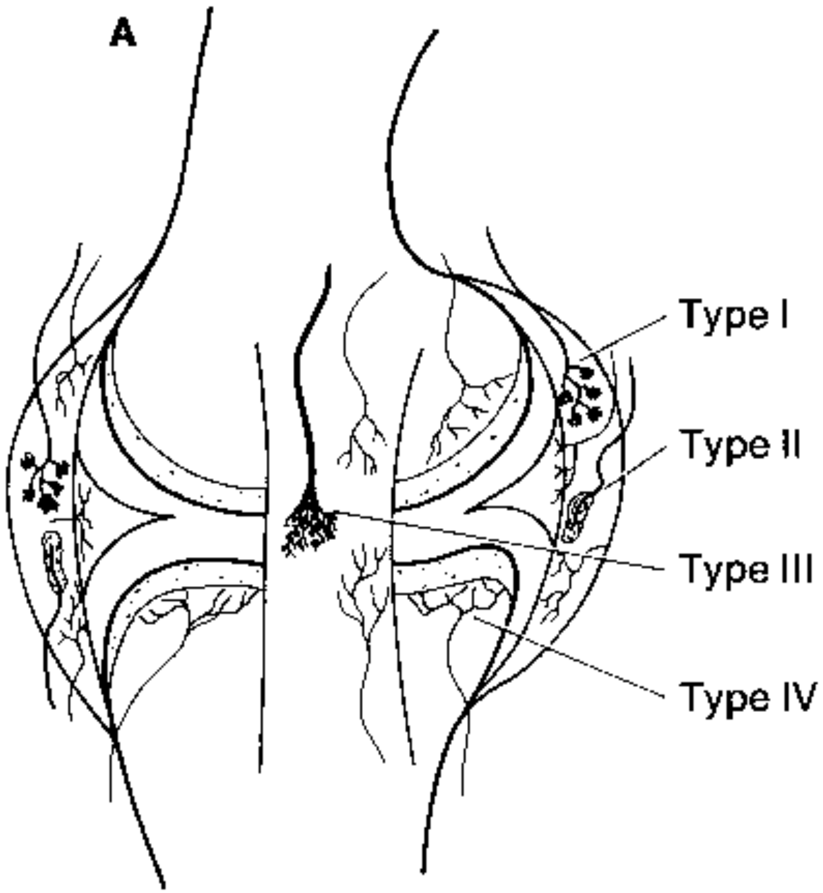
C. If a gamma motor neuron attached to the spindle is also stimulated, the spindle is not unloaded during the contraction and the pause in discharge of the Ia fiber is filled in. This mechanism maintains the spindle firing rate within an optimal range for signaling length changes, whatever the actual length of the muscle.

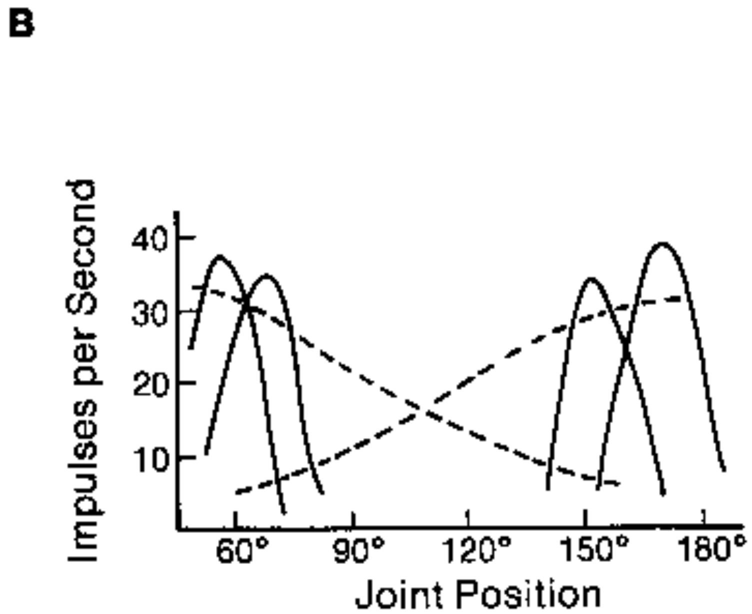
Golgi Tendon Organs



Golgi tendon organs are sensory receptors located at the junction between muscle fibers and tendon. Each tendon organ is innervated by a single (group Ib) axon that loses its myelination after it enters the capsule and branches into many fine endings. When the Golgi tendon organ is stretched (usually because of contraction of the muscle), the nerve endings are compressed by the collagen fibers and the sensory afferent rate of firing increases. Tendon organs are most sensitive to changes in muscle tension.

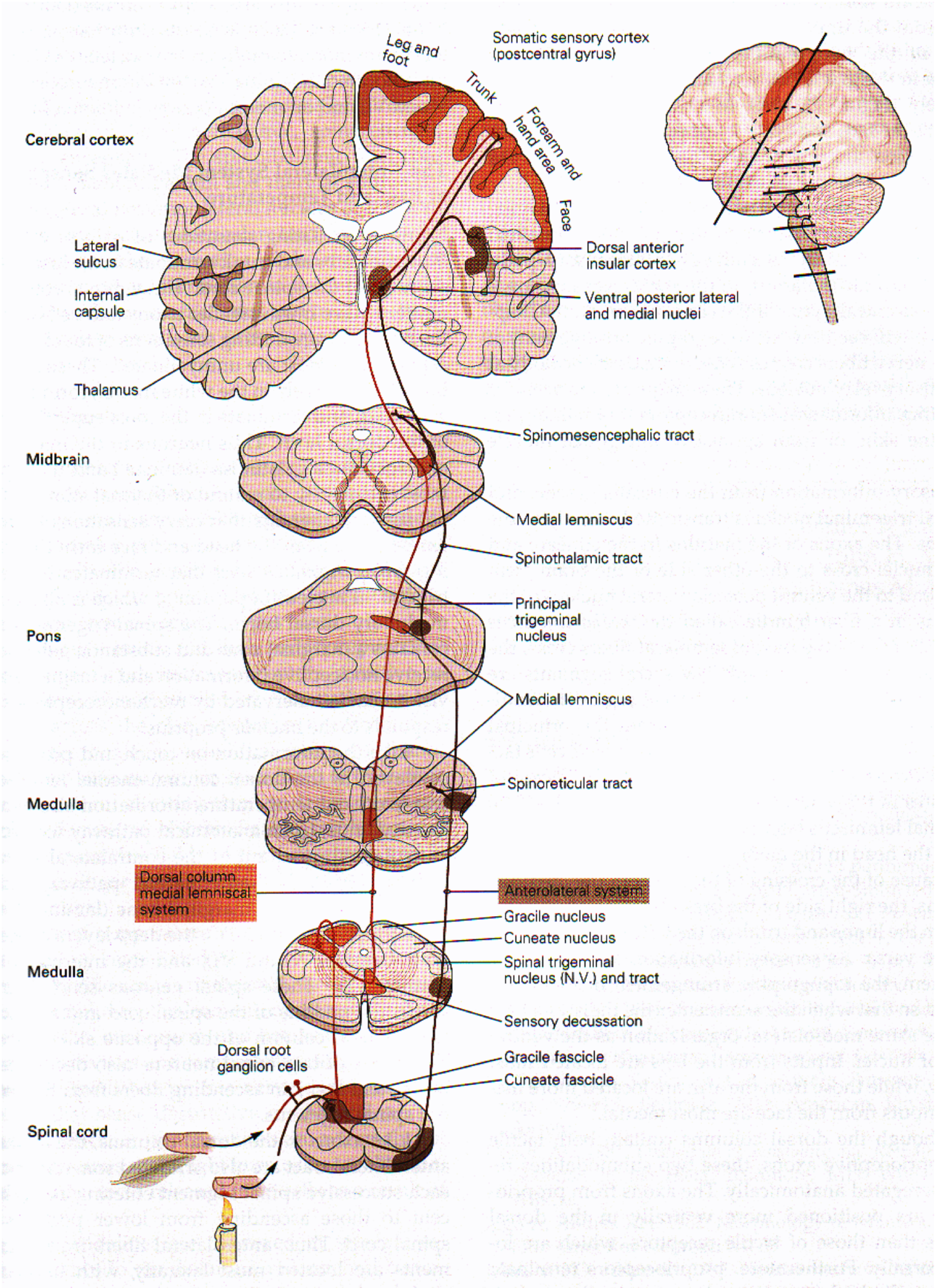
Joint receptors





A. Sensory receptors innervating the knee joint. Type I receptors resemble Ruffini endings of the skin. Type II receptors have the form of flattened Pacinian corpuscle. Type III resemble Golgi tendon organs. Type IV are free nerve endings resembling pain fiber terminals.

B. Responses of the joint receptor nerves for differnt joint positions in the cat. They cover only extremes of the range of joint positions. Dashed lines show recordings from primary endings of muscle spindle in muscles around the joint. They contribute to sensation of joint position.



Afferent pathway

Lemniscal pathway – touch and proprioception

The ascending pathway for information from muscles and joints is called lemniscal pathway, which is evolutionary older. It is similar to that for the tactile information from skin receptors.